Measuring the Effects of Energy Efficiency Policies: Evidence from Turkish Manufacturing Industry

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1 Introduction

From the mid-1700s, with the wider use of steam and onset of industrial revolution, coal became a commercial commodity; from the mid-1800s, petroleum rose to prominence; and from the early 1900s, electricity emerged as a modern secondary energy source. In the last quarter of the twentieth century, natural gas became a globally traded energy raw material. Recently, in addition to hydrocarbon resources with historic-high production capacities, renewable resources such as biomass, wind, and solar pushed the energy supply to very high levels. Nevertheless, the fundamental social and technological changes experienced by humanity in the last two centuries caused an increase in the amount of energy demand and prioritized the access to energy resources together with the transportation of energy to the markets with affordable costs and safe routes. Therefore, energy is one of the most important topics on the world's political agenda due to the several factors such as uncertainties caused by the fluctuations in oil and natural gas prices, the interruption of safe energy supply due to regional conflicts, the fact that more people need access to modern energy, and the enormous quantity of funding required. One other reason why energy plays such a big role in the world political agenda is that, no matter which source is used, every unit produced has an environmental impact. Greenhouse gas emissions, as the most important of such impact, increased at unusually high rates, and the global warming resulting from greenhouse effect created the climate change problem.

Today, global warming and climate change that have emerged mostly as a result of intensive fossil fuel use and rapid urbanization following the industrial revolution

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are perceived as common problems for all humanity. The rules and regulations introduced recently have intensified the global efforts, and the governments have been encouraged to take common steps to keep the average increase in global temperature at a safe level. These steps include changing energy policies and improving energy strategies. As a result of the rising global awareness and binding measures, industrial enterprises are under environmental, social, and financial pressure to keep their production processes based on fossil fuels (primarily coal) under control and to use energy in an efficient way. Another driving force for industrial enterprises to use energy efficiently is the increasing energy costs. Industrial enterprises are increasingly looking for ways to reduce energy costs to increase their competitiveness and to produce the same amount of product with less energy. Putting both environmental and financial concerns together, energy efficiency has become one of the key issues of energy-related politics, strategies, and research.

The energy management system (EnMS) is a contemporary approach associated with increasing the efficiency in energy use. It represents continuous and systematic efforts for energy improvements. Within the scope of EnMS, the implementing firms engage consistent audits, ask for consultancy, and carry out several improvements in their processes in order to develop sustainable strategies for efficient use of energy in their operations. ISO 50001 quality system, which standardizes and certifies, has been introduced to reward these efforts.

In this chapter, we aim to provide insight on energy efficiency and its policy applications shaped around the energy management system. First, we present the key concepts of energy efficiency and EnMS. Measuring the effects of EnMS policies, the energy efficiency projects within the scope of EnMS, the non-energy benefits of the application of such management system, and the standardization of efforts under ISO 50001 are the topics discussed throughout the chapter. Following the conceptualization, we conduct an empirical analysis in Turkish manufacturing industry firms that carried out energy efficiency increasing activities between 2015 and 2017. The analysis aims at observing the relative efficiency of the activities in terms of sectors and projects. The data used are collected within the scope of "Improving Energy Efficiency in Industry in Turkey Project" implemented by the Ministry of Energy and Natural Resources in cooperation with the United Nations Development Programme (UNDP) and United Nations Industrial Development Organization (UNIDO), with funding from the Global Environment Facility (GEF). The firms are from different sub-sectors of Turkish manufacturing industry (58 firms), and they carried out a wide range of activities from minor changes such as changing bulbs to more capital-intensive investments such as large-scale isolations in the given years. The analysis provides results from two orientations as firm-based and activity-based. In order to ensure homogeneity at activity-based evaluations, the activities are grouped into 16 different projects. We evaluate the performance of firms and activities with data envelopment analysis (DEA) in creating energy saving using energy, financial, and environmental factors. We interpret the results at sub-sectoral level and identify the efficient sectors. Moreover, the efficient projects are identified and discussed relying on their size. A simulation model is designed to test the robustness of the activity-based evaluations. All evaluations also consider two different subsets of the firms as ISO certification holders and small- and medium-sized enterprises (SMEs).

The chapter is organized as follows: In Sect. 2, we provide basic discussion of energy efficiency concept and the energy management system. Section 3 presents a brief information about the energy in Turkey together with some facts about the energy consumption in Turkish manufacturing industry. Section 4 presents the empirical analysis and its results. Section 5 concludes.

2 Energy Efficiency

In this section, we aim to provide a conceptual framework on energy efficiency shaped around a contemporary concept, energy management system (EnMS), which is born out of systematic and continuous search for the efficient use of energy.

2.1 Definitions

Energy intensity is generally defined as a measure of the amount of energy used to produce a unit of output. At the macro level, the energy intensity of a country is the amount of primary energy consumed per gross domestic product (GDP). A decrease in energy intensity can indicate that the energy is used more efficiently in a given country. According to the Energy Efficiency Report published by the International Energy Agency in 2018, the improvement (reduction) in global energy intensity was found more than 1.5% for 2017 globally. However, the global improvement goal in energy intensity to combat climate change is expected to be 2.4% annually between the years 2015 and 2030. These data indicate that humanity is still far away from targets to combat climate change (International Energy Agency 2018).

Energy efficiency and energy saving are two terms that are often confused and used interchangeably. Although they are in close relation, there exists a difference. Energy efficiency means reducing the energy intensity in each product, process, or production area without affecting the output or comfort level (Hepbaşlı 2010). In other words, energy efficiency is the ability to achieve the same benefit by using less energy. The energy saving, on the other hand, describes the reduction achieved in the amount of energy consumed at each stage of production and service providing as a result of the measures taken to utilize the energy and energy resources more efficiently (Kavak 2005). In other words, energy saving refers to the reduction in energy consumption measured and recorded in physical terms as a result of actions to improve energy efficiency.

Table 1 Expected saving rates through energy management

Investment cost	Payback period	Savings rate (%) to be achieved
Low cost	1 to 2 years	5 to 15
Average cost	3 to 5 years	15 to 30
High cost	Long-term potential	30 to 50

2.2 *Energy Management System*

Due to increased environmental awareness and increasing energy costs, research on how to use energy more efficiently has increased. The primary concept coming out of the efforts is energy management. It is related with the optimization of energy use and basically defined as to use energy rationally and effectively to maximize profits and increase competitiveness (Hepbaşlı 2010, p. 8). Energy management is inseparable from efforts for energy efficiency. It is related with continuous improvement of the energy performance of the industrial enterprise and paying systematic attention to energy in order to maintain improvements (Practical Guide for Implementing an Energy Management System 2014). Energy management helps firms to improve their productivity and product quality (Doty and Turner 2013).

Energy management is a critical factor for the survival of enterprises in the short term and for their success in the long term. As stated by Doty and Turner (2013), "implementing new energy efficiency technologies, new materials and new manufacturing processes and the use of new technologies in equipment and materials for business and industry is also helping companies improve their productivity and increase their product or service quality." Therefore, energy savings gained by means of energy management provide firms an advantage in terms of energy cost and competitiveness. Table 1 presents the average savings that organizations can expect depending on their investment costs on energy efficiency. Larger savings are expected to be accomplished with higher investments and provide longer-term improvement potentials (Doty and Turner 2013).

Energy management system (EnMS) is the conceptualized term for energy management and stands for a systematic and continuous approach to sustainable energy improvements (Javied et al. 2015). A short definition of EnMS is to make energy efficiency continuous. This can be achieved by adopting a systematic approach to energy management that is based on the Deming cycle in the form of plan-do-check-act (PDCA) for continuous improvement (United Nations Industrial Development Organization-UNIDO 2015). The Deming cycle developed around the 1950s is based on the idea that the *business processes be placed in a continuous feedback loop (Plan-Do-Check-Act) so that managers can identify and change the parts of the process that need improvements* (Deming 1993). The Deming cycle under the EnMS is a process approach that ensures continuous improvement. With EnMS, significant energy and cost advantages can be achieved in both industrial enterprises and houses in proportion to the investment cost.

2.2.1 Measuring the Effects

Energy management system (EnMS) is not a concept that can be instantly applied in an industrial enterprise. In order to make energy efficiency sustainable and spread it to the business as a culture, a system should be formed, and this system should be internalized by all employees. The establishment period of EnMS in an industrial enterprise covers roughly 6–9 months depending on enterprise size, senior management commitment, and resistance to change. In the process of establishing the system, people in the whole enterprise have certain tasks. However, the most important responsibility in implementation is on the energy manager and the energy management unit. Energy manager acts as a bridge between senior management and other units. The important success criterion is senior management commitment to energy management and the space it provides to the energy manager. Senior management's support for the energy manager with all resources, including employees, is one of the important criteria that can increase the quality of the system and speed of implementation (Hepbaşlı 2010).

Several studies have been conducted on the benefits of EnMS for organizations. Caffal (1995) states that 40% savings can be achieved in the total energy consumption of industrial enterprises implementing energy management systems. According to Thollander et al. (2007), with the implementation of energy efficiency programs, it is possible to achieve improvements by 16–40% in energy performance. However, it is not fair to expect such high levels of improvement in all EnMS-implementing industrial organizations. For instance, a survey conducted by Bonacina et al. (2015) reveals that out of 65 participating firms, the firms that implemented EnMS in the short term achieved around 5% savings. The energy saving rate achieved can vary depending on the extent to which the system is implemented. Ates and Durakbaşa (2012) observed in case studies they conducted in iron-steel, paper, ceramics, and textile sectors that only 22% of industrial enterprises implemented the energy management principles properly. Another similar study on this topic is the study of Thollander and Ottosson (2010) with foundries and paper producers in Sweden. The rate of implementing energy management principles in these sectors is 25% and 40%, respectively. In a similar study by Jovanović et al. (2017) for Serbia, this rate was 59%.

There exist several parameters that determine the savings from EnMS. Examples of such parameters may include the sector in which the industrial enterprise operates, its size, location, technological level of its machinery, implementation rate of EnMS principles, and its success. In short, the success of EnMS may vary by correct implementation and continuity. In the empirical analysis section of this chapter, we aim to provide evaluations on applications of EnMS in Turkish manufacturing firms.

2.2.2 Energy Efficiency Projects

Within the scope of EnMS, every measure to reduce energy intensity in industrial enterprises, or in other words to increase energy efficiency, can be defined as an energy efficiency project. By conducting energy audits, businesses can generally determine energy projects, project costs, payback periods, and amount of energy savings to be achieved. Energy audit reveals the instant energy efficiency savings potential of the industrial enterprise or building being audited. For such potential to be realized and provide savings, they must be converted into investment. Firms can have energy efficiency audits done by their internal energy management unit, energy manager, and/or external energy efficiency consultancy (EVD) companies. Our empirical analysis includes firms from Turkish manufacturing that have applied energy efficiency activities between 2015 and 2017.

2.2.3 Non-energy Benefits

The expected impact of energy efficiency projects resulting from an audit in an industrial enterprise is to save energy. However, the impact created within the organizations is not limited to energy saving. There exist some secondary impacts, which may dominate the primary impact in some cases. Below, some non-energy benefits are listed in six categories (adapted from Worrel et al. 2003):

- *Emission*: Reduced CO, CO_2, NO_x, SO_x emissions
- *Operation and Maintenance*: Reduced need for engineering controls, low cooling requirement, increased facility security, reduced wear and tear on equipment and machines, reduced labor requirements
- *Production*: Increased product output and returns, increased equipment performance, reduced process cycle times, increased product quality, increased production safety
- *Waste Management*: Waste fuel, heat and gas usage, reduced product waste, reduced waste water, reduced hazardous waste, reduced used material
- *Business Environment*: Reduced need for personal protective equipment, improved lighting, reduced volume, improved sound quality, improved air quality
- *Others*: Reduced liability, improved firm image, reduced capital expenditure, additional area, increased personnel morale

Considering the multidimensional nature of impact created by activities carried out for energy efficiency, in our empirical analysis, we use multiple factors as energy saving, financial saving, and carbon saving while evaluating the performance of activities in Turkish manufacturing industry.

2.3 ISO 50001: Energy Management Systems Standard

The ISO 50001 quality system is one of the key concepts to review in explaining EnMS. The ISO 50001 quality system is a result of efforts taken by the United Nations Industrial Development Organization (UNIDO). The United Nations Industrial Development Organization (UNIDO) is a United Nations agency established to support sustainable industrial development in developing countries and transition economies. UNIDO works on improving the energy efficiency in industry through the Industrial Energy Efficiency (IEE) program. In this context, UNIDO engages in various structuring works on EnMS and its standards. The request of UNIDO has been effective in the standardization of EnMS. An energy management committee was established in 2008 under the International Standardization Organization (ISO), which develops and publishes international standards and was recognized as a worldwide federation of 162 national standard organizations (ISO 2018). The objective of the Energy Management Systems Standard (ISO 50001) is to standardize the creation of systems and processes to improve the energy performance of organizations (ISO 50001 2011). The ISO 50001 aims to reduce energy costs and carbon emissions by using energy efficiency potential in a systematic way and identifies strategic energy targets and provides guidance to operationalize through action plans (Franz et al. 2017).

The ISO 50001 standard is based on the efficient use of energy in all processes from raw material supply to final product stage. The standard is an energy efficiency guide not only for industrial organizations but also for buildings. In addition to reducing energy costs, there are several advantages for an industrial organization to have ISO 50001 certification. Owning the certificate can be considered as simple evidence for the image that the organization is environment-friendly and may positively impact its brand value. However, not every organization that implements EnMS has the ISO 50001 quality certificate and vice versa. It can be misleading to conclude that every organization with ISO 50001 quality certification is properly implementing EnMS. In our empirical analysis presented in this chapter, we have a sample of firms that are ISO certified firms in the data set. Some evaluations have also been made regarding to have an ISO certificate or not.

3 Some Facts on Energy in Turkey

Due to factors such as population growth, rapid urbanization, rising prosperity, and growing manufacturing industry, the use of energy in Turkey is increasing steadily. While Turkey's primary energy supply in 2000 was 80.6 Mtoe (million tonnes of oil equivalent), this figure increased annually by 3.2% and reached 136.2 Mtoe in 2016

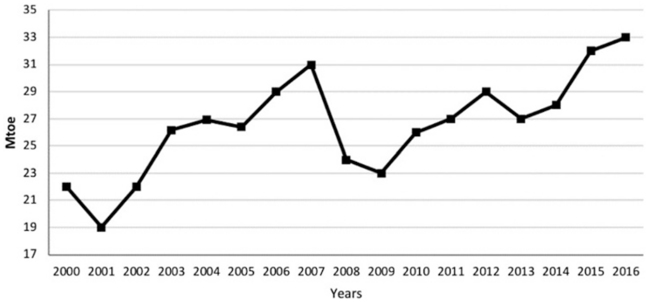

Fig. 1 Manufacturing industry energy consumption by year

(General Directorate of Renewable Energy 2018).[1] The rate of increase in electricity consumption is much higher. In the 10 years between 2007 and 2016, the electricity demand grew 4.3% on average annually, for a total of 46% in the period; and the total electricity consumption increased from 190 TWh (terawatt-hours) to 278.4 TWh.[2]

The share of the manufacturing industry in GDP in 2016 is 16.6% (TURKSTAT 2017). The sector has the second highest share in GDP next to services and is one of the driving factors of growth. The manufacturing sector is followed by wholesale and retail trade with 11.4% and by the construction sector with 8.6%. A significant portion of the manufacturing sub-sectors in Turkey are energy-intensive industries such as iron-steel and those based on stone and clay (cement, ceramics, glass, etc.).

The energy consumption in manufacturing industry in Turkey tends to increase over the years (see Fig. 1 adapted from General Directorate of Renewable Energy (2018) Turkey Energy Efficiency Progress Report (2000–2016)). Turkey is an energy-intensive country compared to developed countries, and its increasing energy demand emphasizes the importance of applying energy efficiency policies in its industries.

Energy efficiency policies in Turkey have been mainly directed by a unit in the Directorate of Electric Works and Studies that is first established in 1981 and later restructured in 1993 as the National Energy Conservation Centre (Kavak 2005). The Energy Efficiency in Industry Branch, a part of the center, conducted studies to increase the energy efficiency in the manufacturing industry. Following the closure of the General Directorate of Electric Works and Studies, the tasks related to energy efficiency were transferred to the General Directorate of Renewable Energy (YEGM) conducting various studies to increase energy efficiency, particularly encouraging industry to increase energy efficiency through various support mechanisms such as Efficiency Improving Projects and Voluntary Agreements.

[1] General Directorate of Renewable Energy (2018) Turkey Energy Efficiency Progress Report (2000–2016) available at: http://www.yegm.gov.tr/document/enver_gelisim_rapor_2018.pdf

[2] Ministry of Energy and Natural Resources (2016) General Directorate of Energy Affairs, General Energy Statistics available at: http://www.eigm.gov.tr/tr-TR/Denge-Tablolari/Denge-Tablolari

4 An Empirical Analysis of Energy Efficiency in Turkish Manufacturing Industry

In this section, we aim to present the design and results of a quantitative analysis of energy efficiency projects/activities carried out as a part of Energy Management System (EnMS) strategies (see Sect. 2.2) in Turkish manufacturing firms. We conduct the microlevel analysis in a sample of firms that applied various energy efficiency activities between 2015 and 2017. We derive conclusions on the effectiveness of applying energy efficiency management policies at firm, sub-sectoral, and activity level.

In our empirical analysis, we make use of the data collected within the scope of "Improving Energy Efficiency in Industry in Turkey Project" implemented by the Ministry of Energy and Natural Resources in cooperation with the United Nations Development Programme (UNDP) and United Nations Industrial Development Organization (UNIDO), with funding from the Global Environment Facility (GEF). The data set consists of firm-level energy efficiency activity data. A variety of activities have been carried out by the firms between 2015 and 2017. The data set reports:

- Annual energy consumption per firm
- Sub-sector information of the firms
- Information whether the firm is ISO certified
- Information whether the firm is a small- and medium-sized enterprise (SME)
- Energy efficiency activities applied in the given firm
- Energy saving of the firm out of each activity measured in tonne of oil equivalent (toe)
- Financial saving of the firm out of each activity measured in Turkish liras (TL)
- Carbon (CO_2) emission saving of the firm out of each activity measured in tonnes

There are 58 firms and around 200 activities. We approach to the data from two perspectives and provide two types of evaluations: firm-based evaluations and activity-based evaluations in the following subsections. Before moving to the evaluations, below we provide the method, data envelopment analysis, which is utilized for evaluating the performance at both dimensions.

4.1 Methodology: Data Envelopment Analysis

Data envelopment analysis (DEA) is a nonparametric performance measurement approach for identifying relative efficiency of decision-making units (DMUs) that are producing multiple outputs using multiple inputs. The DEA has been presented to the literature by the study of Charnes et al. (1978). Since then, DEA models have been widely applied for the real-world organizations in different industries including public and private sectors all over the world. In DEA modeling, the efficiency of a

DMU is measured relative to all other units with the simple restriction that all DMUs lie on or below an efficient frontier. A production possibility set containing "all input-output correspondences which are feasible in principle including those observed units being assessed" is constructed (Thanassoulis 2001). DEA modeling does not require any assumptions about the functional form of relationship between inputs and outputs. The efficiency score of each decision unit is obtained by solving linear programs. For each unit in a data set, a separate linear programming model is solved to investigate if there is a possibility for a unit to improve its performance. If there is no potential improvement for a unit (which means that it is performing efficiently relative to others), the linear programming model results in assigning an efficiency score of 100% to that unit. The unit or units with 100% efficiency define the efficient frontier. Below, we provide basic modeling idea of DEA.

Let us consider n decision-making units. We assume that each decision-making unit j for $j = 1, 2, \ldots, n$ uses m different inputs, x_{ij}. For i = 1, 2, . . ., m and produces s different outputs, y_{rj}. For $r = 1, 2, \ldots, s$. Let ϕ represent the efficiency score for unit o. Variables λ_j are introduced corresponding to each decision-making unit ($j = 1, 2, \ldots, n$) to form a Production Possibility Set (PPS) consisting of observed units, their convex combinations, and outperformed units. The units on the boundary (frontier) of the PPS are defined as efficient and attain the efficiency score of 100%, where the efficiency scores for others are measured relative to the frontier. The linear programming formulation to calculate the efficiency score of unit o is given below (Cooper et al. 2006):

$$Max\ \phi$$

$$s.t.$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le x_{io} \qquad i = 1, 2, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge \phi y_{ro} \qquad r = 1, 2, \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \ge 0 \qquad j = 1, 2, \ldots, n$$

Data envelopment analysis is a well-established method when multiple factors exist to evaluate the performance of the units. It is widely applied in measuring efficiency in energy sector at different levels (see Zhou et al. 2008; Mardani et al. 2017 for reviews).

Table 2 Sub-sector information of the firms

	Sub-sector	# of firms	# of ISO certified	# of SMEs
1	Automotive	5	3	2
2	Cement	4	3	0
3	Ceramics	3	3	0
4	Chemicals	8	3	2
5	Fabricated metal products	9	4	1
6	Fertilizer	1	0	0
7	Iron and steel	9	5	1
8	Stone and soil based	4	0	2
9	Textile	11	2	0
10	Wood processing and furniture	4	2	0
	Total	58	25	8

Table 3 Input and output factors in evaluating firms

	Factor name	Unit of measurement
Input 1	Annual energy consumption	Tonne of oil equivalent (toe)
Input 2	Total cost	Turkish lira (TL)
Output 1	Total energy saving (yearly)	Tonne of oil equivalent (toe)
Output 2	Total financial saving (yearly)	Turkish lira (TL)
Output 3	Total carbon saving (yearly)	Tonnes

4.2 Firm-Based Evaluations

The data set consists of 58 Turkish manufacturing firms that implemented different types of energy efficiency improvement activities within the period of 2015–2017. The firms operate mainly in ten different sub-sectors of the manufacturing industry listed in Table 1 together with the number of firms from each sub-sector. A subset of firms possesses ISO certificate (see Sect. 2.3), and a smaller subset are small- and medium-sized enterprises (SMEs). The number of ISO-certified firms and SMEs in each sub-sector is also provided in Table 2.

In order to measure efficiency of firms with respect to applied energy efficiency policies, we apply data envelopment analysis (DEA) which allows us a multidimensional and relative evaluation of the performance. Our modeling scheme includes both energy-related factors (annual energy consumption, energy savings, and carbon savings) and financial factors (cost and financial savings). Annual energy consumption is an input indicator to provide homogeneity in assessments since relative evaluation should also consider the size of the operation. Total cost is also taken as an input. Output indicators are related with savings. Table 3 summarizes the input and output indicators used in firm-based evaluations.

A potential question may arise at this point regarding the correlation of output factors. At first glance, output factors of financial and carbon savings may be thought to be correlated with total energy saving. It is important to note that total financial

Table 4 Correlations between output factors

Factors	Correlation with total energy saving
Total financial saving	0.0527
Total carbon saving	0.1312

Table 5 Sub-sectors of efficient firms

Sub-sector	# of firms	# of efficient firms	% of efficient firms
Chemicals	8	6	75
Wood processing and furniture	4	3	75
Cement	4	2	50
Stone and soil based	4	2	50
Automotive	5	2	40
Textile	11	4	36
Iron and steel	9	2	22
Ceramics	3	0	0
Fabricated metal products	9	0	0
Fertilizer	1	0	0
Total	58	21	36

saving and total carbon saving values of the firms have not been produced from their total energy savings. They are independent values relying on the type of the activities carried out. It is possible to have a high level of energy saving but a relatively low level of carbon saving depending on the activities. Similarly, financial saving values are not simply a scaling of energy saving with a fixed rate, since the prices may vary between sub-sectors. In order to clarify this issue, in Table 4, we present the correlation coefficients (Pearson's) between energy saving and two other factors. As seen in the table, the values are quite low to ensure that the analysis can include all three factors as outputs.

By using the input and output factors mentioned above, DEA models provided in Sect. 4.1 are solved for each firm to obtain efficiency scores between 0 and 1. This measure provides the relative performance of a firm in pursuing energy efficiency activities (100% being the efficient firms). Out of 58 firms, 21 firms (almost 36%) are obtained as "efficient." The distribution of efficient firms among sub-sectors is presented in Table 5. Eight out of 21 efficient firms are from chemicals sub-sector. Wood processing and furniture sub-sector is also a successful sector having three firms out of four in this sector obtained as efficient. There are some sub-sectors with no efficient firms such as ceramics, fabricated metal products, and fertilizer. None of the firms in those sub-sectors are relatively efficient in pursuing energy efficiency activities.

The average DEA score of the sample is 81.71%. Figure 2 provides average DEA scores for sub-sectors. On average, stone and soil-based manufacturing sub-sector has the highest level of efficiency out of their activities, followed by cement and chemicals sub-sectors. Although wood processing and furniture sub-sector has three firms out of four as efficient, the average DEA score is approximately 82%, which is lower than most of the sub-sectors. This is due to a very low level of efficiency for

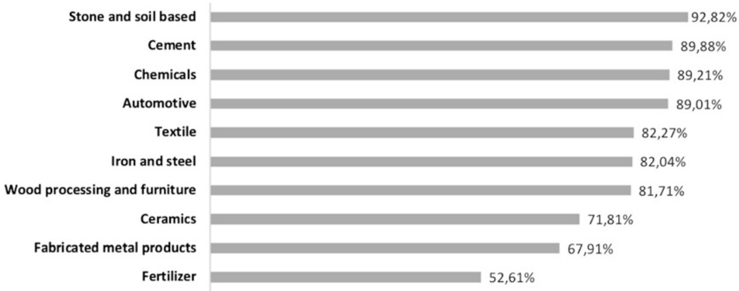

Fig. 2 Average DEA scores with respect to sub-sectors

Table 6 Efficient ISO holders and SMEs

Ratio	% value
Efficient ISO holders/ISO holders	32
Efficient ISO holders/total # of efficient firms	38
Efficient SMEs/total SMEs	50
Efficient SMEs/total # of efficient firms	19

the inefficient firm in this sub-sector. The ceramics, fabricated metal products, and fertilizer sub-sectors are at the bottom of this figure with the lowest average DEA scores. As indicated, no firms in those sectors are found to be efficient. Apparently, the efficiency score levels are also low. It seems the activities in these sub-sectors have not been very efficient compared to other sub-sectors.

Table 6 presents ratios of efficient ISO-certified firms and SMEs. Eight out of 25 ISO-certified firms are found to have a DEA score of 100%. This corresponds to approximately 32% of the ISO holders. The percentage among efficient firms is 38%. The average DEA score of the ISO-certified firms is 79.10%, which is below the average (81.71%). By looking at the ratio of efficient units and the average DEA score, it is not very likely to say that ISO-certified firms are dominating the performance. The half of the SMEs are found to be efficient (four out of eight). The average score for these firms is 85.31%, above average.

4.3 Activity-Based Evaluations

A wide range of energy efficiency activities have been carried out by the firms ranging from minor changes such as changing bulbs to more capital-intensive investments such as large-scale isolations. The original data includes around 200 nonstandardized activities in total. Most activities cover similar tasks but coded differently by the data-providing firms. Our first task is to organize this widespread range of activities into homogeneous groups. With the help of UNIDO experts, the energy efficiency activities carried out are grouped into 16 main projects. Brief descriptions of those projects are given as the following:

Compressed Air Practices: All improvement practices done in compressed air systems are collected under this heading.

Process Investments: Overall improvement activities in production lines and processes.

Periodical Preventive Care: Maintenance of all energy-using equipment in regular intervals.

Isolation: Insulation to prevent heat loss in boilers. (Insulation in furnaces has been undertaken as a separate heading: *Heater Thermal Insulation*.)

Awareness Education: Trainings given to factory employees on energy efficiency. Trainings could be given to the operators of important energy users and/or the entire factory.

Waste-Heat Recovery: Heat recovery in processes that go through heat loss and using this recovery in other processes.

LED Lighting: Replacing bulbs with energy-efficient LED bulbs.

Energy-Efficient Pump Investment: Using energy-efficient pumps.

Improvement of Fan Systems: Adjustments done so that fans can work with optimal efficiency.

Change of Motors: Replacing the engines in the process with energy-efficient engines.

Efficient Boiler and Steam Practices: Boiler rehabilitations, line insulation, steam jacket practices, valve changes, and bluff settings are collected under this heading.

Variable Speed Drive (VSD) Usage: Equipping engines with VSD so that they can work more efficiently with fluctuating load.

Improvement of the Cooling Systems: Improvement work on radiator assemblies, cooling towers, and chillers.

Electrical System, Power Distribution Unit, and Board Investments: All improvements related to the improvement of the factory's electric wiring, control-command settings, and intelligent monitoring systems have been gathered under this heading.

Lighting: All lighting investments except for LED bulb practices have been included under this title (e.g., natural lighting investments).

Heater Thermal Insulation: Heat insulation in furnaces.

The names and the number of implementations in 58 firms are given in Table 7. Note that every firm pursued multiple activities and therefore in total, 299 implementations have been realized within the period of 2015–2017. The most popular project is *compressed air practices* with 40 implementations. It is also one of the most common among ISO-certified firms together with the *process investments*.

In this part of the analysis, we approach to the data set from the activity dimension (the grouped activities are referred to as projects hereafter). We apply DEA to measure the efficiency of the projects listed in Table 7. The input and output factors

Table 7 Implemented energy efficiency projects by the firms

	Project	# of implementations	# of ISO holder implementations	# of SME implementations
1	Compressed air practices	40	13	6
2	Process investments	34	13	6
3	Periodical preventive care	25	10	6
4	Isolation	24	7	6
5	Awareness education	22	9	5
6	Waste-heat recovery	21	10	4
7	LED lighting	19	9	4
8	Energy-efficient pump investment	16	5	2
9	Improvement of fan systems	16	7	2
10	Change of motors	15	8	2
11	Efficient boiler and steam practices	15	6	2
12	Variable speed drive (VSD) usage	13	8	1
13	Improvement of the cooling systems	12	8	1
14	Electrical system, power distribution unit, and board investments	11	8	2
15	Lighting	10	5	3
16	Heater thermal insulation	6	2	0
	Total	299	128	52

Table 8 Input and output factors in evaluating projects

	Factor name	Unit of measurement
Input 1	Total cost	Turkish lira (TL)
Output 1	Total energy saving (yearly)	Tonne of oil equivalent (toe)
Output 2	Total financial saving (yearly)	Turkish lira (TL)
Output 3	Total carbon saving (yearly)	Tonnes

in the analysis are provided in Table 8. Total cost is the input factor, whereas savings are taken as outputs.

Data envelopment analysis scores for projects are provided in Table 9. Four out of 16 projects are found to be efficient. The least efficient projects are found to be *LED lighting* and *periodical preventive care* with low DEA scores. In order to provide insight on what DEA brings to the analysis, Table 8 also includes ranks of projects based on the ratios of each type of saving to the costs. Ranks 1, 2, and 3 correspond to the ranks of projects with respect to total energy saving/total cost, total financial saving/total costs, and total carbon saving/total cost ratios, respectively. The ranks emphasize the multidimensional nature of the analysis. The individual ratios may produce consistent results with DEA such as in *efficient boiler and steam practices*,

Table 9 DEA scores for projects (in comparison with ratios)

Project	DEA score (%)	Rank 1	Rank 2	Rank 3
Efficient boiler and steam practices	100.00	1	1	1
Improvement of fan systems	100.00	2	2	3
Heater thermal insulation	100.00	6	11	9
Electrical system, power distribution unit, and board investments	100.00	15	14	14
Lighting	94.86	12	12	2
Waste-heat recovery	92.27	5	9	5
Process investments	84.47	13	16	12
Awareness education	56.31	3	3	4
Improvement of the cooling systems	34.94	4	5	8
Change of motors	20.51	11	15	13
Compressed air practices	17.13	9	8	10
Isolation	11.61	7	6	6
Energy-efficient pump investment	11.10	16	13	15
Variable speed drive (VSD) usage	9.10	8	4	7
LED lighting	5.77	14	10	16
Periodical preventive care	5.41	10	7	11

which has the ranking as 1 with respect to every ratio. However, in some cases the ratios may be misleading as in *electrical system, power distribution unit*, *and board investments* project. This project seems to be outperformed by many projects regarding the individual rankings; however, it is an efficient project when a multiple factor analysis is performed.

Note that the analysis focuses on a yearly return on investment type of measure since the savings are associated with the first year of the investments. As indicated in Table 1, the effects of the investments are observed over a period depending on the investment cost. Above results provide insight on the **short-term** returns. In order to observe the state of DEA scores regarding the scale of the projects, we provide Table 10. In this table, the projects are ranked with respect to their cost and the DEA scores are also presented. As observed, the efficient projects are distributed among different scales (large-scale, medium-scale, and low-scale). *Electrical system, power distribution unit*, *and board investments* project are the largest-scale projects and one of the efficient ones. On the other hand, two relatively lower-scale projects (*improvement of fan systems* and *heater thermal insulation*) are also obtained as efficient.

Finally, we explore the projects in two subsets of the data set: the efficiency of projects applied by ISO-certified firms and the efficiency of projects applied by SMEs. As indicated before, 128 of 299 implementations have been carried out by the ISO-certified firms, and 52 implementations belong to SMEs. Data envelopment analysis modeling in these two subsets reveals the results presented in Table 11. *Efficient boiler and steam practices* and *electrical system, power distribution unit, and board investments* projects are also efficient for ISO-certified firms. In addition

Table 10 DEA scores for projects ranked by cost

Project	Cost ranking	DEA score (%)
Electrical system, power distribution unit, and board investments	1	100.00
Process investments	2	84.47
Change of motors	3	20.51
Waste-heat recovery	4	92.27
Energy-efficient pump investment	5	11.10
Compressed air practices	6	17.13
LED lighting	7	5.77
Periodical preventive care	8	5.41
Isolation	9	11.61
Efficient boiler and steam practices	10	100.00
Variable speed drive (VSD) usage	11	9.10
Improvement of the cooling systems	12	34.94
Awareness education	13	56.31
Lighting	14	94.86
Improvement of fan systems	15	100.00
Heater thermal insulation	16	100.00

Table 11 DEA scores for projects applied by ISO-certified firms and SMEs

Project	ISO DEA score (%)	SME DEA score (%)
Compressed air practices	7.63	54.66
Process investments	62.12	74.28
Periodical preventive care	3.42	52.13
Isolation	2.45	53.87
Awareness education	18.26	100.00
Waste-heat recovery	79.33	100.00
LED lighting	2.86	14.33
Energy-efficient pump investment	10.50	9.18
Improvement of fan systems	36.44	37.36
Change of motors	2.85	14.59
Efficient boiler and steam practices	100.00	49.03
Variable speed drive (VSD) usage	2.93	87.33
Improvement of the cooling systems	2.30	100.00
Electrical system, power distribution unit, and board investments	100.00	76.50
Lighting	100.00	100.00
Heater thermal insulation	1.52	–

to those, *lighting* project that involves improvements in electric lighting equipment is also obtained as efficient among ISO holders. In small- and medium-sized enterprises, efficient projects are completely different from the previous. (Note that no SME has applied *heater thermal insulation*; therefore there is no score for this project in the related column.) *Awareness education*, *waste-heat recovery, improvement of cooling systems*, and *lighting* projects are the efficient projects for SMEs.

4.4 Robustness of Activity-Based Evaluations

The effects of the investments are observed over a period depending on the investment cost and the sustainability of the changes. In our analysis, we evaluate the short-term results with respect to savings to investment cost. In this part, we aim to analyze potential future performance of 16 projects undertaken in order to observe whether any of projects have potential to change its status to efficient and vice versa. For this purpose, we design a 1000-run simulation model, where in each instance, a 16×3 random increase matrix is generated (the random values are in a range between 0% and 50%) and the energy, financial, and carbon savings for the projects are increased by these random rates. Data envelopment analysis models are solved in each run, and as a result, 1000 efficiency scores are obtained for each project assuming that the savings will increase by some random amount in the following years. The analysis enables us to interpret the sensitivity of the results with respect to future potential increases in the savings (energy, financial, and carbon). The average efficiency scores and min-max efficiency scores obtained through simulation are presented in Table 12 together with the original scores (as given in Table 9).

According to simulation results, *efficient boiler and steam practices*, *improvement of fan systems*, and *heater thermal insulation* project protect their status as being efficient (in all 1000 runs). The efficiency of *electrical system, power distribution unit, and board investments* project is still very close to being efficient (ranging from 95.53% to 100% efficiency). Some projects reveal a potential to be in the efficient set relying on their max values such as *process investments*, *waste-heat recovery*, and *lighting*. These projects can also be accounted for potentially effective in the long run. Nevertheless, the simulation results generally point out the robustness of the preliminary efficiency scores with close average scores and a predominantly low level of deviation. The projects with low efficiency levels such as *periodical preventive care* and *LED lighting* keep exhibiting low levels of efficiency throughout the simulation.

Table 12 Simulation results

Project	Original score (%)	Average efficiency (1000 runs) (%)	Min (%)	Max (%)	St. Dev (%)
Compressed air practices	17.13	17.15	11.80	24.74	2.59
Process investments	84.47	83.50	62.38	100.00	8.74
Periodical preventive care	5.41	5.56	3.66	7.95	0.85
Isolation	11.61	11.75	7.80	17.11	1.95
Awareness education	56.31	57.23	39.77	83.51	8.05
Waste-heat recovery	92.27	87.29	60.25	100.00	10.71
LED lighting	5.77	5.86	3.86	8.65	1.02
Energy-efficient pump investment	11.10	11.29	7.64	16.53	1.87
Improvement of fan systems	100.00	100.00	100.00	100.00	0.00
Change of motors	20.51	20.23	13.85	29.52	3.01
Efficient boiler and steam practices	100.00	100.00	100.00	100.00	0.00
Variable speed drive (VSD) usage	9.10	9.22	6.23	13.11	1.46
Improvement of the cooling systems	34.94	35.09	23.57	49.03	5.66
Electrical system, power distribution unit, and board investments	100.00	99.98	95.53	100.00	0.22
Lighting	94.86	91.11	64.25	100.00	9.45
Heater thermal insulation	100.00	100.00	100.00	100.00	0.00

5 Conclusions

With rising global awareness and binding energy prices, industrial enterprises are under environmental, social, and financial pressure to attain higher levels of efficiency in their energy use. Within the scope of energy efficiency, a contemporary approach is the energy management system (EnMS) that represents continuous and systematic efforts for improvement in efficient use of energy by the enterprises. In this research, we conduct an empirical analysis to measure relative performance in Turkish manufacturing firms that apply EnMS principles and carried out energy efficiency increasing activities between 2015 and 2017. Data envelopment analysis (DEA) is employed in two dimensions. Evaluations are presented at two levels: firm level and activity level. A simulation model is also employed to test the robustness of the DEA results in the longer term.

In adapting energy efficiency improvement activities, firm-based evaluations reveal that:

- Out of 58 firms, 21 firms (almost 36%) are relatively efficient. Eight out of 21 efficient firms are from chemicals sub-sector.
- There are some sub-sectors with no efficient firms such as ceramics, fabricated metal products, and fertilizer. These sub-sectors also attain the lowest average efficiency scores.

- Stone and soil-based manufacturing sub-sector has the highest level of average efficiency followed by cement and chemicals sub-sectors.
- Wood processing and furniture sub-sector seems to be a successful sector having three firms out of four in this sector obtained as efficient. However, the average DEA score is approximately 82%, which is lower than most of the sub-sectors. This is due to low efficiency scores for some of the inefficient firms in this sub-sector.
- Thirty eight percent of the efficient firms are ISO certified. The average DEA score of the ISO-certified firms is 79.10%, which is below the average.
- The half of the SMEs are found to be efficient (four out of eight). The average score for these firms is 85.31%, which is above average.

In evaluating 16 projects applied by the firms in the sample, the activity-based evaluations reveal that:

- There are 299 implementations of 16 projects in the manufacturing industry. 128 implementations have been carried out by ISO-certified firms and 52 by SMEs. The mostly implemented project is compressed air practices with 40 implementations.
- Four out of 16 projects are found to be efficient. These are *efficient boiler and steam practices*; *electrical system, power distribution unit, and board investments*; *improvement of fan systems*; and *heater thermal insulation. Electrical system, power distribution unit, and board investments* are the project that the most money have been spent on among 16 projects. I*mprovement of fan systems* and *heater thermal insulation* projects has the least amount of investment, yet efficient.
- *Efficient boiler and steam practices* and *electrical system, power distribution unit, and board investments* projects are also efficient for ISO-certified firms. In addition, *lighting* project that involves improvements in electric lighting equipment is also efficient among ISO holders.
- *Awareness education*, *waste-heat recovery*, *improvement of cooling systems*, and *lighting* projects are the efficient projects for SMEs.
- A 1000-run simulation model verifies the efficient projects and projects with very low levels of efficiency as well as identifies *waste-heat recovery* and *lighting* projects to have a potential to be effective in the long run.

To sum up, energy management has become increasingly crucial for the survival of enterprises in the short term and for their success in the long term. More and more industrial enterprises are taking action to adapt new strategies and apply several changes to increase their energy efficiency levels continuously. Even small changes at microlevel have a potential to create greater impact globally. The rising awareness is expected to force the industry to act in the long term. We believe that such research as presented in this chapter contributes to strategic decisions in applying the energy efficiency improvement activities. It is possible to list several policy implications for different stakeholders. Government bodies, industry chambers, and companies can be counted among these stakeholders. Some policy implications can be listed as shown below:

- The results can guide the determination of industry, company, and project-based energy efficiency incentives.
- The results can guide companies in determining the projects they will implement in energy efficiency.
- The results can be used to strengthen and restructure the legal and institutional frameworks.
- Periodical evaluation of energy efficiency savings will also support sustainability by providing data to education and capacity building.

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