PSYCHOLOGICAL, SOCIAL AND FINANCIAL BARRIERS TO ENERGY EFFICIENCY

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# Drivers of efficiency gaps in manufacturing firms

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# Drivers of efficiency gaps in manufacturing firms

Westfälische Wilhelms-Universität Münster

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## Executive Summary

This paper provides an in-depth assessment of energy-efficiency related investment behavior by German manufacturing firms using production census data.

In a first part we identify remaining potential for cost-efficient investments among non-investing firms, and especially small-and-medium enterprises (SME) where the share of investing firms is significantly lower than among large firms. These findings are in the with the "energy efficiency gap/paradox" literature.

In a second part, the analysis identifies major drivers and barriers to investment activity using logit estimations. The regression results confirm several significant firm-level characteristics such as larger emissions and exports or previous experience in the usage of renewable energy sources. More interestingly, the results further highlight the importance of competitor behavior and potential peer-group effects. For SME, however, we find no structure of firm characteristics that correlate with a higher likelihood of investment activity.

In a final part, assess the payback periods of investments based on a back-of-the-envelope calculation. The time until amortization for large firms is line with the existing literature, ranging between 2 and 10 years. On the contrary, investments by SME have a much longer payback period, as the necessary spending for technological improvements are relatively large compared to the annual energy costs.

Overall, our research indicates that energy efficiency gaps may be more severe among SME and that future policies could facilitate the financing of energy efficiency investments.

## Summary for Policymakers

Regarding the analysis of firm-level behavior, we analyzed a German firm-level census data set, which includes investments into energy-using technologies. The main research question was what were the drivers and barriers of firms regarding investments into energy efficient technology. We assess the factors that determine a firm's likelihood of investing into energy efficient technology and find that large firms are far more likely to do so than small-and-medium enterprises (SME). For the latter, the data also suggest large potential for further energy efficiency improvements.

Furthermore, we find that firm-level characteristics are significantly correlated with the take-up of investments, especially for large firms. Results also suggest substantial influence of peer firms' emissions performance and investment behavior. For SME on the contrary, firm-level characteristics are not significantly correlated with investment behavior. One exception is that the likelihood of investment activity increases for SME when peer firms show substantially better emissions performance.

Thus, future policies may utilize peer pressure and networks for knowledge spillover. Back-of-the-envelope calculation also suggest longer payback periods of investments for SME. The analysis reveals that policies should consider instruments to increase the attractiveness and feasibility of investments, especially for SME.

# 1. Introduction

The energy efficiency gap or energy efficiency paradox describes the non-initiation of cost-effective improvements in energy efficiency. A prominent example is the reluctance of households or firms to invest in energy efficient technologies despite a positive net present value and short payback periods. The literature suggests that most common reasons for this phenomenon are a lack of time, personnel, access to finance and knowledge about energy efficiency options. To date, the literature benefits from insights of a significant number of studies on private consumer and household energy behavior (Federal Environmental Agency, 2008, Gerarden et al., 2015)

However, less attention has been directed towards potential inefficiencies among firms. In Germany, the manufacturing sector is a main final energy consumer with about 28 percent of national consumption in 2016 and directly responsible for about 20 percent of national greenhouse gas emissions (Federal Environmental Agency, 2016b). Thus, a variety of national energy and climate policies is directed towards this sector, often with a focus on large firms. A current example is the introduction of compulsory energy audits for large firms in Germany starting in 2015. This policy is the implementation of Art. 8 of the EU Energy Efficiency Directive (Art. 8 Abs. 47 EDL-G) as a part of the German national action plan for energy efficiency (BMWi, 2014) that carries the slogan Efficiency First. The federal government expects additional reductions of 3.4 Mio t $CO_2$-eq. from audits of firms with at least 500 employees.

At the same time, this policy is not mandatory for small and medium enterprises (SME) who, individually, may be small agents.[1] But in the German manufacturing sector, they comprise 97% of firms, 43% of employees and 20% of revenue. Such firms contribute to the German "Mittelstand", which is often described as the "backbone" of the German economy (BMWi, 2016). Increasing energy efficiency among small and medium sized firms can play an integral part in national climate policy ambitions.[2]

This goal is achievable via and improved energy behavior and management, or the adoption of more energy-efficient capital. Next to reducing energy costs, investments in energy efficiency may also increase firms overall productivity and profitability and reduce financial risks from energy price increases.

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[1] We apply the SME definition of the European Union (http://ec.europa.eu/growth/smes/ business- riendly-environment/sme-definition_de), demanding staff headcount of less than 250 in combination with either a maximum of 50 Mio. turnover or a balance sheet of 43 Mio. or less. However, in our dataset we only observe firms with at least 20 employees, which excludes at least 60% of the aforementioned firms.

[2] A current example is the "Mittelstandsinitiative Energiewende und Klimaschutz" by the Federal Ministry for the Economy, the Federal Ministry for the Environment, Association of German Chambers of Industry and Commerce, among others: https://www.mittelstand-energiewende.de/.

In the year 2016, German manufacturing firms invested in total 61,085 Mio €, of which 2,343 Mio. € were used for protection of the environment (Destatis, 2018). Examples are the reduction of air and water pollution, but also climate protection measures where investments amounted to 876 Mio. €. The majority (711 Mio. €) was directed into energy efficiency improvements measures. The remainder split up between renewable energy (77 Mio. €) and other measures to reduce greenhouse gas emissions (87 Mio. €). Clearly, firms with more than 250 employees account for the majority of energy efficiency investments in particular (536 Mio. €). Still, it is remarkable that investments by SME account for more than a quarter of total investments (175 Mio. €).

However, empirical findings still point out a large potential for cost-effective improvements due to technology adoption or behavioral change, of around 25% (Thollander and Palm, 2012). A representative business survey by the KfW (Schwartz and Braun, 2013) finds that between 2011 and 2013 only one in three SME implemented measures to improve energy efficiency, which is why the study suggests a large remaining potential for improvements. As our analysis will show, the conditional energy intensity is much larger for small and medium size firms than for large firms.

This may be due to production process characteristics, economies of scale, or substantiate a potential ”energy efficiency gap”. These investment barriers tend to be more pressing for smaller firms as SME often do not have the capacity for energy management and, depending on its share of costs, energy efficiency is rarely seen as a high priority, especially during the development phase of the company. Further, the access to capital may be more restricted for smaller firms (DeCanio, 1993, International Energy Agency, 2015). Fleiter, Schleich and Ravivanpong (2012) investigate a subsidized voluntary energy audit for German SME and find that participants are reluctant to adopt profitable measures mainly due to high investment costs, a lack of capital and time, fear of hidden costs as well as a low priority of the issue. The program evaluation by Fleiter, Gruber, Eichhammer and Worrell (2012) mostly confirms these findings and also reports that the program did not reduce two other major barriers of investments, which is the risk of disruption in the production process as well as quality losses. However, most of these studies rely on business surveys or on other sample data. In this paper we rely on representative and highly detailed firm-level data of the German census in order to assess firm characteristics that boost or hinder energy efficiency investments. Moreover, we dissect whether these determinants are substantially different between SME and large companies for previously discussed reasons. A value added of our study is that we can observe the actual investment behavior based on production census data rather than surveys that suffer from external validity issues.

This paper aims to answer several key questions: First, are there potential energy efficiency gaps in firms and especially in SME? Are they smaller for firms investing in energy efficiency? What kind of firms invest into energy efficient technology, and do the driving characteristics differ between SME and large firms? What is the impact of energy efficiency investments on the energy intensity of production, on average? What are the average savings in energy costs from investments, and how long is the average payback period? As investing firms differ in their characteristics from non-investors, we use a Matching Difference-in-Differences estimation approach to account for selection bias. Based on the estimated parameter and a simple back-of-the-envelope calculation we assess energy savings and payback periods in our data. Presumably, owing to its simplicity, payback period assessment is the most popular tool used among firms in order to appraise energy efficiency projects (Nehler and Rasmussen, 2016). This approach also allows an estimation of implicit discount rates that renders observed technology adoption reasonable (Dubin and McFadden, 1984). Studies by Anderson and Newell (2004), Abadie et al. (2012) and DeCanio (1998) confirm that payback periods and investments costs are the main determinant for project approval. As such, Anderson and Newell (2004) conclude that firms value investments costs more than potential savings in energy costs, which is consistent with the energy efficiency 'gap' or 'paradox'. We will further discuss the literature on payback periods and discount rates in Section 5.

The remainder of this paper is structured as follows. Section 2 describes the dataset. In Section 3, we discuss drivers and barriers for investments with a particular focus on firm size. We estimate the effect of energy efficiency investments in Section 4. In Section 5 we present a model to calculate respective energy savings and payback periods, with a discussion on the role of discount rates. Section 6 concludes.

## 2. Data and descriptive statistics

### *2.1 Data*

Our analysis is built upon the German production census firm-level data AFiD (Amtliche Firmendaten für Deutschland; Official firm data for Germany) provided by the Research Data Centres of the Statistical Offices Germany (2014). It is a confidential dataset and built upon a modular structure comprising the years 2006 until 2014.

The AFiD-Panel Industrial Units builds upon the German Production Census, the Monthly Report on Plant Operation and the Investment Census. All plants that belong to manufacturing firms with 20 or more employees are required to complete these surveys. This panel provides plant-level information on economic indicators such as Gross Output, Revenue, Exports and Export Share, and the Number of Manufactured Products. Larger firms usually possess more resources to gather information and install new technologies. We define two firm sizes: small-and-medium sized firms (up to 250 employees and up to 50 Mio € revenue) and large firms (250 or more employees and/or more than 50 Mio € revenue) in accordance with the EU definition.

We proxy a firms financial capacity via revenues and, due to collinearity issues, control for the firm size via the labor intensity variable (i.e. the number of employees per gross output). We include the share of revenue from exports, as Richter and Schiersch (2017) find that a higher export intensity is associated with significantly lower $CO_2$ intensity among German manufacturing firms. As a global market scope may increase the management quality and awareness of energy innovations (Roy and Yasar, 2015)), we include a dummy for multinational firms.

We aggregate the plant data to the firm level in order to minimize discrepancies from firm-internal accounting methods. We further obtain the number of employees (Size) and generate an SME dummy that is equal to one for firms that fall under the EU definition of SME, and otherwise is equal to 0. Another dummy (Multi-Plant) indicates firms operating more than one plant in a given year.

The AFiD-Module Use of Energy provides consumption data for electricity and 14 different fuel types. Relating total Energy Consumption to Gross Output also yields our Energy Intensity indicator. A larger (log) energy increases the potential financial savings from more efficient technology. We further include the (log) direct $CO_2$ emissions from energy use, as some manufacturing firms are also subject to carbon pricing under the EU ETS. As in Löschel et al. (2018), we use energy-carrier specific $CO_2$ emissions factors to estimate direct $CO_2$ emissions from energy usage and respective $CO_2$ Intensity (see Appendix for details).

Energy efficiency investments may also be more attractive and salient for firms with own electricity generation facilities from fossil fuels, which we indicate with a dummy (Fossil fuels). We also indicate firms using renewable energy sources (Renewables), e.g. solar, wind, hydropower or biomass, which may indicate preferences for and awareness of low-carbon technologies. On the contrary, investments into renewables may also could crowd-out financing for energy efficiency technologies.

Next to firm-internal factors, investment behavior may be affected by industry-specific characteristics, especially competitor behavior. For this reason we define the Relative Size, Relative Energy Intensity and Relative $CO_2$ Emissions as the respective firm value divided by the mean value of the (more narrow) 3-digit industry. As such, relatively larger firms may better exploit economies of scale or possess more resources to uncover optimization potential. Being less energy efficient than competitors may be a driver to invest in order catch up in terms of low energy costs of production. The same rationale may hold regarding $CO_2$ emissions, especially if a firm is regulated under the EU ETS.

The AFiD-Module Environmental Protection Investments provides information on the Euro value of investments into environmental protection measures (Eco-Investments), e.g. regarding air pollution, water pollution, waste and noise reduction, landscape preservation and more. Further, the module provides investments into renewable energy sources but also investments into energy efficiency measures and other means to mitigate greenhouse gas emissions. The latter provides our key outcome variable. Examples are recuperators, heat pumps, cogeneration of heat and power, insulation of buildings, refurbishments of heating and hot water generation, and efficient grids. In case of new blast furnaces or the generation of new power plants, firms only state the part of investment costs that is responsible for an increase in energy efficiency vis-a-vis comparable technologies. Based on the monetary value, we generate a dummy variable that is equal to one if a firm has made any positive investment into energy efficiency and climate change mitigation in a given year. This is our key outcome variable in the analysis of Section 3 and a key explanatory variable in Section 4. At this point it has to be noted that a clear separation between replacement of production capital and specific investments into more energy-efficient technology may be difficult. It may be also remain unclear to answering firms, despite the Statistical Offices best effort to fully inform respondents and check the dataset for plausibility. We further generate covariates to account for peer pressure or spillover effects: the share of investing competitor firms, as well as the share of competitors with eco-investments, in the same 3-digit industry.

The Cost Structure Survey (CSS) contains specific costs data, e.g. due to energy usage or R&D activities. We first derive the share of energy costs among total costs, and divide it by total energy consumption to obtain the average price of a unit of energy. We account for the energy cost share and the average price of energy, which presumably are major incentives to install new energy saving technologies. Firms spending a larger share of their revenue on R&D may also benefit from innovation via a more efficient means of production (Popp (2001)). We use a dummy to further distinguish between corporations and sole proprietorship. At last, we control for the share of interest payments per revenue (Debt Share).

Large firms with more than 500 employees are obliged to permanently report to the CSS, while smaller firms with at least 20 employees are gathered by a random sample - the latest stem from 2003, 2008, and 2012.

In years 2009 onwards, the dataset is based on the NACE rev. 2 (Statistical Classification of Economic Activities on the European Community) industry classification. For the years 2006-2008 we change the industry classification from the earlier NACE rev 1.1 to NACE rev. 2 using the official reclassification guide of the German statistical offices and the 4-digit industry code of each firm.

We deflate all monetary variables to 2010 levels on the 2-digit sector level sector via the index of producer prices for industrial products on industry by the German Federal Statistical offices (Destatis).[3]

It is noteworthy that our dataset only contains a subset of all manufacturing firms, because only plants of firms with at least 20 employees are required to answer the surveys. In 2014 the Federal Statistical Office reports 44,338 manufacturing plants of which 21,829 had less than 50 employees.[4] For comparison, our dataset only contains 42,320 plants, because firms are only required to fill out reports when the firm has at least 20 employees. Thus, by definition our analysis covers only a smaller number of the existing small-and-medium enterprises. Specifically, our analysis is able to analyze firms with 20-250 employees, whereas any conclusions my not hold for very small firms with less than 20 employees.

## *2.2 Descriptive statistics*

**Investment activity**

Our assessment begins with an overlook on the number of firms that invest into energy efficiency technology, both over time and across firm size (Table 1). During our sample period with 316,614 observations, i.e. firm years (Column 2 of Table 1), we find 16,423 observations (Column 3 of Table 1) where firms show respective investment activity in a particular year. Over all years, the share of observations with any investment activity is 5.2 %. The number of investing firms is steadily increasing over time, up from 885 firms investing in 2006 to 2,840 firms investing in 2014. Likewise, the average value of firm-level investments (Column 4 of Table 1) more than quadrupled in these ten years from 4.5 Mio. € in 2006 to 18.5 Mio. € in 2014. The overall investments in the manufacturing sector also reflect the increasing importance of energy efficiency as they rose from 152 Mio. € in 2006 to 670 Mio. € in 2014.

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[3] The price indices data is available at the Federal Statistical Office website: https://www-genesis.destatis.de/genesis/online (Producer Price Index 61241-0003)

[4] The plant size information is available at the Federal Statistical Office website: https://www-genesis.destatis.de/genesis/online (Beschäftigte und Umsatz der Betriebe im Verarbeitenden Gewerbe: Deutschland, Jahre, Beschäftigtengrenklassen, Wirtschaftszweige (WZ2008 Hauptgruppen und Aggregate))

*Table 1: Observations with investments, total and over years (2006-2014)*

| | Number of observations | | Investments (in 1000€) | |
|---|---|---|---|---|
| | **Total** | **Investing** | **Mean** | **Sum** |
| **Total** | | | | |
| | 316,614 | 16,423 (5.2%) | 12.2 | 3,875,217 |
| **Year** | | | | |
| 2006 | 33,868 | 1,129 (3.3%) | 4.5 | 152,097 |
| 2007 | 34,293 | 1,356 (4.0%) | 8.5 | 292,148 |
| 2008 | 35,123 | 1,411 (4.0%) | 9.5 | 333,736 |
| 2009 | 35,176 | 1,380 (3.9%) | 10.9 | 383,602 |
| 2010 | 35,048 | 1,604 (4.6%) | 9.5 | 334,042 |
| 2011 | 35,227 | 1,935 (5.5%) | 13.9 | 489,640 |
| 2012 | 35,640 | 2,001 (5.6%) | 17.7 | 631,543 |
| 2013 | 36,115 | 2,583 (7.2%) | 16.3 | 588,660 |
| 2014 | 36,124 | 3,024 (8.4%) | 18.5 | 669,750 |

*Note: Observations are firm-years. Statistics comprise all firms, including non-investors. Median value of investments is zero for all years and across both firm sizes. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations.).*

Across all industries, firms are engaging with investments in energy efficiency (Table 2). The majority of these firms operate in energy intensive industries such as Fabricated Metals, Food, Machinery, Rubber & Plastic, and Chemicals. The relative amount of investing firms is especially large in the smaller industries Coke & refinery, Tobacco, Pharmaceuticals, as well as in the larger industries of Basic Metals and Chemicals. Industries with the largest sum of investments over our sample period are Food and Chemicals, followed by Automotive, Paper, Machinery, Rubber and Plastic, Fabricated Metals and Basic Metals.

A central question of this paper is to assess structural differences in investment behavior between large firms and small-and-medium enterprises. As shown in Table 3, the overall number of SME-observations in our sample (11,526) is relatively small compared to large firm-observations (305,088). Over the whole sample period there are only 179 observations (firm-years) of SME investing into energy efficiency, which is only 1.6 % of all SME observations. For comparison, we find 16,244 out of 305,088 observations (5.3%) of large firms investing into energy efficiency. The average investment sum by SME is 0.6 Mio € vs. 12.7 Mio. € for large firms, which could reflect smaller production facilities and energy demand and fewer resources (personnel and financial) of SME.

*Table 2: Observations with investments, total and across industries (2006-2014)*

| | Number of observations | | Investments (in 1000€) | |
|---|---|---|---|---|
| | **Total** | **Investing** | **Mean** | **Sum** |
| **Total** | 316,614 | 16,423 (5.2%) | 12.2 | 3,875,217 |
| **NACE 2-digit industry** | | | | |
| 10) Food | 40,534 | 2,184 (5.4%) | 12.5 | 510,003 |
| 11) Beverages | 4,316 | 407 (9.4%) | 24.9 | 107,383 |
| 12) Tobacco | 192 | 25 (13.0%) | 66.9 | 12,838 |
| 13) Textiles | 5,809 | 386 (6.6%) | 5.5 | 31,865 |
| 14) Wearing apparel | 1,838 | 48 (2.6%) | 1.5 | 2,771 |
| 15) Leather | 1,477 | 36 (2.4%) | 2.3 | 3,462 |
| 16) Wood | 8,486 | 280 (3.3%) | 4.1 | 34,633 |
| 17) Paper | 7,033 | 602 (8.6%) | 41.2 | 290,036 |
| 18) Printing | 11,828 | 391 (3.3%) | 7.0 | 82,302 |
| 19) Coke; refinery | 336 | 71 (21.1%) | 473.7 | 159,146 |
| 20) Chemicals | 10,164 | 1,044 (10.3%) | 48.6 | 494,401 |
| 21) Pharmaceuticals | 2,140 | 274 (12.8%) | 55.7 | 119,230 |
| 22) Rubber, plastic | 24,062 | 1,577 (6.6%) | 10.2 | 246,017 |
| 23) Non-metallic minerals | 12,619 | 607 (4.8%) | 14.0 | 177,251 |
| 24) Basic metals | 7,944 | 868 (10.9%) | 25.2 | 200,346 |
| 25) Fabricated metals | 57,779 | 2,522 (4.4%) | 4.1 | 238,246 |
| 26) Electronics | 13,971 | 692 (5.0%) | 10.0 | 140,226 |
| 27) Electrical eq. | 16,328 | 911 (5.6%) | 8.3 | 135,220 |
| 28) Machinery | 45,834 | 1,882 (4.1%) | 6.1 | 279,177 |
| 29) Motor vehicles | 9,568 | 639 (6.7%) | 45.1 | 431,084 |
| 30) Other transport equip. | 2,045 | 155 (7.6%) | 28.7 | 58,748 |
| 31) Furniture | 8,476 | 249 (2.9%) | 3.1 | 25,924 |
| 32) Other manuf. | 12,243 | 353 (2.9%) | 5.3 | 64,978 |
| 33) Repair, installation | 11,592 | 220 (1.9%) | 2.6 | 29,933 |

*Note: Observations are firm-years. Statistics comprise all firms, including non-investors. Median value of investments is zero for all years and across both firm sizes. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations.).*

In order to supports the impression of the descriptive statistic we run a non-parametric Chi-Squared test. The Null hypothesis is an equal share of investing firms across firm size. With a p-value of (0.0001) we can reject the Null hypothesis. This means that observations with SME status are significantly less correlated with energy efficiency investments than large firm-observations. Thus, we further inquire the question why large firms are more likely to invest into energy efficiency than small firms, using the explanatory variables of our dataset.

Note that the figures in Table 3 reflect observations and recall that investment activity may be cyclical. Therefore, Table 4 also provides the number of firms showing investment activity at least once during our sample period. In order to account for market entry and exit, we derive the values in 2006, 2010 and 2014. Unsurprisingly, the number of firms investing at least once is much larger, with more than one quarter of large firms and one in ten SME by 2014.

During our sample period, the number of investing large firms increased by from 6,778 to 7,670. By 2014, the number of operating SME with investment activity is 180, almost twice as many as in 2006, which reflects an increasing uptake of investments also by firms with smaller production plants and fewer resources.

*Table 3: Observations with investments, total and over firm size (2006-2014)*

| | **Number of observations** | | **Investments (in 1000€)** | |
|---|---|---|---|---|
| | **Total** | **Investing** | **Mean** | **Sum** |
| **Total** | | | | |
| | 316,614 | 16,423 (5.2%) | 12.2 | 3,875,217 |
| **Firm size** | | | | |
| SME | 11,526 | 179 (1.6%) | 0.6 | 6,825 |
| Large Firms | 305,088 | 16,244 (5.3%) | 12.7 | 3,868,392 |

*Note: Observations are firm-years. Statistics comprise all firms, including non-investors. Median value of investments is zero for all years and across both firm sizes. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations.).*

*Table 4: Number of firms investing at least once during sample period 2006-2014, over firm size*

| | **Number of firms** | | | | | |
|---|---|---|---|---|---|---|
| | **Large firms** | | | **SME** | | |
| **Year** | | | | | | |
| 2006 | 34,052 | 6,778 | (25%) | 1,422 | 103 | (8%) |
| 2010 | 34,939 | 7,543 | (28%) | 1,899 | 151 | (9%) |
| 2014 | 35,821 | 7,670 | (27%) | 1,793 | 180 | (10%) |

*Note: Table comprises the number of firms investing at least once and between 2006 and 2014, with the number obtained at different years. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations.).*

# 3. Drivers and barriers of energy efficiency investments

In this Section, we exploit the panel dataset to assess why firms differ in energy efficiency levels and to uncover major drivers and barriers regarding energy efficiency investments.

## *3.1 Potential energy efficiency gaps*

In a next step, we assess whether investing firms are less energy intensive than peers. In Table 5, we display the summary statistics for all firms and separately for investing firms as well as for non-investing firms. Values are averages over the whole sample period 2006-2014, taken from all firms existing in the year 2010.

*Table 5: Firm-level summary statistics (2006-2014)*

| | **Investors** | | **Non-investors** | |
|---|---|---|---|---|
| | **Mean** | **Median** | **Mean** | **Median** |
| Energy Consumption | 55,725 | 3,416 | 6,429 | 795 |
| Energy Intensity | 236.80 | 0.24 | 13.24 | 0.16 |
| $CO_2$ Emissions | 50,548 | 1520 | 3,748 | 330 |
| $CO_2$ Intensity | 111.66 | 0.11 | 5.44 | 0.07 |
| Size | 4,539 | 1,227 | 1,162 | 585 |
| Revenue | 129,563 | 16978 | 19,684 | 6,060 |
| Export Share | 0.27 | 0.20 | 0.20 | 0.10 |
| Eco-Investments | 0.27 | 0.17 | 0.05 | 0.00 |
| International | 0.13 | 0.00 | 0.08 | 0.00 |
| Renewables | 0.10 | 0.00 | 0.06 | 0.00 |
| International | 0.14 | 0.00 | 0.07 | 0.00 |
| Fossil | 0.14 | 0.00 | 0.07 | 0.00 |
| Multi Plant Firm | 55,725 | 3,416 | 6,429 | 795 |
| N | 27,575 | | 7,473 | |

*Note: Covariate mean and median values over the years 2006 until 2014 separately for investment activity status. The number of firms is taken from the year 2010. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations).*

The descriptive results already reveal that investing firms substantially differ from non-investing peers. The former consume more energy and generate more $CO_2$ emissions, are larger, generate more revenue and have larger export shares. On average, they rather invest into other measures to protect the environment, use fossil fuels (e.g. to generate own electricity) or consume renewable energy sources. Often investing firms operate internationally and in multiple plants.

Next we apply a simple OLS regression of firm-level (log) energy intensity on the investment dummy, firms size and other key firm characteristics to further investigate the role investments. The relatively low share of investing SME also provides ground for the assumption that a potential energy-efficiency gap may be larger for SME than large firms. We include an SME dummy in the regression to test this hypothesis as well.

$$Y_i = \alpha + \beta_1 \mathbf{X} + \beta_2 \cdot SME + \sigma_s + \theta_i \quad ,$$

where $\sigma_s$ are 2-digit industry dummies. The vector of controls $\mathbf{X}$ comprises both firm-internal factors as well as external factors, such as competitor behavior.

As firms enter or exit the panel over time, we run the same regression in 2006, 2010 and 2014.

In all regressions, the dummy for investment activity is negative and highly significant (Table 6). In the years 2006 and 2010, investing firms use about 4 percent less energy per output than peers. In 2014 this difference is even 17 percent. The results further show that SME are much more energy intensive than large firms. However, it is up to further research whether this is merely a result of different economies of scale and scope, or whether this result actually reflects inefficiencies in energy usage.

Table 6: OLS Regression over all industries Dep. var.: Energy intensity of production in a certain year.

| **Covariate** | **2006** | **2010** | **2014** |
|---|---|---|---|
| *Firm-internal factors (X1)* | | | |
| Investor | -0.046 *** | -0.041 *** | -0.170 *** |
| | (0.011) | (0.010) | (0.012) |
| SME | 0.314 *** | 0.358 *** | 0.447 *** |
| | (0.021) | (0.025) | (0.030) |
| Investor-SME | 0.306 *** | 0.071 | 0.416 *** |
| | (0.092) | (0.069) | (0.076) |
| $CO_2$ emissions (ln) | *** | 0.395 *** | 0.651 *** |
| | (0.003) | (0.003) | (0.003) |
| Labor Intensity | -0.004 * | -0.009 *** | 0.001 |
| | (0.002) | (0.002) | (0.001) |
| Revenue | 0.000 *** | 0.000 *** | 0.000 *** |
| | (0.000) | (0.000) | (0.000) |
| Export ratio | -0.558 *** | -0.578 *** | -0.939 *** |
| | (0.020) | (0.020) | (0.023) |
| International | -0.408 *** | -0.397 *** | -0.641 *** |
| | (0.015) | (0.015) | (0.017) |
| Renewables | 0.201 *** | 0.175 *** | 0.255 *** |
| | (0.017) | (0.016) | (0.017) |
| Fossil fuels | 0.026 *** | 0.032 *** | -0.019 * |
| | (0.010) | (0.009) | (0.011) |
| *External factors (X2)* | | | |
| WZ3 Energy Efficiency | 0.000 * | -0.001 | 0.001 |
| | (0.000) | (0.000) | (0.001) |
| WZ3 Eco Investments | 0.114 * | 0.141 | 0.096 |
| | (0.569) | (0.412) | (0.549) |
| Relative Size | -0.240 *** | -0.238 *** | -0.361 *** |
| | (0.005) | (0.005) | (0.006) |
| Relative $CO_2$ | 0.057 *** | 0.055 *** | 0.048 *** |
| | (0.003) | (0.003) | (0.003) |
| Relative Energy Intensity | 0.074 *** | 0.062 *** | 0.062 *** |
| | (0.001) | (0.001) | (0.001) |
| N | 33,543 | 34,737 | 35,811 |
| Adj. R-squared | 0.5928 | 0.5994 | 0.6969 |
| Prob > F | 0 | 0 | 0 |

*OLS regression across all industries in certain years. Covariate values are mean values over whole sample period 2006-2014. All models include 2-digit industry dummies. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel*

## *3.2 Investment decision*

Economic theory suggest that firms will invest into energy efficiency when expecting a positive net benefit. Investment behavior may be one-time or cyclical. For this reason, we define the dichotomous variable $D_i$ is equal to one if firm i exerts investment activity in at least one year t during sample years 2006 until 2014. Using a logit model, we uncover the marginal effects of firm characteristics and industry factors on the likelihood of investment activity. Therefore, we regress the investment dummy $D_i$ on a vector of covariates that may determine the firms expected payoff from investing in energy efficient technology:

$$D_i = \alpha + \beta_1\mathbf{X} + \sigma_s + \theta_i$$

Again, the vector of controls X comprises firm-specific factors as well as and external influence. This baseline set of covariates is available to all firms. Note that we use the mean of covariate values over the whole sample period in order to account for annual fluctuations in covariates (mean reversion). Further, this method accounts for investment patterns of firms. We further control for industry-specific characteristics via 2-digit industry dummies $\sigma_s$. The standard error is $\theta_i$. The results are shown in the second column of Table 7.

In order to further distinguish drivers for investments between SME and large firms, we specify a second model where we interact all control variables with an SME dummy:

$$D_i = \alpha + \beta_1\mathbf{X} + \beta_1\mathbf{X} \cdot SME + \sigma_s + \theta_{is}$$

For the purpose of brevity, we show non-interacted coefficients (for large firms) in the third column and coefficients interacted with the SME-dummy in the last column of Table 3.

In Table 8 we present results of the same regression on the smaller CSS subsample where we can include additional firm-internal explanatory variables, such as the share of energy costs or the average price for a unit of energy.

*Table 7: Full sample logit regression (marginal effects) where the dependent variable is a dummy indicating whether a firm invests at least into energy efficiency and GHG mitigation during the sample period (2006-2014).*

| | Model I | | Model II (Interaction terms) | | | |
|---|---|---|---|---|---|---|
| | All firms | | Large firms | | SME | |
| *Firm-internal factors* | | | | | | |
| SME | -0.038 | ** | - | | - | |
| | (0.017) | | - | | - | |
| Energy intensity | -0.008 | *** | -0.007 | ** | -0.002 | |
| | (0.003) | | (0.003) | | (0.017) | |
| $CO_2$ emissions | 0.063 | *** | 0.062 | *** | 0.003 | |
| | (0.002) | | (0.002) | | (0.009) | |
| Labor intensity | 0.008 | ** | 0.007 | ** | -68.357 | |
| | (0.004) | | (0.004) | | (100.076) | |
| Revenue | 0.000 | | 0.000 | | 0.000 | |
| | (0.000) | | (0.000) | | (0.000) | |
| Export ratio | 0.030 | *** | 0.031 | *** | -0.176 | |
| | (0.010) | | (0.010) | | (0.110) | |
| International | -0.072 | *** | -0.072 | *** | -0.015 | |
| | (0.008) | | (0.008) | | (0.078) | |
| Renewables | 0.075 | *** | 0.074 | *** | 0.020 | |
| | (0.008) | | (0.008) | | (0.060) | |
| Fossil fuels | -0.001 | | -0.001 | | -0.022 | |
| | (0.004) | | (0.004) | | (0.062) | |
| *External factors* | | | | | | |
| WZ3 Energy Efficiency | 0.000 | *** | 0.000 | *** | 0.000 | |
| | (0.000) | | (0.000) | | (0.001) | |
| WZ3 Eco Investments | 0.334 | *** | 0.341 | *** | -0.559 | |
| | (0.057) | | (0.057) | | (0.438) | |
| Relative Size | 0.014 | *** | 0.014 | *** | 0.191 | |
| | (0.003) | | (0.003) | | (0.168) | |
| Relative $CO_2$ | -0.003 | ** | -0.003 | ** | -0.739 | ** |
| | (0.001) | | (0.001) | | (0.362) | |
| Relative Energy Intensity | -0.001 | | -0.001 | | 0.003 | |
| | (0.001) | | (0.001) | | (0.016) | |
| N | 34,737 | | 34,713 | | | |
| R squared | 0.1179 | | 0.1237 | | | |
| Prob > F | 0 | | 0 | | | |

*Logit regression results over the whole sample period 2006-2014 and across all industries. Coefficients are marginal effects (margins command in STATA). All models include 2-digit industry dummies. The regression includes all firms operating in the year 2010. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations).*

In the full sample, the SME coefficient is highly significant at the one percent level and suggest that SME are, on average, about 4 percent less likely to invest than large firms (table 7). Likelihood increases when firms are relatively less energy intensive, and when they emit relatively more $CO_2$ than peers. Labor intensity and revenue do not exert much explanatory power. On the contrary, firms with larger export shares are much more likely to invest. This finding may be a result of better energy management by exporters, as can be assumed based on the findings by Richter and Schiersch (2017) that exporters are less emission intensive. A lower probability of investment for international firms than domestic firms is not an intuitive result under the a-priori assumption that firms with more international market experience are also more prone to energy management practices. Potentially it may be a result of streamlining the production line and technology. However, a further explanation of this major barrier would require the work of surveys or case studies. Consumption of renewable energy substantially increase the likelihood. This seems plausible as they indicate that firms are aware of energy technology or have an energy management in place.

Indeed both of the industry-level factors are significant. A larger share of close competitors in the same 3-digit industry investing into energy efficiency, as well as other means of environmental protection, correlates with an increased likelihood of a firm to do the same. The coefficients are highly significant at the one percent level. Further, we find a positive effect when firms relatively larger and emitting relatively less $CO_2$ than close competitors.

A major results of the second model specification (last two columns of Table 7) is that almost all covariates interacted with the SME dummy are insignificant. Thus, the significant correlations identified before mostly apply to large firms only. Thus, the structural characteristics of SME do not seem to determine investment activity and make it harder to identify firms in this group that could be targeted with future energy efficiency policies. One exception are SME that which emit much less compared to close competitors. Among large firms though, future policy incentives could be promoted more towards large and export-oriented emitters.

*Table 8: CSS subsample logit regression (marginal effects) where the dependent variable is a dummy indicating whether a firm invests at least into energy efficiency and GHG mitigation during the sample period (2006-2014).*

| | **Model I** | | **Model II (Interaction terms)** | | |
|---|---|---|---|---|---|
| | **All firms** | | **Large firms** | | **SME** |
| *Firm-internal factors* | | | | | |
| SME | -0.103 | | | | |
| | (0.071) | | | | |
| Energy intensity | 0.005 | | 0.005 | | -0.149 |
| | (0.005) | | (0.005) | | (0.172) |
| $CO_2$ emissions | 0.082 | *** | 0.083 | *** | -0.041 |
| | (0.003) | | (0.003) | | (0.080) |
| Labor intensity | 0.003 | | 0.003 | | 938.783 |
| | (0.007) | | (0.007) | | (856.370) |
| Revenue | 0.000 | | 0.000 | | 0.000 |
| | (0.000) | | (0.000) | | (0.000) |
| Export ratio | 0.037 | ** | 0.037 | ** | 0.190 |
| | (0.016) | | (0.016) | | (0.567) |
| International | -0.085 | *** | -0.085 | *** | -- |
| | (0.011) | | (0.011) | | (omitted) |
| Renewables | 0.066 | *** | 0.067 | *** | -- |
| | (0.012) | | (0.012) | | (omitted) |
| Fossil fuels | -0.008 | | -0.008 | | -0.096 |
| | (0.006) | | (0.006) | | (0.209) |
| *External factors* | | | | | |
| WZ3 Energy Efficiency | 0.000 | *** | 0.000 | *** | 0.003 |
| | (0.000) | | (0.000) | | (0.011) |
| WZ3 Eco Investments | 0.437 | *** | 0.435 | *** | 0.659 |
| | (0.083) | | (0.083) | | (2.657) |
| Relative Size | 0.008 | ** | 0.007 | ** | -1.065 |
| | (0.003) | | (0.003) | | (1.777) |
| Relative $CO_2$ | -0.002 | | -0.002 | | 2.247 |
| | (0.002) | | (0.002) | | (4.625) |
| Relative Energy Intensity | -0.003 | * | -0.003 | * | -0.477 |
| | (0.002) | | (0.002) | | (0.361) |
| Energy cost share | -0.582 | *** | -0.588 | *** | 5.314 |
| | (0.101) | | (0.102) | | (3.602) |
| Energy price | 0.000 | | 0.000 | | -3.617 |
| | (0.000) | | (0.000) | | (2.397) |
| R&D share | 0.306 | ** | 0.307 | ** | 9.816 |
| | (0.120) | | (0.120) | | (9.527) |
| Corporation | -0.004 | | -0.004 | | -0.045 |
| | (0.007) | | (0.007) | | (0.174) |
| Debt share | -0.583 | ** | -0.609 | ** | 9.986 |
| | (0.295) | | (0.297) | | (6.593) |

| | | |
|---|---|---|
| N | 34,737 | 34,737 |
| R squared | 0.1179 | 0.1187 |
| Prob > F | < 0.0001 | < 0.0001 |

*CSS subsample logit regression results over the whole sample period 2006-2014 and across all industries. Coefficients are marginal effects (margins command in STATA). Stars (*) indicates dummy variables. All models include 2-digit industry dummies. The regression includes all firms operating in the year 2010. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations).*

In the CSS subsample with additional covariate, the results coefficients are mostly robust (Table 8). The first exemption is the SME dummy, which is larger but insignificant. One major finding is that firms with larger energy cost shares are much less likely to install new energy efficient technology. If one expects those firms to be more inclined to decrease energy costs, this is a counter-intuitive finding. One potential explanation is the possibility that these firms have already undertaken investments prior to our sample period and mostly exploited potential for energy efficiency improvements.

Interestingly, we also find that the average price of energy does not significantly affect the decision to invest, which is also contrary to our expectation of a positive relationship. However, firms that spend relatively more on RD are also more prone to invest, which is a plausible driver for investment activity. At last, the negative and significant debt share coefficient substantiates the argument that financial constraints are a major barrier to investment activity.

The findings of second model specification (including the SME-dummy interaction terms) on the CSS subsample mostly resemble the full sample regression (last two columns of Table 8). Now the coefficients with significant p-value only apply to large firms anymore.

# 4 Impact on energy intensity

In this section, we aim to estimate whether a firm's decision to invest in energy efficient technology has an impact on its short run energy intensity of production. Energy intensity is defined as total energy consumption per gross output. We create a dummy variable $D_t$

that is equal to one for firms investing in year t. Investment activity may be one-time or cyclical, which is why we define the treatment group as firms that invest exactly once during our sample period. Likewise, firms that do not invest over our sample period are defined as the control group. As our dummy variable comprises different technologies and varying amounts of investment, our measurement is the average treatment effect on the treated for the average investment activity.

Based on this definition we estimate the difference-in-differences of energy intensity across both groups. That means we calculate how the energy intensity of investing firms changes after their first-and-only investment year towards the next year, and compare the change of control firms over the same time period. Formally, we estimate the Difference-in-Differences for the impact of investments on energy intensity via the following OLS regression:

$$\Delta Y_{it} = \alpha + D_t + \beta \mathbf{X}_{it} + \lambda_s \cdot \pi_t + E_{it}$$

where $\Delta Y_{it}$ is the change in energy intensity from the once-and-only investment year towards the following year, $X_{it}$ is a vector of lagged covariates, $\lambda_s \cdot \pi_t$ are year-industry (2-digit level) dummies respectively and $E_{it}$ is an errors term. The covariates are the same as in the logit estimation (see Table 7) and "lagged" means that we use the average of covariate values from one and two years prior to the investment year t. This way we account for fluctuations and mean reversion.

Difference-in-differences accounts for the structural difference of firms and self-selection (see Table 5) under the condition of common pre-trends. We run the regression over the the whole sample period and exploit the full sample of firms. Thus we do not use CSS covariates.

In a second model specification, we pre-process the dataset via the Coarsened Exact Matching (CEM) approach proposed by Iacus et al. (2011, 2012), in order to balance treated and control firms in key covariates before running the same Difference-in-Differences regression. This means we select matching covariates that are stratified into blocks by an algorithm. Each investing firm has covariate values in a certain block of each covariate, and it is matched to all non-investing firms with covariate values in exactly the same blocks. As matching covariates, we select all significant lagged covariates of the logit estimation: (log) Energy Intensity, (log) $CO_2$ emissions, Export Ratio, dummies (International, Fossil

Dummy, and Renewables). An exact matching within firm size category (SME vs. large firms) and within 2-digit industries further accounts for heterogeneity. Having obtained a matched sample, we run the same regression again. Therein we including the same covariates as in the OLS to control for remaining differences after matching.

*Table 9: Regression results: Impact of investment on energy*

| Dep. var.: change in log energy intensity | **Estimation Model** | |
|---|---|---|
| | **OLS** | **CEM** |
| Energy efficiency investment | 0.001 | 0.004 |
| | (0.005) | (0.007) |
| | [-0.009 ; 0.013] | [-0.009; 0.016] |
| Control variables | x | x |
| Matching on control variables | | x |
| Number of obs | 196,340 | 57,769 |
| Prob >F | <0.0001 | <0.0001 |
| Adj R-squared | 0.2831 | 0.2611 |

*Dep. var.: change in log energy intensity towards one year after first-and-only investment into energy efficient technology – relative to never-investing firms (Difference-in-Differences). Robust standard errors in round parentheses. 95 percent confidence interval in square parentheses. Regression results over whole sample period 2006-2014. P-values: *: p<0.1, **: p<0.05, ***: p<0.01. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations).*

The regression results in Table 9 show that in both models, the coefficient for firms investing for the first-and-only time are slightly positive, which would indicate energy intensity increasing by 0.1 or 0.4 percent. The coefficients are insignificant even at the ten percent level, such that we cannot reject the null hypothesis of no effect from investment activity on energy intensity. However, we can infer more from the 95% confidence intervals (shown in square parentheses below coefficients). For both the OLS and CEM regression, the confidence intervals suggest that the reduction in energy intensity may be up to 0.9 percent due to investment activity. We utilize this result in our next section.

# 5 Payback periods and discount rates

In this next Section, we use the previous estimates to monetize savings from investments and compare them to the average sum invested. This way we aim to assess financial benefits and the average payback period of energy efficiency investments.

## *5.1 Literature findings*

By this date, the energy economics literature has well studied the behavior of households regarding energy efficiency investments. In particular, a major string of research investigates implicit discount rates of consumer, often with respect to higher upfront purchase costs for more energy efficient goods such as electronic equipment. Energy efficiency investments with shorter payback period will be favoured with larger implicit discount rates.

As such, a seminal study by Hausman (1979) models the trade-off between initial capital costs and lower operating costs from energy. In an empirical application, the paper finds a large average discount rate of 20 percent regarding the purchase of new air conditioners by U.S. households. In the context of U.S. Energy Guide labels, Newell and Siikamäki (2015) use surveys to elicit individual discount rates among U.S. families. The study estimates mean individual discount rates of 19 percent and a median value of 11 percent, conditional on large influence of socioeconomic characteristics.

However, the investment behavior of firms on this matter is subject to a different decision making process due to its organizational structure and more complex incentive structures of managers. Most firm-level studies report implicit discount rates above a risk-adjusted discount under classical investment analysis though (DeCanio, 1998). Anderson and Newell (2004) assess the uptake of investments suggested to U.S. firms who participated in a government-sponsored energy audit program. The majority of approved projects had a payback period of 2 years or less. Other studies confirm the suggestion that short payback periods are a major decision criteria:

In a related assessment program for SME in the U.S., Abadie et al. (2012) find a mean payback periods of less than two years DeCanio (1998) assess the U.S. EPA GreenLights program for commonplace energy-saving lighting investments. The average reported payback period is 3.3 years and the median 2.8 years. A rather large average payback period of 6 years is reported in an evaluation of voluntary energy audit for German SME by

Fleiter et al. (2012). The authors conclude that longer payback periods may be a major barrier for investment activity, especially with uncertainty over energy prices. Löfgren et al. (2008) apply a structural option value model to estimate the hurdle rates of firms regarding pollution abatement technology investments. Their results imply computed hurdle rates between 2.7 and 3.6 in different industries. Qiu et al. (2015) estimate the implied discount rate and payback thresholds that U.S. manufacturing firms apply to energy efficiency projects. The analysis reveals that on average, firms use a discount rate of more than 40%, which is several times larger than the usual range for cost of capital among industrial firms. On average, realized projects required a payback period of no more than 9 months. In a survey by DECC (2014), the majority of British SME report that only projects with a short payback, mostly of two years or less, are considered as economic. A major barrier to efficiency investments may be the threat of smaller savings than anticipated. See for example the evaluation of the U.S. Weatherization Assistance Program by Fowlie et al. (2018). As we measure energy consumption ex-post, such divergence is not among the caveats to our analysis.

### *5.2 Calculation framework*

For our calculation, we exploit the fact that the AFiD dataset provides firms' annual energy consumption and energy costs. Consider a firm in time period 0 consuming energy E0 at an average unit price $P_0$ in order to produce an optimal output $Y_0$. Let $Z_0$ be the initial energy intensity, i.e. the energy consumed to generate one unit of output: $Z_0 = E_0/Y_0$. Then total costs of energy consumption, $C_0$, are given as: $C_0 = P_0 \cdot Z_0 \cdot Y_0$ .

In case firms invest in energy efficient technology, we assume that this leads to a decrease in energy intensity, relative to firms in the same sector that did not invest, over and above general improvements in energy intensity over time that apply to all firms.

However, there are several mpirical challenges when calculating an average return of the investment, such as a clear identification of the effect as well as comparing differing sums of investment (see Section 4 for discussion). Therefore, our simplified workaround is the assumption that the current energy intensity would decrease owing to investment activity. That is, we assume varying parameters for a relative reduction of current energy intensity ($Z_0$) and its effect on energy costs. As such, the confidence interval of Section 4 suggests the usage of a 0.01 percent reduction. This would in turn decrease current energy costs ($C_0$) by 0.01 percent respectively, yielding the cost savings $S_0$.

Further assuming that this saving $S_0$ is constant over time we calculate the time periods until the cumulated cost savings become larger than the upfront investment costs $K_0$, ceteris paribus. For simplicity, the interest rate is also assumed to be zero.

In Table 10 we display the median value of respective statistics (to account for outliers that skew the distribution and the mean value) where we only consider firms that invest for the first-and-only time during our sample period. The upper row only present the median values for large investing firms, the last row only include median values for the distribution among investing SME.

*Table 10: Energy savings and payback periods*

| | ***Values of*** | | ***Assumed payback period when energy costs decrease by*** | | |
|---|---|---|---|---|---|
| | ***Energy costs*** | ***Energy efficiency investments*** | ***0.1 %*** | ***1 %*** | ***2 %*** |
| ***Investing large firms (N=*** | *796* | *34* | *9.7* | *4.8* | *2.4* |
| ***Investing SME (N=15)*** | *41* | *12* | *72.6* | *36.3* | *18.2* |

*Statistics show median values for energy costs, energy efficiency investment values and respective difference (each in 1000 €), as well as calculated payback periods. Statistics only comprise firms investing for the first-an-only time during our sample period 2006-2014. (Source: Research Data Centres of the Statistical Offices Germany (2014): Official Firm Data for Germany (AFiD) Cost Structure Survey, AFiD-Panel Industrial Units, AFiD Module Use of Energy, AFiD Module Environmental Protection Investments, survey years 2006-2014, own calculations).*

The first three columns show the energy costs, the energy efficiency investments as well as the respective difference between costs and investments.

Among large firms, energy costs are 0.8 Mio. € at the median. This compares to median energy efficiency investments of 49,000 €, which is about 4 percent of energy costs.

The average energy costs of SME are 41,000€ which compares to an average investment of 12,000€. This constitute almost one fourth of energy costs.

For the approximation of payback periods (shown in the last three columns) we vary the assumed factor of energy intensity reduction between 0.5, 1.0 and 2.0 percent.

Among large firms the median payback period varies between 9.7 (at 0.1 % energy cost reduction) and 2.4 years (at a 2 % energy cost reduction), which is close to the time periods reported in the empirical literature (see Section 5.1).

For SME the calculated payback is several times larger. They may be inaccurate owing to the low number of firms and the simplicity of our approach. Nonetheless, they highlight a key finding: the time until amortization is longer for SME than for large firms. One reason may be that necessary sums for investment are not a minor burden compared to the energy costs. This could potentially explain the low share of SME with investments in our data. Therefore, energy efficiency policies could further strengthen support to overcome financial constraints of SME and high implicit discount rates regarding energy efficiency projects.

# 6 Conclusion

In this report, we use production census data for an in-depth assessment of energy-efficiency related investment behavior by German manufacturing firms. Therein we answer several question. Our first step is to assess whether firms carrying out energy efficiency investments during our sample period show a more rational use of energy than peers. The results are in favour of remaining potential for cost-efficient investments among non-investing firms, which is in line with previous literature (on the so called "energy efficiency gap/paradox"). The potential for improvement seems to be even larger for small-and-medium enterprises, another focus of our study. However, we find the share of investing firms to be significantly lower among SME than large firms. In a next step of the paper, we use logit estimations to identify major drivers and barriers to investment activity. On the one hand we find significant correlations with firm-level characteristics such as a larger emissions, export orientation and usage of renewable energy sources. On the other hand, the regression results also support the importance of external influence, such as the investment behavior of close competitors. A second logit model specification distinguishes determinants by firm size. A key insight is that explanatory covariates are only significant for large firms. Thus, the data cannot identify SME with higher likelihood of investments. Otherwise, this could have served as guidance for a more precise targeting of support measures to firms.

In a final part of the paper we try to estimate an impact of firms' investment activity on short-run energy intensity using Difference-in-Differences approach. The confidence interval provides a starting point for our simple payback period model of investments. Owing to the scale of production, large firms face larger energy costs and undertake larger investments than SME. Approximated payback periods are plausibly short for large firms, ranging between 2 and 10 years. For SME, however, the time until amortization is several times larger. One potential reason may be the fact that investments sums constitute a relatively larger fraction of energy costs and thus a larger financial burden. Overall, our research indicates that energy efficiency gaps may be more severe among SME and that future policies could support the feasibility of financing energy efficiency investments.

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# Appendix

### Estimating direct $CO_2$ emissions from energy usage

The AFiD-Module Use of Energy comprises energy consumption data (in kWh) separately for electricity and 8 fuel types, e.g. natural gas, oil and coal products. As in Löschel et al. (2018) we use fuel-specific $CO_2$ emission factors by the Federal Environmental Agency (2016a) in order to estimate energy-related $CO_2$ emissions of firms. The energy consumption variable for coal products, other mineral oil products and other gases are aggregated from more detailed fuels, which is why we weight the emission factor for each 3-digit industry and year according to the share the of subsumed fuels consumed in (AG Energiebilanzen: http://www.ag-energiebilanzen.de/).

For electricity, we refer to the $CO_2$ emission factor by the Federal Environmental Agency (2016c) that accounts for international trade effects. We set the emission factor to zero for own electricity generation from water and other sources (e.g. solar panels), as well as for other renewable energy sources.

For district heating we refer to values from the Federal Environmental Agency (2008). A recommended by staff from a personal phone consultation in March 2017, we use the value of 2005 for all years in our panel (2006-2014).

*Table 6: Mean annual CO2-emission factors by fuel type over years 2006-2014*

| Fuel type | g/kWh | Fuel type | g/kWh |
|---|---|---|---|
| Electricity (from grid) | 620 | Lignite raw | 381 |
| Natural gas | 212 | Lignite briquet | 358 |
| Light heating oil | 266 | Other coal products | 359 |
| Heavy heating oil | 288 | Other mineral oil | 281 |
| Disctrict heat | 213 | Other gases | 311 |
| Liquid gas | 236 | Other fuels | 256 |
| Coal | 338 | Other renewables | 0 |
| Coke | 389 | | |

Mean values over whole sample period 2006-2014, deviations across years and industries not shown for clarity (Source: Federal Environment Agency 2016a, 2016b, 2008, AG Energiebilanzen).