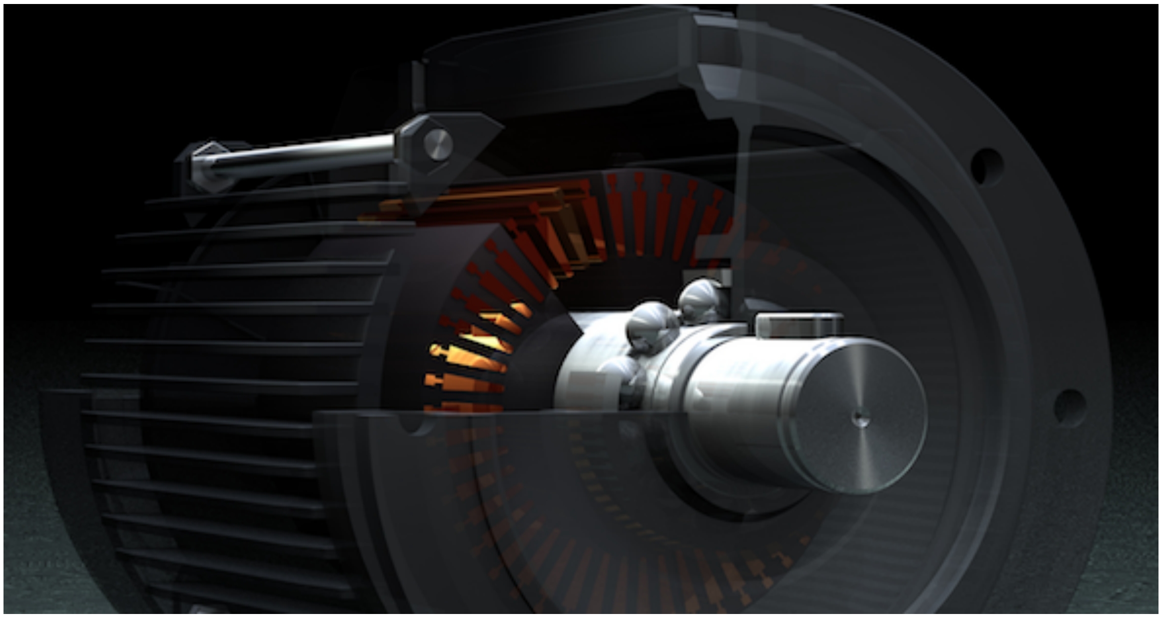
# Energy Efficiency and $CO_2$ Emissions Reduction Potential in Industrial Motor Systems in Egypt



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## Disclaimer

## Acknowledgements

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# Executive Summary

According to the International Energy Agency (IEA), electric motor systems consume more than half of global electricity. Industrial electric motor systems account for approximately 70 percent of total global industrial electricity usage. Electric motors operate fans; pumps; and materials-handling, compressed-air, and processing equipment.

One major barrier to effective policy making and global action to improve the energy efficiency of industrial motor systems is lack of information on the magnitude and cost-effectiveness of the potential savings from energy-efficiency practices. This lack of information is part of the reason that there is no comprehensive energy-efficiency strategy or roadmap for industrial motors systems. It is much easier to quantify the incremental energy savings from substituting an energy-efficient motor for a standard motor than it is to quantify the energy savings from applying energy-efficiency practices to an existing motor system.

To address the lack of data on potential savings from industrial motor systems energy efficiency, Global Efficiency Intelligence, LLC. with support from UNIDO conducted this study for industrial motor systems in Egypt.

This report focuses on analyzing energy use and the potential for energy efficiency and carbon dioxide ($CO_2$) emissions reduction in three major industrial motor systems, i.e. pump systems, fan systems and compressed air systems in Egypt.

In this report, we analyze various energy-efficiency technologies and measures each industrial motor systems type. Using the bottom-up energy-efficiency cost curve model, we estimated *cost-effective* electricity-savings potentials for each industrial motor systems type in Egypt, separately. We also estimated total *technical* electricity-savings potentials (what is technologically possible), assuming 100% adoption of series of efficiency measures. Table 1 summarizes the energy-savings results.

Table 1. Industrial motor systems electricity-savings potential in Egypt in 2015

| | Cost-effective Energy Saving Potential (GWh/yr) | Technical Energy Saving Potential (GWh/yr) |
|---|---|---|
| **Pump systems** | 1,813 | 2,068 |
| **Fan systems** | 1,008 | 1,212 |
| **Compressed air systems** | 952 | 1,269 |

In Egypt, the share of total technical electricity-savings potential for industrial pump systems compared to total manufacturing pump systems energy use is 49%. The share of total technical electricity-savings potential for industrial fan systems compared to total manufacturing fan systems energy use in Egypt is 38%. The share of total technical electricity-savings potential for industrial compressor systems compared to total manufacturing compressor systems energy use is 39%.

Using the average $CO_2$ emissions factor of the electricity grid in Egypt, we also calculated the $CO_2$ emissions reduction associated with the electricity-savings potential. The $CO_2$ emissions reduction will help the country to meet its greenhouse gas emissions reduction targets. In addition, the reduction in demand for electricity generation will help to reduce other air pollutants emissions and improve local and regional air quality in cities and provinces.

The pump systems energy-efficiency cost curves show that two measures – “isolating flow paths to non-essential or non-operating equipment”, “Trim or change impeller to match output to requirements”, and “installing variable speed drives” – account for more than 65% of the energy-savings potential in industrial pump systems, and all are cost-effective.

The fan systems energy-efficiency cost curves show that two measures – “isolating flow paths to non-essential or non-operating equipment” and “installing variable speed drives” – account for about than half of the energy-savings potential in industrial fan systems, and both are cost-effective.

The compressed air systems energy-efficiency cost curves show that three measures – “Fix Leaks, adjust compressor controls, establish ongoing plan”, “Install sequencer”, and “Initiate predictive maintenance program” – account for more than half of the energy-savings potential in industrial compressed air systems, and all are cost-effective.

Among the key policy implications of our study is that the cost savings from cost-effective efficiency measures can bring down the cost of conserved energy (CCE) of many non-cost-effective measures to just below the unit price of electricity in Egypt. This indicates that effective, cost-efficient fiscal incentive programs for motor systems should bundle efficiency measures, which will maximize savings and allow the savings to pay for non-cost-effective measures whenever possible.

Energy efficiency in industrial motor systems stimulates economic growth and creates jobs in a variety of ways (direct, indirect, and induced jobs creation). Investment in energy efficiency creates more jobs per dollar invested than traditional energy supply investments. Energy efficiency also creates more jobs in the local economy, whereas energy supply jobs and investment dollars often flow outside the country.

Our approach can be considered a screening method for determining the energy-savings potential of efficiency measures that can assist national and local governments, policy makers, and utilities in understanding the potentials and cost of energy efficiency measures, as a basis for designing effective policies. Actual energy-savings potentials and costs of energy-efficiency measures and technologies will vary with plant-specific conditions.

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# 1. Introduction

Electric motors are used in the agricultural, commercial, industrial, residential, and transportation sectors, among others. Motor applications in each sector include (IEA, 2011a):

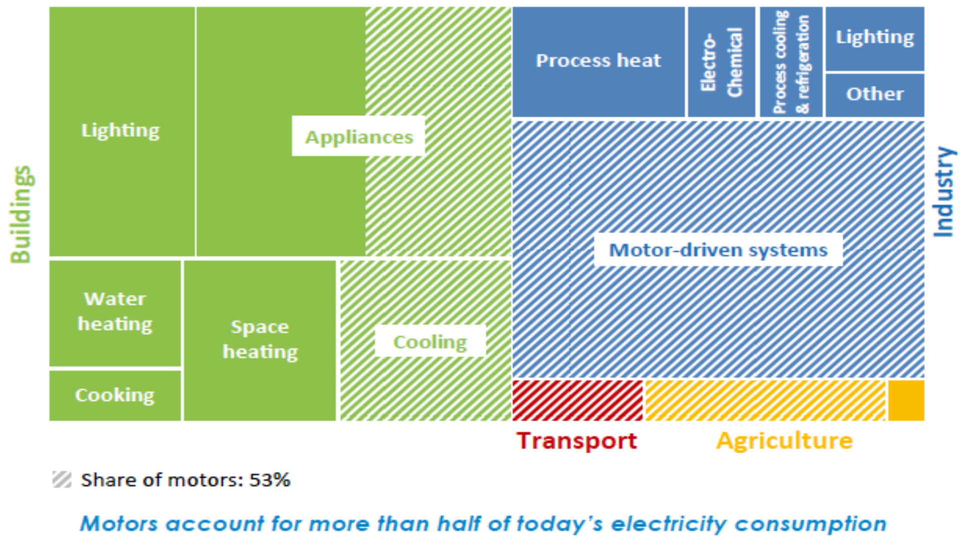
- Industrial applications: motors operate pumps, fans, and conveyors; delivering compressed air; providing motive power for other machinery
- Building applications: motors operate pumps; fans; conveyors; elevators; and compressors in heating, ventilation, and air-conditioning (HVAC) systems
- Appliance applications: motors operate refrigerators, air conditioners, personal computer and laptop fans, hard drives, cooking appliances, oven fans, extractor fans, garden appliances, and pool pumps
- Agricultural applications: motors operate pumps and various forms of conveyance
- Transportation applications: motors operate electric trains, trucks, cars, and motorbikes

In all applications listed above, the electric motor is one part of the electromechanical system – the only part that, along with its controller, uses electricity. The amount of electricity needed for the motor to function depends on the magnitude of mechanical power needed as well as the extent of losses during power delivery. Although there are losses within the motor, the losses are greater within the mechanical system that distributes power from the motor to the final application (IEA 2011a).

There is wide range of electric motor sizes, from very small (less than 0.1 kilowatt [kW]) to extremely large (greater than 1,000 kW) (IEA, 2016). Mid-sized electric motors that have an average power output of 0.75 to 375 kW account for the largest percentage of motor electricity consumption. Although varying motor designs and technologies exist, energy-intensive asynchronous alternating-current (AC) induction motors are widely used and consume the most energy. Small electric motors are less efficient than larger, power-intensive motors (IEA 2011a).

According to the International Energy Agency (IEA), around half of global electricity consumption is attributable to electric motor systems (Figure 1). Industrial electric motor systems account for about 70% of total global industrial electricity usage.

Industrial motors are normally part of larger systems, and a key way to reduce motors' electricity consumption is to optimize other parts of the system in addition to the motor. Losses within electric motors are only a small share of the total losses experienced in the entire system of which the motor is a part. Figure 2 illustrates a typical industrial motor system made up of connected components. The efficiency of each component is important to the efficiency of the entire system.



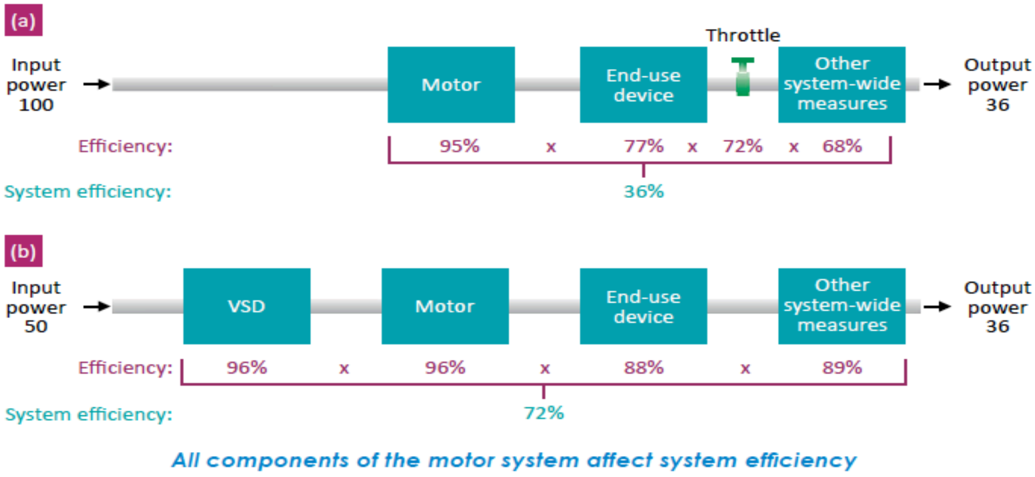
Source: IEA, 2016

Figure 1. Global total final electricity use by end use in 2014

In general, motors are usually fairly efficient, especially in developed and developing countries that have robust minimum energy performance standards (MEPS). MEPS are being adopted in more and more countries as well as becoming more stringent in countries where they have been established for a period of time. IEA predicts that, by 2040, premium efficiency standard (IE3) motors or better will account for approximately 60% of the electricity used by motor systems. Because motor efficiency improvements will only marginally increase the motor system's efficiency, we must look to improve the efficiency of the equipment being driven by the motor. Optimization measures such as predictive maintenance, avoiding oversized motors, and matching motor systems to specific needs could improve the energy efficiency of motor-driven systems significantly (IEA, 2016). Even more savings can be achieved by looking not only beyond the motor to the whole motor system but beyond the system to the end-use device, as shown in Figure 2.

In this report, we focus on pump systems, fan systems and compressed air systems which represent three main types of motor systems that together account for around 60% of electricity use in industrial motor systems.

The share of electricity used by pump, fan, and compressed air systems varies among manufacturing subsectors. Table 2 shows the share of total motor systems electricity use in each U.S. manufacturing subsector. It also shows the share of pump, fan, and compressor systems from total motor systems electricity use.



Note: VSD = variable speed drive.

Source: IEA, 2016

**Figure 2. Illustration of two industrial electric motor-driven systems: (a) normal and (b) efficient**

**Table 2. Share of motor systems electricity use in each manufacturing subsector**

| Industrial Sub-sector | Motor Systems Electricity Use as % of Total Electricity Use in each Industrial Subsector * | Pump Systems Electricity Use as % of Motor System Electricity Use in the Subsector ** | Fan Systems Electricity Use as % of Motor System Electricity Use in the Subsector ** | Compressed Air Systems Electricity Use as % of Motor System Electricity Use in the Subsector ** |
|---|---|---|---|---|
| Food, beverage, and tobacco products | 83% | 15% | 7% | 7% |
| Textile, apparel, and leather products | 75% | 16% | 12% | 12% |
| Pulp and paper and wood products | 88% | 43% | 27% | 6% |
| Petroleum and coal products | 91% | 47% | 16% | 25% |
| Chemicals | 69% | 35% | 16% | 37% |
| Plastics and rubber products | 66% | 14% | 10% | 11% |
| Non-metallic minerals | 64% | 13% | 13% | 11% |
| Primary metals | 36% | 8% | 16% | 14% |
| Fabricated metal products | 57% | 16% | 11% | 12% |
| Machinery | 64% | 16% | 11% | 11% |
| Electronic products and electrical equipment | 63% | 9% | 7% | 7% |
| Transport equipment | 62% | 13% | 10% | 11% |
| Other manufacturing industries | 68% | 32% | 15% | 17% |

* These shares include process cooling and refrigeration and non-process-facility HVAC.

** These shares exclude systems that are in process cooling and refrigeration and non-process-facility HVAC.

Source: U.S. DOE, 2015

One of the major barriers to effective policy making and increased global action to improve energy efficiency in industrial motor systems is lack of information and data on the magnitude and cost-effectiveness of the energy-savings potential in industrial motor systems in individual countries. This lack of information creates an obstacle to developing a comprehensive strategy and roadmap for improving motor systems efficiency. It is far easier to quantify the incremental energy savings of substituting an energy-efficient motor for a standard motor in a motor system than it is to quantify the energy savings of applying other energy-efficiency practices to an existing motor system.

To address these barriers, Global Efficiency Intelligence, LLC. with the support from UNIDO conducted this study for industrial motor systems in Egypt. This report focuses on analyzing energy use, energy efficiency, and $CO_2$ emissions-reduction potential in industrial motor systems in Egypt.

# 2. Methodology

## 2.1. Scope of the study

We analyze the industrial motor systems energy-efficiency potential in Egypt.
The industrial sector in this report covers manufacturing subsectors. The base year for our analysis is 2015, the latest year for which energy-use data were available at the time of the study.

Country-specific data were collected from various sources. Electricity use for industrial subsectors in Egypt was calculated based on information from several sources as explained in the next subsection. Also collected were the average unit price of electricity for industrial users in Egypt in 2015 and the emissions factor for grid electricity in Egypt in 2015.

For this study, we built on the information collected and the method developed during our study for the United Nations Industrial Development Organization (UNIDO 2010). We refined the methodology from that study and used more recent data, applying it to Egypt.

To conduct these studies, we also developed a framework to obtain expert input to supplement existing data. We consulted 13 motor system experts on the percentage of system energy use by industrial sector, energy efficiency of systems in a market with a defined set of characteristics, creation of a list of common energy-efficiency measures, and the energy savings and implementation costs associated with these measures. A Delphi-type approach was taken in which several cycles of input, analysis, and review were performed to refine the expert input.

## 2.2. Estimation of Electricity Use by Industrial Motor Systems in Egypt, by Manufacturing Subsector

Because no database reports manufacturing subsector electricity use in Egypt, we estimated these values. The international energy agency (IEA) publishes national data on energy consumption for different countries including Egypt. In these data set, they report electricity use by different economy subsector (residential, commercial, industrial, and transport) and fuel (IEA 2017). This source does not report electricity use by manufacturing subsector for Egypt. For subsector level data, we used PWC (2015) report in which they had reported the share of electricity use in each industrial subsector in Egypt. We applied those shares to total electricity use by industry reported in IEA (2017) in order to estimate the manufacturing subsectors electricity use in Egypt in 2015.

Once we estimated the electricity use for each manufacturing subsector in Egypt, we used the ratios given for motor systems electricity use in U.S. DOE (2015) to estimate the energy use of these systems in the manufacturing subsector for Egypt. Table 2 in the Introduction section of this report shows the ratios used for this analysis.

## 2.3. Base-Case System Efficiency Scenario Definition

We established three base-case efficiency scenarios (LOW-MEDIUM-HIGH) for industrial motor systems based on previous research and expert input. There was a remarkable degree of agreement among the experts concerning the range of efficiency for each system type that could be expected in these base-case scenarios. After defining the base cases, we assigned base case values to Egypt studied, to establish a reference point for current motor system performance in the country. The base-case values were based on the information available for Egypt as well as on experts input.

The first step in establishing a base case was to create a unique list of system energy-efficiency practices representative of each of the three efficiency scenarios for motor systems. Tables A.1-A.3 in Appendix lists the practices assigned to each base-case efficiency level for industrial pump systems, fan systems, and compressed air systems, respectively.

We asked motor systems experts to estimate the range of system energy efficiency they would expect to see when auditing a system in an industrial facility with the characteristics given for each efficiency base-case scenario (LOW-MEDIUM-HIGH).

Table A.4-A.6 in Appendix shows the consolidated results, including the base-case values used in calculating the efficiency cost curves. There was a high degree of agreement among experts regarding the range of system energy efficiency that would be expected based on the list of characteristics assigned to the base cases. We used the average of low and high values for the LOW-MED-HIGH efficiency base cases in our analysis.

After defining the base-case efficiencies for each motor system, we assigned a base case to Egypt as a reference point for current industrial motor system performance in Egypt based on available information.

Table 3. shows the base-case efficiencies assigned for each industrial motor systems in Egypt

**Table 3. Base-case motor systems efficiencies assigned to Egypt**

| Motor System | Base Case Efficiency Level |
|---|---|
| Pump systems | LOW |
| Fan systems | LOW |
| Compressed air systems | LOW |

### 2.4. Energy-Efficiency Measures and Their Savings and Costs

We developed a list of motor system energy-efficiency measures and asked motor system experts their opinion on energy savings likely to result from each measure implemented independent of the others, expressed as a percentage improvement over each of our base cases (LOW-MED-HIGH).

The experts were also asked to provide cost information for each measure, disaggregated by motor size range. The size ranges were selected based on categories developed for the most detailed motor system study available (U.S. DOE, 2002). In this study, “motor system size” refers to a motor system’s aggregate hp or kW. The costs provided are for when efficiency measures are implemented in systems with LOW base case efficiency level. However, for systems that have Medium or High efficiency base case, the cost of efficiency measures where reduced using an adjustment factor.

In addition to the energy-efficiency improvement cost, we asked experts to provide the useful lifetime of the measures, disaggregated into two categories of operating hours (1,000 - 4,500 hours per year and more than 4,500 hours per year). In some instances, the initial list of measures included several measures that would be unlikely to be implemented together (i.e., it is more likely that one would be selected). In those cases, we chose the most common measure based on experts’ judgment.

Tables 4-5 show example of typical percentage improvements in efficiency over each base case as well as an estimated typical capital cost of one motor system energy-efficiency measure, differentiated by system size. The actual installed cost of some system measures can be highly variable and dependent on-site conditions, including the number and types of end uses. The need to add or modify physical space to accommodate new equipment can also be a factor in installed cost.

**Table 4. Example energy-efficiency measure and typical % efficiency improvement impact on pump systems in Egypt**

| **Energy-Efficiency Measure** | **Typical % improvement in energy efficiency practice** | | |
|---|---|---|---|
| | % Improvement over LOW eff. base case | % Improvement over MED eff. base case | % Improvement over HIGH eff. base case |
| Replace pump with more energy efficient type | 20% | 15% | 5% |

**Table 5. Example of capital cost of a typical pump system energy-efficiency measure in Egypt**

| **Energy-Efficiency Measure** | **Typical Capital Cost (*US$*)** | | | | |
|---|---|---|---|---|---|
| | ≤50 hp | >50 hp ≤100 hp | >100 hp ≤200 hp | >200 hp ≤500 hp | >500 hp≤1000 hp |
| | ≤37 kW | >37kW ≤75kW | >75kW ≤150kW | >150kW ≤375kW | >375kW ≤745kW |
| Replace pump with more energy efficient type | $7,200 | $14,400 | $18,000 | $21,600 | $50,400 |

Systems larger than 1,000 hp (745kW) are usually custom designed, and their cost is highly variable. The cost data from experts for this size system varied so much that it injected significant uncertainty into the final results, so we excluded systems larger than 1,000 hp (745kW) from the final analysis. Because systems larger than 1,000 hp account for about 4%, 17%, and 32% of total industrial pump, fan, and compressor systems electricity use in Egypt, respectively, excluding these systems from the analysis resulted in a proportional decrease in total system energy use and a corresponding decrease in the energy savings resulting from the energy-efficiency measures analyzed. This limitation should be considered when reviewing the results presented in this report.

This report uses the estimated full cost of the energy-efficiency measures analyzed rather than the incremental cost. This choice was based on the goal of our analysis, which was to assess the total potential for energy efficiency in industrial motor systems in the base year (2015) assuming a 100% adoption rate. Therefore, we assumed that all the measures are installed in the base year, so the full cost of the measures should be used because the existing systems are not all at the end of their lifetimes.

## 2.5. Development of Energy-Efficiency Cost Curves

The energy-efficiency cost curve (also known as the energy conservation supply curve) is an analytical tool that captures both the engineering and economic perspectives of energy efficiency. The curve shows energy-efficiency potential as a function of the marginal cost of conserved energy (CCE). CCE can be calculated from Equation A.1.

$$\textbf{Cost of Conserved Energy (CCE)} = \frac{\textbf{(Annualized capital cost + Annual change in O\&M costs)}}{\textbf{Annual energy savings}} \qquad \textbf{(Eq. A.1)}$$

The annualized capital cost can be calculated from Equation A.2.

$$\textbf{Annualized capital cost} = \textbf{Capital Cost}*(d/\ (1-(1+d)^{-n}) \qquad \textbf{(Eq. A.2)}$$

d: discount rate, n: lifetime of the energy efficiency measure

In this study, because only one type of cost (capital cost) was available for each measure, the capital cost was used to calculate the CCE without regard for any change in operations and maintenance cost (given in Eq. A.1). Some of the measures themselves are improvements in maintenance practices.

After calculating the CCE for all energy-efficiency measures, the measures are ranked in ascending order of CCE. Also, on an efficiency cost curve, an energy price line is determined. All measures that fall below the energy price line are identified as “cost-effective.” That is, saving a unit of energy by means of the cost-effective measures is cheaper than buying a unit of energy. On the curves, the width of each measure (plotted on the x-axis) represents the annual energy saved by that measure. The height (plotted on the y-axis) shows the measure’s CCE. Figure 3 shows an illustrative example of an energy-efficiency cost curve for measures A and B.

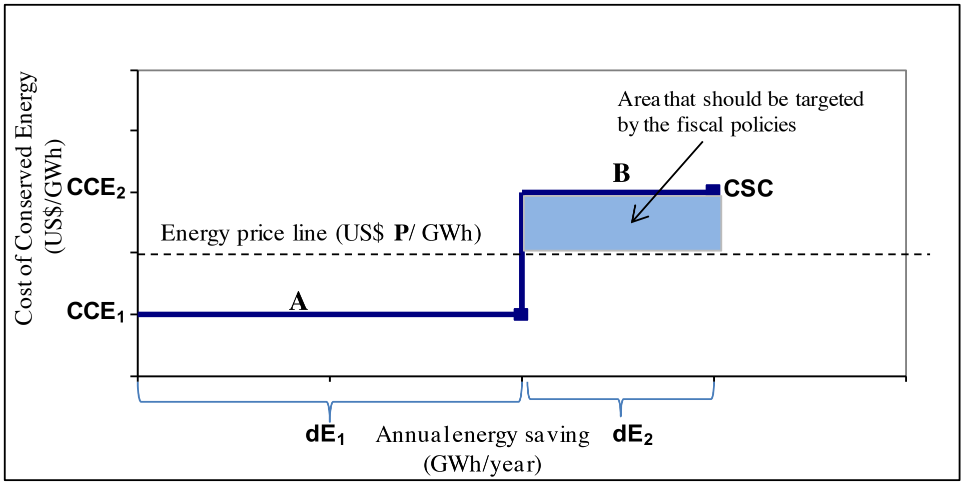


**Figure 3. Illustrative example of an energy-efficiency cost curve**

In our analysis, a real discount rate of 15% was assumed. This choice seems to be reasonable since the commercial banks interest rates in Egypt are quite high and it was over 18% in 2017. The choice of the discount rate also depends on the purpose of the analyses and the approach (prescriptive versus descriptive) used. A prescriptive approach (also called social perspective) uses lower discount rates (4% to 10%), especially for long-term issues like climate change or public-sector projects (Worrell et al. 2004). Low discount rates have the advantage of treating future generations equal to our own, but they also may cause relatively certain, near-term effects to be ignored in favor of more uncertain, long-term effects.

Figure 4 is a schematic of the process of calculating motor system energy-efficiency cost curves. The details of each step are explained in the following sections.

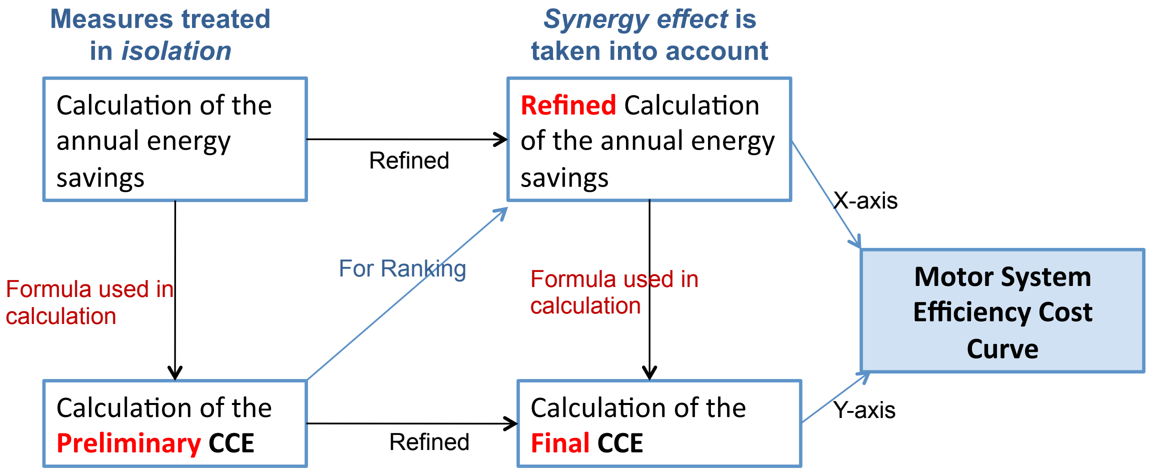


**Figure 4. Calculation process for constructing motor system energy-efficiency cost curves**

For calculating energy savings from each motor system efficiency measure, the following inputs were available:

- The efficiency base-case scenarios for motor systems (low, medium, high), developed as described above. As explained earlier, Egypt was assigned a base-case motor system efficiency.
- For each motor system efficiency measure, experts provided a typical percentage improvement in energy efficiency over each base-case efficiency.
- Electricity use in the manufacturing subsectors for Egypt.
- From the above information, the annual electricity savings can be calculated for each individual industrial motor system efficiency measure when measures are treated individually and can be implemented regardless of the implementation of other measures.

However, implementation of one measure can influence the efficiency gain from the next efficiency measure implemented. When the first measure is implemented, the base-case efficiency is improved. Therefore, the efficiency improvement of the second measure will be less than if the second measure was implemented first or considered alone. Because of this, in our analysis, the measures were treated in relation to each other (as a group). In other words, the efficiency improvement from implementation of one measure depends on the efficiency improvement achieved by the previous measures implemented. We call this the *synergy effect*.

In this method, the *cumulative* electricity savings are calculated by taking into account the synergy effect of the measures rather than by treating the measures in isolation from one another. For instance, the cumulative annual electricity savings from measure #3 include the efficiency gains from the previous measures implemented (measures #1 and #2).

Calculation of the cumulative savings rather than individual savings is also desirable because the cumulative electricity savings will be used to construct the motor system efficiency supply curves. At the same time, the ranking of the measures significantly influences the energy savings attributed to each measure. That is, given a fixed percentage improvement of efficiency from each individual measure, the higher the rank of the measure, the larger the contribution of that measure to the cumulative savings. To define the ranking of the efficiency measures before calculating the cumulative energy savings using the method described above, we calculated a preliminary CCE for each measure, treating each in isolation from the others, i.e., without taking any synergy effect into account. The measures were ranked based on their preliminary CCEs, and this ranking was used to calculate the final cumulative annual energy savings as well as the final CCE (Figure 4). Table 6 shows some of the assumptions used in the analyses.

**Table 6. Average unit price of electricity for industry and emissions factor for grid electricity in Egypt in 2015**

| | **Egypt** |
|---|---|
| Average unit price of electricity for industry in 2015 (US$/kWh) | 0.06 |
| Emission factor for grid electricity in 2015 (kgCO$_2$/MWh) | 583 |

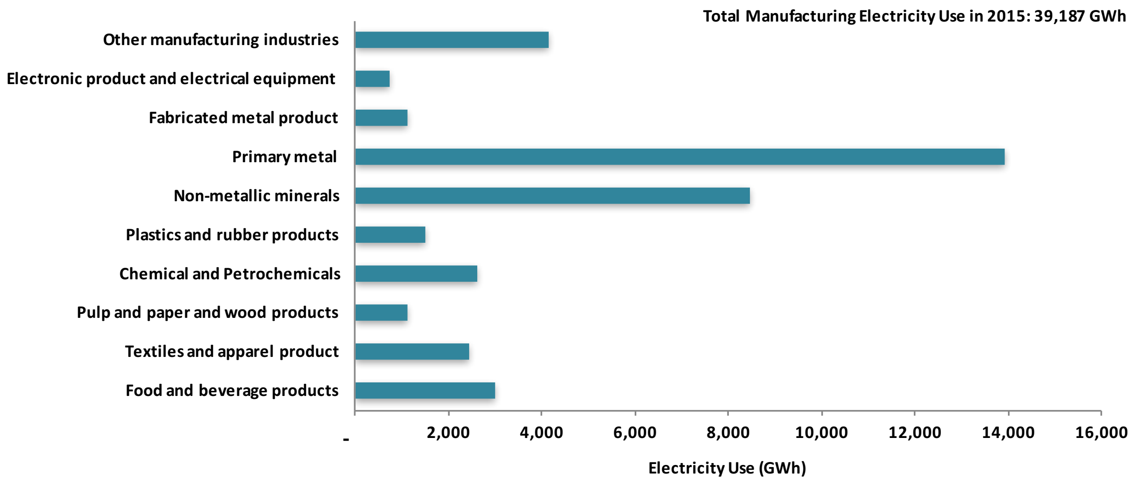
Sources: MERE 2017; IGES 2016

It should also be noted that the purpose of our analysis is to determine the cost-effectiveness of efficiency measures and estimate the total electricity savings potential for industrial motor systems. This study does not analyze scenarios based on the assumption of different penetration rates of the measures in the future; instead, we aimed to identify the magnitude of the total savings potential in 2015 and associated costs.

# 3. Energy Use in Manufacturing and Industrial Motor Systems in Egypt

## 3.1. Industrial Electricity Use in Egypt by Manufacturing Subsector

Using the methodology explained in Section 2, we estimated industrial electricity use in 2015, by manufacturing subsector, for Egypt (Figure 5). In Egypt, the primary metal industry had the highest electricity consumption in 2015 followed by the non-metallic minerals industry (dominated by the cement industry).



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Figure 5. Industrial electricity use by manufacturing subsector in Egypt in 2015

## 3.2. Industrial Motor Systems Electricity Use in Egypt by Manufacturing Subsectors

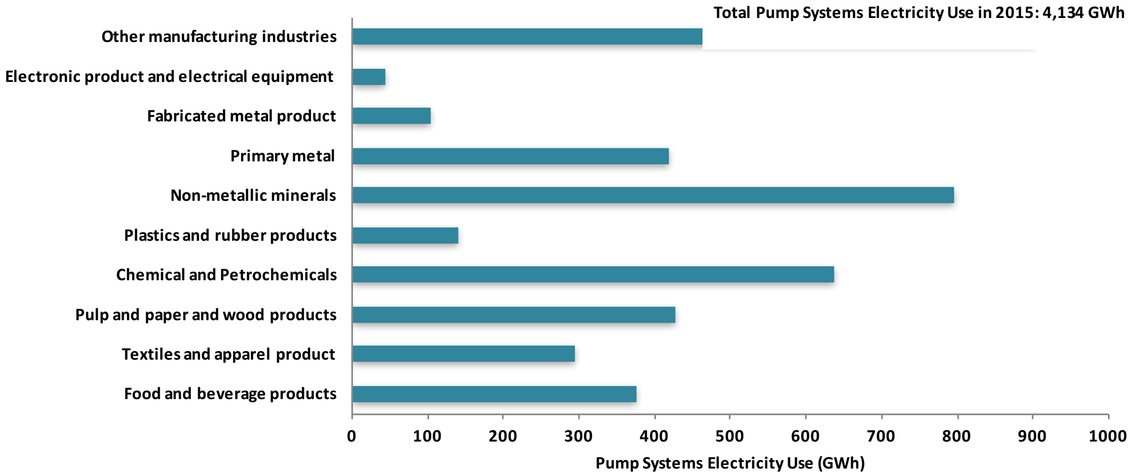
Table 7 shows the estimated industrial motor systems electricity use by manufacturing subsectors for Egypt studied in 2015. We estimated these values for Egypt using the share of motor systems electricity use from total electricity use in each manufacturing subsector given in U.S. DOE (2015).

Table 7. Industrial motor systems electricity use by manufacturing subsectors for Egypt in 2015

| Manufacturing subsectors | Industrial motor systems electricity use (GWh) |
|---|---|
| Food, beverage and tobacco product | 2,502 |
| Textiles, apparel and leather product | 1,837 |
| Pulp and paper and wood products | 995 |
| Chemical | 1,820 |
| Plastics and rubber products | 995 |
| Non-metallic minerals | 6,358 |
| Primary metal | 5,019 |
| Fabricated metal product | 644 |
| Electronic product and electrical equipment | 475 |
| Other manufacturing industries | 2,818 |
| **Total** | **23,463** |

Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

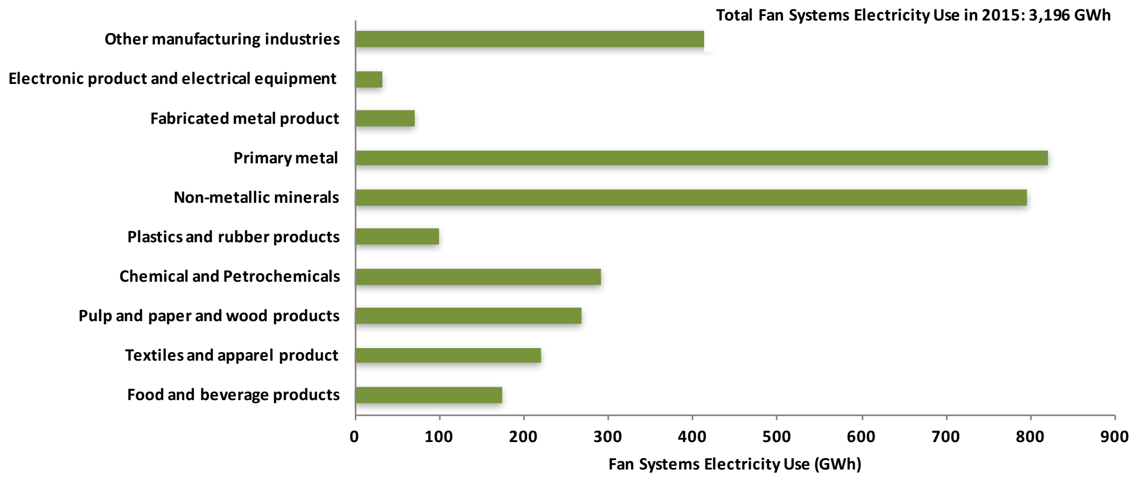
Figure 6 shows that in Egypt, the non-metallic minerals industry had the highest pump systems electricity use in 2015 followed by pump systems in the chemical and petrochemical industry.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Figure 6. Estimated industrial pump systems electricity use by manufacturing subsectors in Egypt in 2015

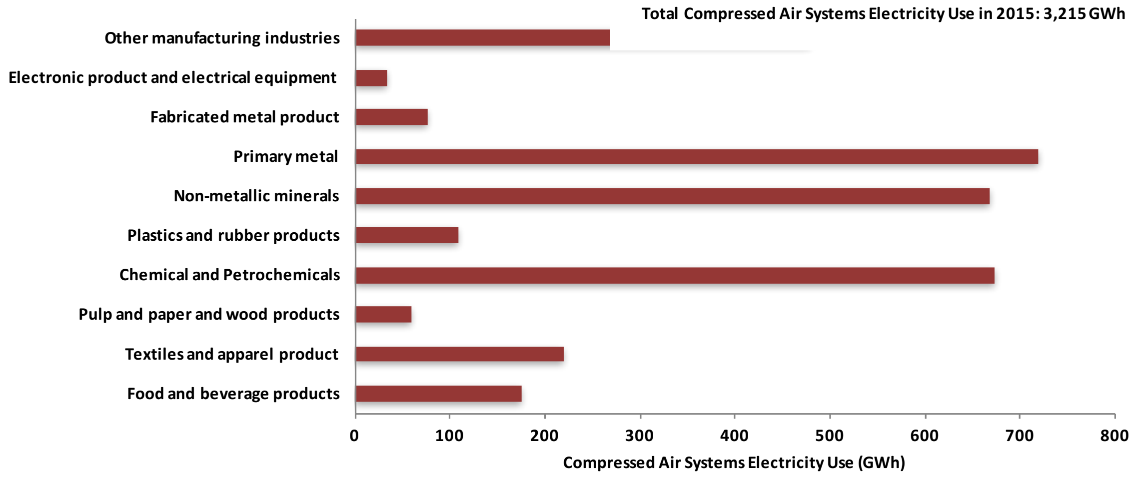
Figure 7 shows that in Egypt, the primary metal industry had the highest fan systems electricity use in 2015 followed by fan systems in the non-metallic minerals industry.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Figure 7. Estimated industrial fan systems electricity use by manufacturing subsectors in Egypt in 2015

Figure 8 shows that in Egypt, the primary industry had the highest compressed air systems electricity use in 2015 followed by compressed air systems in the chemical and petrochemical industry and non-metallic minerals sector.

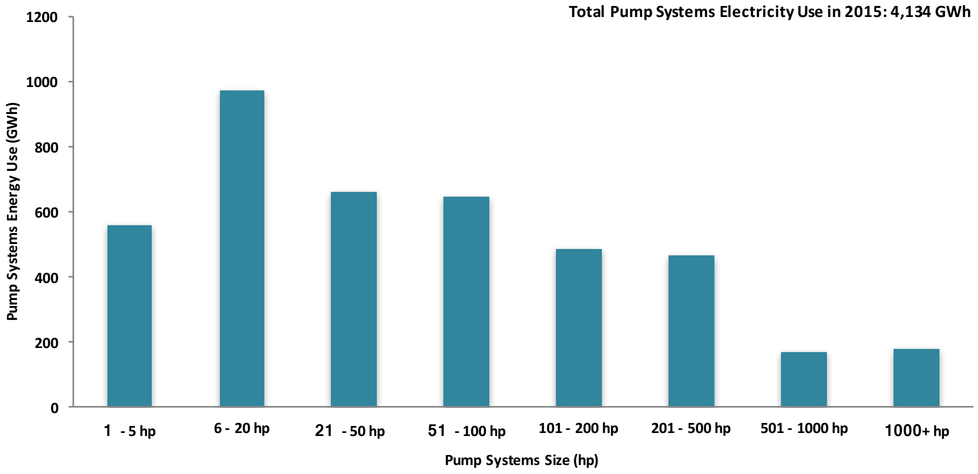


Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Figure 8. Estimated industrial compressed air systems electricity use by manufacturing subsectors in Egypt in 2015

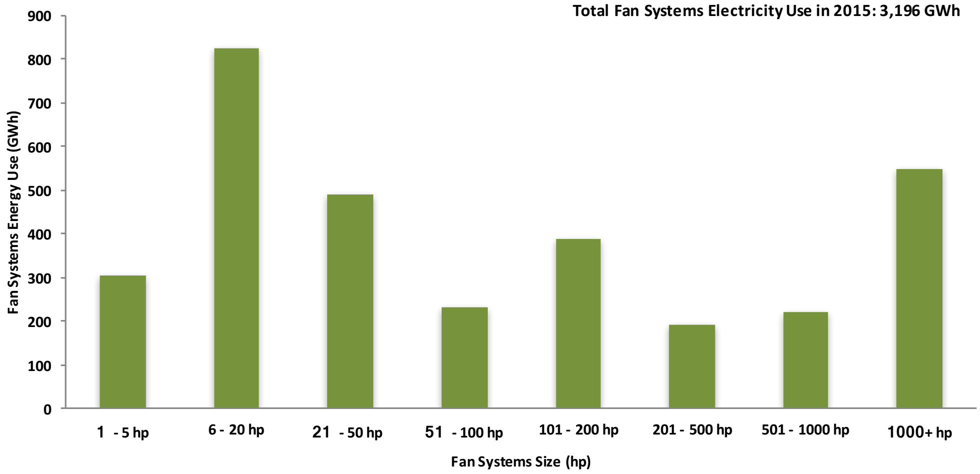
## 3.3. Electricity Use in Industrial Motor Systems in Egypt by System Size

Figure 9-11 show the estimated industrial motor systems electricity use by system type and size in Egypt in 2015. It should be noted that the values for motor systems exclude energy use in motor systems that are in process cooling and refrigeration and non-process facility Heating, ventilation and air conditioning (HVAC). In Egypt, pump systems with size range of 6hp - 20hp has the highest share of total industrial pump systems electricity use. Similarly, fan systems with size range of 6hp - 20hp has the highest share of total industrial Fan systems electricity use. Compressed air systems with size range of over 1000hp has the highest share of total compressed air systems electricity use.



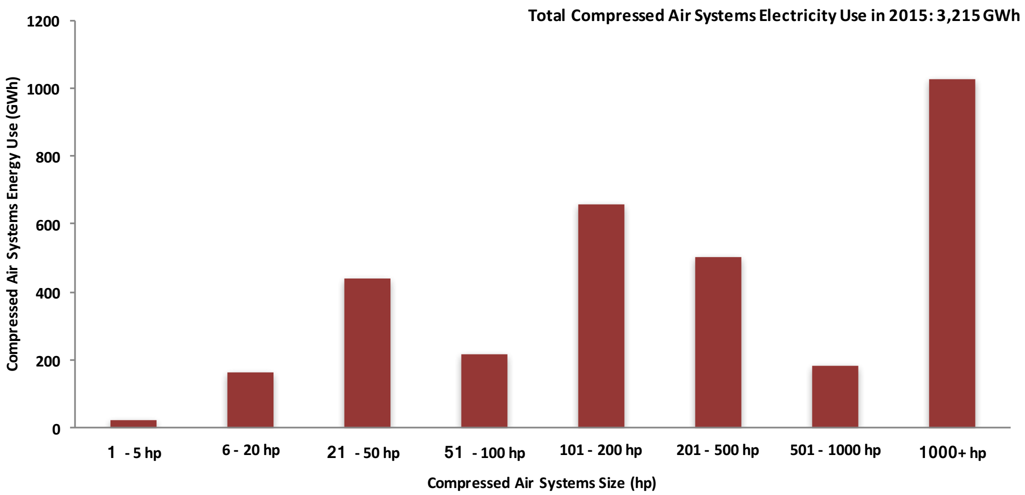
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 9. Estimated industrial pump systems electricity use by system size in Egypt in 2015**



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 10. Estimated industrial fan systems electricity use by system size in Egypt in 2015**



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 11. Estimated industrial compressed air systems electricity use by system size in Egypt in 2015**

As explained in methodology section, systems larger than 1000 hp (745kW) are usually custom-designed and the cost are highly variable for these systems. Therefore, we have excluded these systems from the energy saving and cost analyses in this report. Including systems larger than 1000 hp would significantly increase the energy saving potentials calculated in this report.

# 4. Energy-Efficiency Potential in Industrial Motor Systems in Egypt

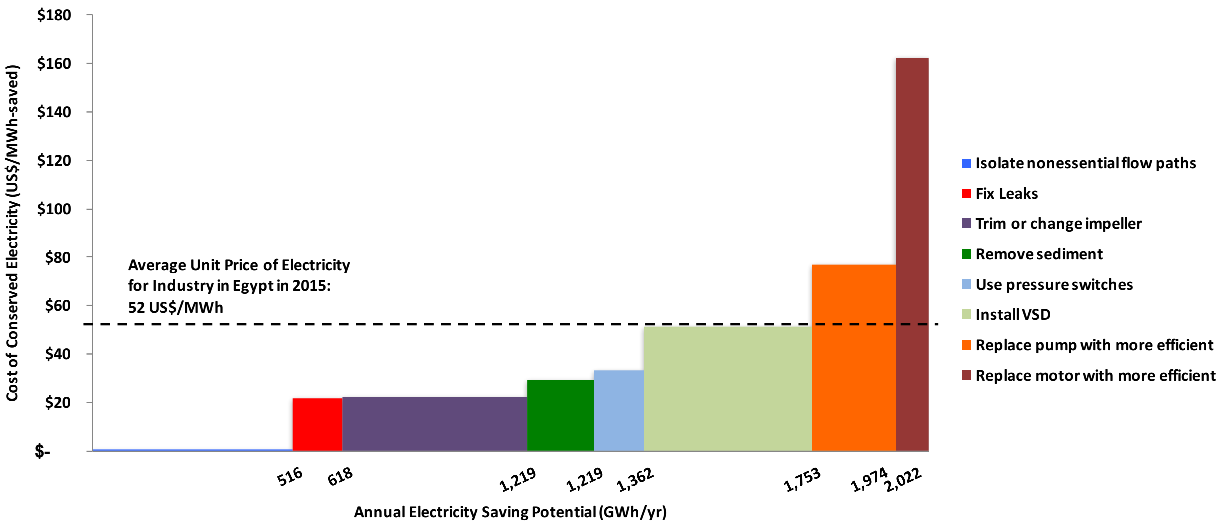
Based on the methodology explained in section 2, we constructed energy-efficiency cost curves for the industrial motor systems in Egypt studied. Our purpose was to capture separately the cost-effective potential and total technical potential for electricity efficiency improvement in these systems by implementing eight energy efficiency measures. We also calculated the $CO_2$ emissions reduction potential associated with the electricity savings. These potentials are the total existing potentials for energy-efficiency improvement in industrial motor systems for the year 2015. In other words, the potential represented here assumes a 100% adoption rate. We are aware that a 100% adoption rate is not likely and that values approaching a high adoption rate would only be possible over a period of time. However, assuming different penetration rates for the energy-efficiency measures in the future was beyond the scope of our study. Note that the energy-savings analysis in this report excludes motor systems used for process cooling and refrigeration and non-process facility HVAC.

## 4.1. Energy-Efficiency Cost Curve for Industrial Pump Systems in Egypt

Figure 12 shows the energy-efficiency cost curve for industrial pump systems in Egypt. The y-axis on the graph shows the CCE, and the x-axis shows the cumulative annual electricity savings potential of efficiency measures. Table 8 lists the measures on the cost curve along with the cumulative annual electricity-savings potential and final CCE of each measure as well as the cumulative $CO_2$ emissions-reduction potential. The energy-efficiency measures in the gray area of the table are cost effective (i.e., their CCE is less than the unit price of industrial-sector electricity in Egypt in 2015), and the efficiency measures that are in the white area are not cost-effective.

Out of eight energy-efficiency measures, six are cost-effective. The most cost-effective measure for pump systems in Egypt is “isolating flow paths to non-essential or non-operating equipment”, which has a CCE equal to zero. The second and third most-cost-effective measure are “Fix Leaks, damaged seals, and packing” and “Trim or change impeller to match output to requirements”. Installing variable-speed drives (VSDs) on pumps has one of the largest energy saving potential and is also cost-effective.

The least-cost-effective measure (i.e., the one with the highest CCE) for Egypt’s industrial pump systems is one that is commonly chosen: “replacing motors with more efficient types”. Another interesting and possibly counter-intuitive finding is that the energy-savings potential from replacing motors is smaller than the energy-savings potential of all other efficiency measures studied and replacing motor also appeared to be not cost-effective. Note that this analysis is intended to support policy makers, but is not a substitute for individualized assessments of motor system efficiency opportunities at a specific facility.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 12. Energy Efficiency Cost Curve for industrial pump systems in Egypt**

**Table 8. Cumulative annual electricity saving and $CO_2$ emission reduction potential for efficiency measures in industrial pump systems in Egypt ranked by final CCE**

| No. | Energy Efficiency Measures | Cumulative Annual Electricity Saving Potential (GWh/yr) | Final Cost of Conserved Energy (US$/MWh-Saved) | Cumulative Annual $CO_2$ Emission Reduction Potential (kton $CO_2$ /yr) |
|---|---|---|---|---|
| 1 | Isolate flow paths to nonessential or non-operating equipment | 516 | 0 | 301 |
| 2 | Fix Leaks, damaged seals, and packing | 618 | 22 | 360 |
| 3 | Trim or change impeller to match output to requirements | 1,058 | 22 | 617 |
| 4 | Remove sediment/scale buildup from piping | 1,219 | 29 | 711 |
| 5 | Use pressure switches to shut down unnecessary pumps | 1,362 | 33 | 794 |
| 6 | Install variable speed drive | 1,753 | 51 | 1,022 |
| 7 | Replace pump with more energy efficient type | 1,974 | 77 | 1,151 |
| 8 | Replace motor with more efficient type | 2,022 | 162 | 1,179 |

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) The energy and $CO_2$ savings presented for each measure are the cumulating savings from that measure and all previous measures with lower CCE. 3) This analysis provides an indication of the cost-effectiveness of system energy efficiency measures at the country level. The cost-effectiveness of individual measures will vary based on plant-specific conditions.
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Table 9 shows that the total technical energy-savings potential is 49% of total industrial pumping system electricity use in Egypt in 2015. This is a significant saving potential primarily because we assumed that compressed air systems in Egypt have LOW efficiency base case. This is in line with our previous studies for other developing countries (e.g. Thailand, Brazil, Vietnam). Egypt's industrial pump systems have a cost-effective potential of 42% of total industrial pumping system electricity use in Egypt in 2015.

**Table 9. Total annual cost-effective and technical energy saving and $CO_2$ emissions reduction potential in industrial pump systems in Egypt**

| | Cost-effective Potential | Technical Potential |
|---|---|---|
| Annual electricity saving potential for pump systems in Egypt's industry (GWh/yr) | 1,753 | 2,022 |
| Share of saving from the total pump system energy used in Egypt's industry in 2015 | 42% | 49% |
| Share of saving from the total electricity used in Egypt's industry in 2015 | 4.5% | 5.2% |
| Annual $CO_2$ emission reduction potential from Egypt's industry (kton $CO_2$/yr) | 1,022 | 1,179 |
| Number of households electricity consumption in Egypt that can be supplied by energy saved | 624,203 | 720,188 |

**Notes**: 1) Savings are based on 100% adoption of the energy efficiency measures. 2) Systems larger than 1000 hp are excluded from the energy saving and cost analyses. 3) The energy saving potential exclude pump systems that are in process cooling and refrigeration and non-process facility Heating, ventilation and air conditioning (HVAC).
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Table 10 shows the cumulative annual electricity-savings potential for industrial pump systems energy-efficiency measures in Egypt, by system size. The largest share of potential energy savings is in systems smaller than 50 horsepower (hp), with the next-largest share in systems that are between 51hp and 100hp.

As explained in the methodology section in Section 2, the implementation of one measure can influence the efficiency gain from the next efficiency measure implemented. That is, when one measure is implemented, the base-case efficiency is improved. Therefore, the efficiency improvement from the second measure will be less than if the second measure had been implemented first or was considered alone. Because of this, our analysis treated the measures in relation to each other (as a group). In other words, the efficiency improvement from implementation of one measure depends on the efficiency improvement achieved by the previous measure(s) implemented. We call this the *synergy effect*.

In this method, the *cumulative* electricity savings are calculated by taking into account the synergy effect of the measures rather than treating the measures in isolation from one another. For instance, the cumulative annual electricity savings from the implementation of measure #3 includes the efficiency gains from all the previous measures implemented (measures #1 and #2).

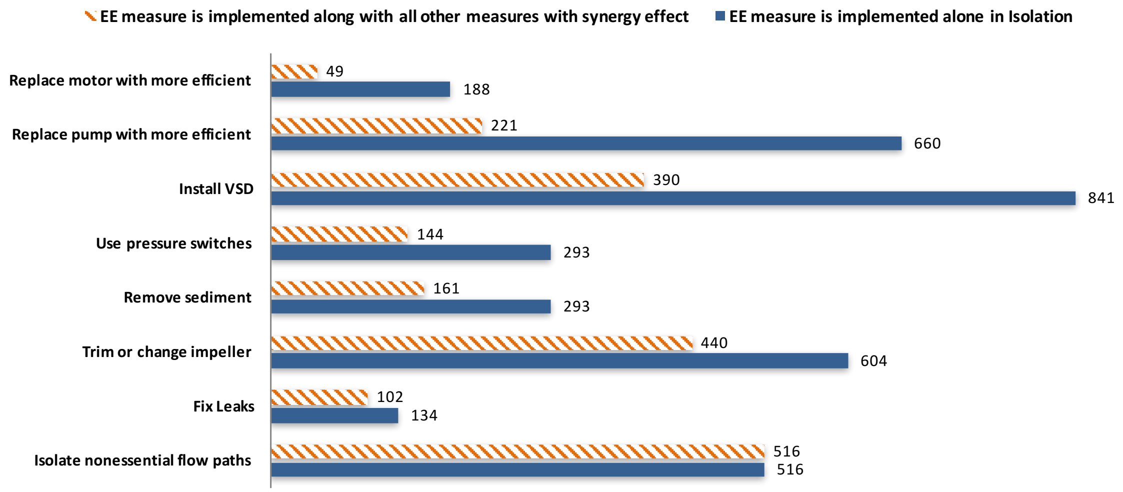
**Table 10. Cumulative annual electricity saving potential for efficiency measures in industrial pump systems in Egypt by system size (GWh/yr)**

| No. | Energy Efficiency Measures | ≤50 hp (≤37 kW) | 51-100 hp (38- 75kW) | 101- 200 hp (46-149kW) | 201- 500 hp (150-373kW) | 501-1000 hp (374 - 746kW) | Total |
|---|---|---|---|---|---|---|---|
| 1 | Isolate flow paths to nonessential or non-operating equipment | 286 | 84 | 63 | 61 | 22 | 516 |
| 2 | Fix Leaks, damaged seals, and packing | 343 | 101 | 76 | 73 | 26 | 618 |
| 3 | Trim or change impeller to match output to requirements | 587 | 173 | 130 | 124 | 45 | 1,058 |
| 4 | Remove sediment/scale buildup from piping | 676 | 199 | 149 | 143 | 52 | 1,219 |
| 5 | Use pressure switches to shut down unnecessary pumps | 755 | 222 | 167 | 160 | 58 | 1,362 |
| 6 | Install variable speed drive | 972 | 286 | 215 | 206 | 74 | 1,753 |
| 7 | Replace pump with more energy efficient type | 1,094 | 322 | 242 | 232 | 84 | 1,974 |
| 8 | Replace motor with more efficient type | 1,121 | 330 | 248 | 238 | 86 | 2,022 |

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) Energy savings presented for each measure is the cumulating savings from that measure and all previous measures with lower CCE.
3) Systems larger than 1000 hp are excluded from the energy saving and cost analyses.
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

However, if policy makers want to assess the impact of a single efficiency measure without considering the implementation of other measures, savings should be calculated for that particular measure implemented in isolation. Figure 13 compares the energy-savings potential for each efficiency measure implemented in isolation to the energy-savings potential for each measure implemented along with other measures; the latter is the savings value that we use on the energy-efficiency cost curve.

The measures that are less cost-effective on the efficiency cost curve and that appear at the top of the graph in Figure 13 show the largest differences between the energy savings calculated for the measure in isolation versus the energy savings calculated for the measure in combination with other measures. Note that summing up the energy savings of individual measures implemented in isolation will give an inaccurate result because of the synergy effect explained above.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

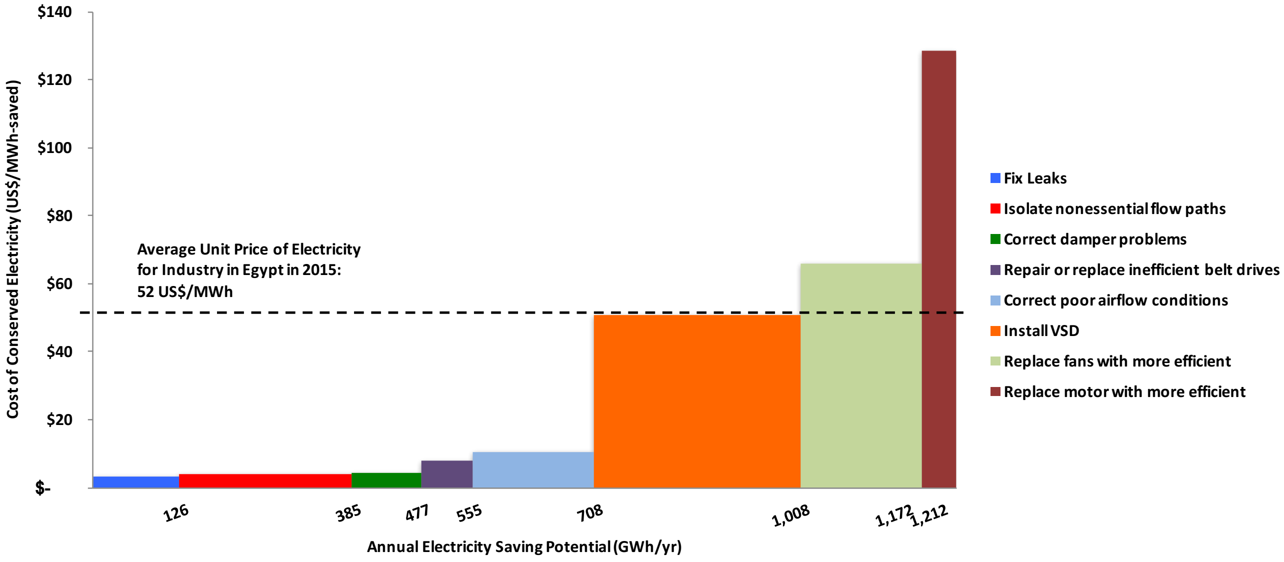
**Figure 13. Comparison of energy saving potential (GWh/yr) for each efficiency measure in Egypt when each measure is implemented in isolation or is implemented along with other measures**

## 4.2. Energy-Efficiency Cost Curve for Industrial Fan Systems in Egypt

Figure 14 shows the energy-efficiency cost curve for industrial fan systems in Egypt. The y-axis on the graph shows the CCE, and the x-axis shows the cumulative annual electricity savings potential of efficiency measures. Table 11 lists the measures on the cost curve along with the cumulative annual electricity-savings potential and final CCE of each measure as well as the cumulative $CO_2$ emissions-reduction potential. The energy-efficiency measures in the gray area of the table are cost effective (i.e., their CCE is less than the unit price of industrial-sector electricity in Egypt in 2015), and the efficiency measures that are in the white area are not cost-effective.

Out of eight energy-efficiency measures, six are cost-effective. The most cost-effective measure for fan systems in Egypt is “fix Leaks and damaged seals” which has the lowest CCE. Installing variable-speed drives (VSDs) on fans has the largest energy saving potential and is also cost-effective.

The least-cost-effective measure (i.e., the one with the highest CCE) for Egypt fan systems is one that is commonly chosen: replacing motors with more efficient models. By contrast, installing a VSD on fan systems, which results in the highest saving potential, is cost-effective in Egypt. Another interesting and possibly counter-intuitive finding is that the energy-savings potential from replacing motors is smaller than the energy-savings potential of all other efficiency measures studied and this measure is not cost-effective.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 14. Energy Efficiency Cost Curve for industrial fan systems in Egypt**

Table 11. Cumulative annual electricity saving and $CO_2$ emission reduction potential for efficiency measures in industrial fan systems in Egypt ranked by final CCE

| No. | Energy Efficiency Measures | Cumulative Annual Electricity Saving Potential (GWh/yr) | Final Cost of Conserved Energy (US$/MWh-Saved) | Cumulative Annual $CO_2$ Emission Reduction Potential (kton $CO_2$ /yr) |
|---|---|---|---|---|
| 1 | Fix Leaks and damaged seals | 126 | 3.3 | 73 |
| 2 | Isolate flow paths to nonessential or non-operating equipment | 385 | 3.9 | 224 |
| 3 | Correct damper problems | 477 | 4.5 | 278 |
| 4 | Repair or replace inefficient belt drives | 555 | 8.0 | 323 |
| 5 | Correct poor airflow conditions at fan inlets and outlets | 708 | 10.6 | 413 |
| 6 | Install variable speed drive | 1,008 | 50.7 | 588 |
| 7 | Replace oversized fans with more efficient type | 1,172 | 65.9 | 683 |
| 8 | Replace motor with more energy efficient type | 1,212 | 128.6 | 707 |

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) The energy and $CO_2$ savings presented for each measure are the cumulating savings from that measure and all previous measures with lower CCE. 3) This analysis provides an indication of the cost-effectiveness of system energy efficiency measures at the country level. The cost-effectiveness of individual measures will vary based on plant-specific conditions.
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

Table 12 shows that the total technical energy-savings potential is 38% of total industrial fan system electricity use in Egypt in 2015. This is in line with our previous studies for other developing countries (e.g. Thailand, Brazil, Vietnam). We assumed that fan systems in Egypt have LOW efficiency base case. Egypt's industrial fan systems have a cost-effective potential of 32% of total fan system electricity use in Egypt in 2015.

Table 12. Total annual cost-effective and technical energy saving and $CO_2$ emissions reduction potential in industrial fan systems in Egypt

| | Cost-effective Potential | Technical Potential |
|---|---|---|
| Annual electricity saving potential for fan systems in Egypt's industry (GWh/yr) | 1,008 | 1,212 |
| Share of saving from the total fan system energy used in Egypt's industry in 2015 | 32% | 38% |
| Share of saving from the total electricity used in Egypt's industry in 2015 | 2.6% | 3.1% |
| Annual $CO_2$ emission reduction potential from Egypt's industry (kton $CO_2$/yr) | 588 | 707 |
| Number of households electricity consumption in Egypt that can be supplied by energy saved | 358,967 | 431,731 |

**Notes**: 1) Savings are based on 100% adoption of the energy efficiency measures. 2) Systems larger than 1000 hp are excluded from the energy saving and cost analyses. 3) The energy saving potential exclude fan systems that are in process cooling and refrigeration and non-process facility Heating, ventilation and air conditioning (HVAC).

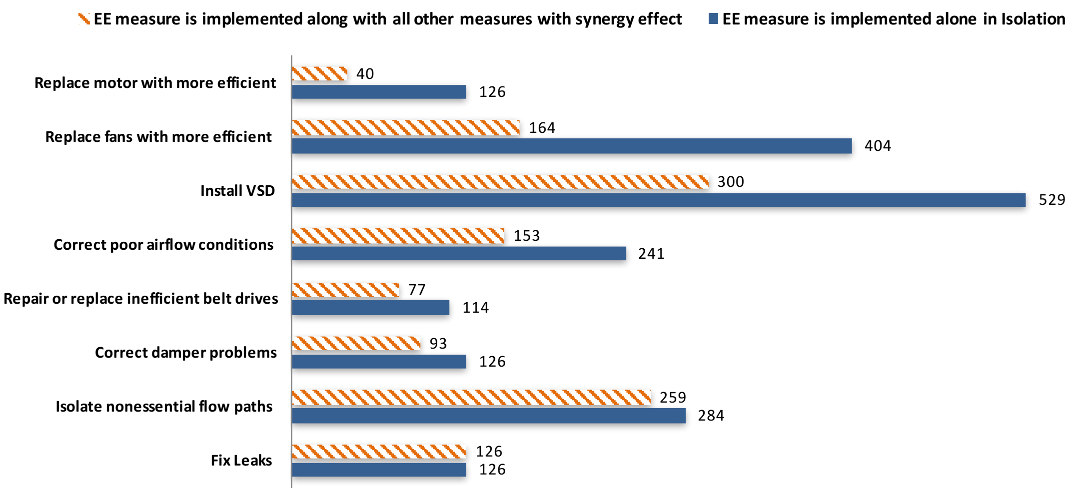
Table 13 shows the cumulative annual electricity-savings potential for industrial fan systems energy-efficiency measures in Egypt, by system size. The largest share of potential energy savings is in systems smaller than 50 horsepower (hp), with the next-largest share in systems that are between 101hp and 200hp.

**Table 13. Cumulative annual electricity saving potential for efficiency measures in industrial fan systems in Egypt by system size (GWh/yr)**

| No. | Energy Efficiency Measures | ≤50 hp (≤37 kW) | 51-100 hp (38- 75kW) | 101- 200 hp (46-149kW) | 201- 500 hp (150-373kW) | 501-1000 hp (374 - 746kW) | Total |
|---|---|---|---|---|---|---|---|
| 1 | Fix Leaks and damaged seals | 77 | 11 | 18 | 9 | 10 | 126 |
| 2 | Isolate flow paths to nonessential or non-operating equipment | 235 | 33 | 56 | 28 | 32 | 385 |
| 3 | Correct damper problems | 292 | 42 | 70 | 35 | 40 | 477 |
| 4 | Repair or replace inefficient belt drives | 339 | 48 | 81 | 40 | 46 | 555 |
| 5 | Correct poor airflow conditions at fan inlets and outlets | 433 | 62 | 103 | 52 | 59 | 708 |
| 6 | Install variable speed drive | 616 | 88 | 147 | 73 | 84 | 1,008 |
| 7 | Replace oversized fans with more efficient type | 717 | 102 | 171 | 85 | 97 | 1,172 |
| 8 | Replace motor with more energy efficient type | 741 | 106 | 177 | 88 | 100 | 1,212 |

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) Energy savings presented for each measure is the cumulating savings from that measure and all previous measures with lower CCE.
3) Systems larger than 1000 hp are excluded from the energy saving and cost analyses.
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

The measures that are less cost-effective on the efficiency cost curve and that appear at the top of the graph in Figure 15 show the largest differences between the energy savings calculated for the measure in isolation versus the energy savings calculated for the measure in combination with other measures. Note that summing up the energy savings of individual measures implemented in isolation will give an inaccurate result because of the synergy effect explained above.



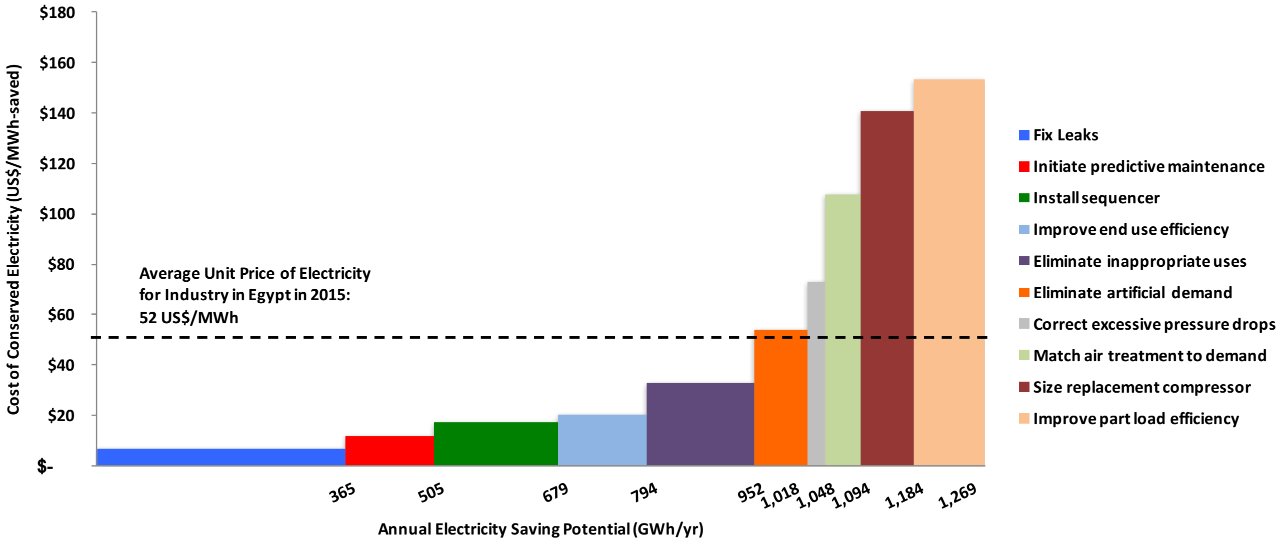
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 15. Comparison of energy saving potential (GWh/yr) for each efficiency measure in Egypt when each measure is implemented in isolation or is implemented along with other measures**

### 4.3. Energy-Efficiency Cost Curve for Industrial Compressed Air Systems in Egypt

Figure 16 shows the energy-efficiency cost curve for industrial compressed air systems in Egypt. The y-axis on the graph shows the CCE, and the x-axis shows the cumulative annual electricity savings potential of efficiency measures. Table 14 lists the measures on the cost curve along with the cumulative annual electricity-savings potential and final CCE of each measure as well as the cumulative $CO_2$ emissions-reduction potential. The energy-efficiency measures in the gray area of the table are cost effective (i.e., their CCE is less than the unit price of industrial-sector electricity in Egypt in 2015), and the efficiency measures that are in the white area are not cost-effective. Out of ten energy-efficiency measures, five are cost-effective. The most cost-effective measure for comoressed air systems in Egypt is "Fix Leaks, adjust compressor controls, establish ongoing plan" which has the lowest CCE followed by "Initiate predictive maintenance program".

The least-cost-effective measure (i.e., the one with the highest CCE) for Egypt compressed air systems is "Improve trim compressor part load efficiency; i.e. variable speed drive". Also, it should be noted that the most cost-effective measure, "Fix Leaks, adjust compressor controls, establish ongoing plan", has the largest energy saving potential as well.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 16. Energy Efficiency Cost Curve for industrial compressed air systems in Egypt**

Table 15 shows that the total technical energy-savings potential is 39% of total industrial compressed air system electricity use in Egypt in 2015. This is a significant saving potential primarily because we assumed that compressed air systems in Egypt have LOW efficiency base case. Egypt's industrial compressed air systems have a cost-effective potential of 30% of total industrial compressed air system electricity use in Egypt in 2015.

**Table 14. Cumulative annual electricity saving and $CO_2$ emission reduction potential for efficiency measures in industrial compressed air systems in Egypt ranked by final CCE**

| No. | Energy Efficiency Measures | Cumulative Annual Electricity Saving Potential (GWh/yr) | Final Cost of Conserved Energy (US$/MWh-Saved) | Cumulative Annual $CO_2$ Emission Reduction Potential (kton $CO_2$ /yr) |
|---|---|---|---|---|
| 1 | Fix Leaks, adjust compressor controls, establish ongoing plan | 365 | 7 | 213 |
| 2 | Initiate predictive maintenance program | 505 | 12 | 294 |
| 3 | Install sequencer | 679 | 17 | 396 |
| 4 | Improve end use efficiency; shut-off idle equip, engineered nozzles, etc. | 794 | 20 | 463 |
| 5 | Eliminate inappropriate compressed air uses | 952 | 33 | 555 |
| 6 | Eliminate artificial demand with pressure optimization/control/ storage | 1,018 | 54 | 593 |
| 7 | Correct excessive pressure drops in main line distribution piping | 1,048 | 73 | 611 |
| 8 | Match air treatment to demand side needs | 1,094 | 108 | 638 |
| 9 | Size replacement compressor to meet demand | 1,184 | 141 | 690 |
| 10 | Improve trim compressor part load efficiency; i.e. variable speed drive | 1,269 | 153 | 740 |

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) The energy and $CO_2$ savings presented for each measure are the cumulating savings from that measure and all previous measures with lower CCE. 3) This analysis provides an indication of the cost-effectiveness of system energy efficiency measures at the country level. The cost-effectiveness of individual measures will vary based on plant-specific conditions.
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Table 15. Total annual cost-effective and technical energy saving and $CO_2$ emissions reduction potential in industrial compressed air systems in Egypt**

| | Cost-effective Potential | Technical Potential |
|---|---|---|
| Annual electricity saving potential for compressed air systems in Egypt's industry (GWh/yr) | 952 | 1,269 |
| Share of saving from the total compressed air system energy used in Egypt's industry in 2015 | 30% | 39% |
| Share of saving from the total electricity used in Egypt's industry in 2015 | 2.4% | 3.2% |
| Annual $CO_2$ emission reduction potential from Egypt's industry (kton $CO_2$/yr) | 555 | 740 |
| Number of households electricity consumption in Egypt that can be supplied by energy saved | 338,983 | 451,818 |

**Notes**: 1) Savings are based on 100% adoption of the energy efficiency measures. 2) Systems larger than 1000 hp are excluded from the energy saving and cost analyses. 3) The energy saving potential exclude compressed air systems that are in process cooling and refrigeration and non-process facility Heating, ventilation and air conditioning (HVAC).
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

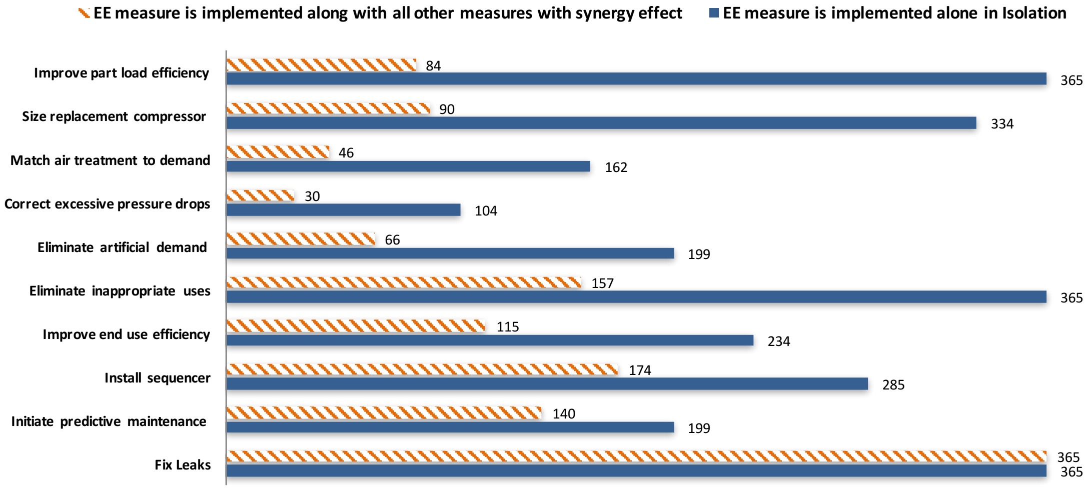
Table 16 shows the cumulative annual electricity-savings potential for industrial compressed air systems energy-efficiency measures in Egypt, by system size. The largest share of potential energy savings is in systems that are between 101hp and 200hp with the next-largest share in systems smaller than 50 hp.

**Table 16. Cumulative annual electricity saving potential for efficiency measures in industrial compressed air systems in Egypt by system size (GWh/yr)**

| No. | Energy Efficiency Measures | ≤50 hp (≤37 kW) | 51-100 hp (38- 75kW) | 101- 200 hp (46-149kW) | 201- 500 hp (150-373kW) | 501-1000 hp (374 - 746kW) | Total |
|---|---|---|---|---|---|---|---|
| 1 | Fix Leaks, adjust compressor controls, establish ongoing plan | 105 | 36 | 110 | 84 | 30 | 365 |
| 2 | Initiate predictive maintenance program | 145 | 50 | 152 | 116 | 42 | 505 |
| 3 | Install sequencer | 195 | 68 | 204 | 156 | 56 | 679 |
| 4 | Improve end use efficiency; shut-off idle equip, engineered nozzles, etc. | 228 | 79 | 239 | 183 | 66 | 794 |
| 5 | Eliminate inappropriate compressed air uses | 273 | 95 | 286 | 219 | 79 | 952 |
| 6 | Eliminate artificial demand with pressure optimization/control/storage | 292 | 101 | 306 | 234 | 84 | 1,018 |
| 7 | Correct excessive pressure drops in main line distribution piping | 301 | 104 | 315 | 241 | 87 | 1,048 |
| 8 | Match air treatment to demand side needs | 314 | 109 | 329 | 252 | 91 | 1,094 |
| 9 | Size replacement compressor to meet demand | 340 | 118 | 356 | 272 | 98 | 1,184 |
| 10 | Improve trim compressor part load efficiency; i.e. variable speed drive | 364 | 126 | 381 | 292 | 105 | 1,269 |

Notes: 1) Energy savings are based on 100% adoption of the efficiency measures. 2) Energy savings presented for each measure is the cumulating savings from that measure and all previous measures with lower CCE.
3) Systems larger than 1000 hp are excluded from the energy saving and cost analyses.
Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

The measures that are less cost-effective on the efficiency cost curve and that appear at the top of the graph in Figure 17 show the largest differences between the energy savings calculated for the measure in isolation versus the energy savings calculated for the measure in combination with other measures. Note that summing up the energy savings of individual measures implemented in isolation will give an inaccurate result because of the synergy effect explained above.



Source: Global Efficiency Intelligence, LLC Analyses (Methodology in Section 2)

**Figure 17. Comparison of energy saving potential (GWh/yr) for each efficiency measure in Egypt when each measure is implemented in isolation or is implemented along with other measures**

## 5. Summary and Conclusions

The purpose of the analyses in this report was twofold: 1) to determine the energy use in industrial motor systems, by manufacturing subsectors, in Egypt, and 2) to quantify the potential for and costs of improving the energy-efficiency of industrial motor systems. We determined the costs of improving motor system energy efficiency by taking into account the costs of and energy savings from different energy-efficiency technologies and measures. Many cost-effective opportunities for motor systems energy-efficiency improvement have been identified but are infrequently adopted, leading to an "efficiency gap." Failure to adopt cost-effective efficiency improvements results from numerous obstacles, both monetary and non-monetary.

To estimate the cost-effective electricity-efficiency potentials of eight energy-efficiency technologies and measures for industrial motor systems, we used a bottom-up energy-efficiency cost curve model. We also estimated technical electricity-savings potentials, assuming 100% adoption of the efficiency measures. Table 17 summarizes the results for Egypt studied. We also calculated the $CO_2$ emissions-reduction potential associated with the electricity-savings potentials, using the average $CO_2$ emissions factor of the electricity grid in Egypt.

**Table 17. Total annual technical energy saving and $CO_2$ emissions reduction potential in industrial motor systems in Egypt**

| | Pump Systems | Fan Systems | Compressed Air Systems |
|---|---|---|---|
| Technical annual electricity saving potential (GWh/yr) | 2,022 | 1,212 | 1,269 |
| Associated $CO_2$ emission reduction potential from industry (kton $CO_2$/yr) | 1,179 | 707 | 740 |

In Egypt, the share of total technical electricity-savings potential for industrial pump systems compared to total manufacturing pump systems energy use is 49%. The share of total technical electricity-savings potential for industrial fan systems compared to total manufacturing fan systems energy use in Egypt is 38%. The share of total technical electricity-savings potential for industrial compressor systems compared to total manufacturing compressor systems energy use is 39%. These are very large and significant saving potential that policy makers in Egypt cannot afford to ignore.

The total technical annual electricity saving potential in the three motor systems studied (pump, fan, and compressed air systems) is equal to annual electricity consumption of over 1.6 million households in Egypt.

In general, CCE has a direct relationship with the discount rate. For example, reductions in the discount rate will result in reductions in CCE, which can increase the cost-effective energy-savings potential (depending on energy prices). A higher energy price can result in more energy-efficiency measures being cost-effective by causing their CCEs to fall below the energy price line.

Because systems larger than 1,000 hp account for about 4%, 17%, and 32% of total industrial pump, fan, and compressor systems electricity use in Egypt, respectively, excluding these systems from the analysis resulted in a proportional decrease in total system energy use and a corresponding decrease in the energy savings resulting from the energy-efficiency measures analyzed. In other words, the energy-savings potentials would be greater if systems larger than 1,000 hp were included in the analysis.

It should be noted that some energy-efficiency measures provide productivity, environmental, and other benefits in addition to energy savings; however, quantifying these benefits is difficult and beyond the scope of this report. Including quantified estimates of other benefits could decrease CCE for the efficiency measures and thereby increase the number of measures that are cost-effective.

In addition, it is important to highlight that electricity is a final form of energy. If we convert the electricity saving calculated in this report to primary energy saving using average power generation efficiency and transmission and distribution losses, the primary energy saving can be up to around 3 times of the electricity saving values.

The approach used in this study and the model developed for this purpose should be viewed as a screening method and tool that can identify energy-efficiency measures and their energy-savings potential and costs to aid national and local governments, policy makers, and utilities in designing energy-efficiency policies. Actual energy-savings potentials and costs of energy-efficiency measures and technologies will vary in relation to plant-specific conditions. Effective energy-efficiency policies and programs are needed to realize (and ultimately exceed) current cost-effective potentials.

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# Appendix

**Table A.1. Characteristics of LOW-MEDIUM-HIGH efficiency base-case scenarios for pump systems**

| No. | LOW Efficiency Base-Case Scenario |
|---|---|
| **1** | Less than 10% of pump systems have been assessed for system energy efficiency. |
| **2** | Maintenance is limited to what is required to support operations. |
| **3** | Flow is typically controlled by throttling or bypass. |
| **4** | Flow regularly exceeds actual system needs. |
| **5** | Variable-speed drives are not commonly used |
| **6** | Motors of all sizes are routinely rewound multiple times instead of replaced. |
| **7** | ~10% of the installed motors are high efficiency--either EPAct or EFF1 equivalent. |
| No. | **MEDIUM Efficiency Base-Case Scenario** |
| **1** | ~20% of pump systems have been assessed for system energy efficiency. |
| **2** | Maintenance is a routine part of operations and includes some preventative actions. |
| **3** | System operators take steps to avoid controlling flow via throttling or bypass. |
| **4** | Efforts are made to efficiently match supply with demand. |
| **5** | Variable-speed drives are frequently proposed as a solution for flow control. |
| **6** | Motors ≥ 37 kW are typically rewound multiple times, and smaller motors may be replaced. |
| **7** | ~25% of the installed motors are high efficiency--either EPAct or EFF1 equivalent. |
| No. | **HIGH Efficiency Base-Case Scenario** |
| **1** | 30% or more of pump systems have been assessed for system energy efficiency. |
| **2** | Both routine and predictive maintenance are commonly practiced. |
| **3** | Flow is not controlled by throttling or bypass except in emergencies. |
| **4** | Fluid is only pumped where and when needed to meet demand. |
| **5** | Variable-speed drives are one of several flow-control strategies commonly applied to increase system efficiency. |
| **6** | Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (typ <37 kW). |
| **7** | 50% or more of the installed motors are high efficiency--either EPAct or EFF1 equivalent. |

**Table A.2. Characteristics of LOW-MEDIUM-HIGH efficiency base-case scenarios for fan systems**

| No. | **LOW Efficiency Base Case Scenario** |
|---|---|
| **1** | Less than 10% fan systems representing 40% of the connected fan load have been assessed for system energy efficiency |
| **2** | Maintenance is limited to what is required to support operations |
| **3** | Flow is usually controlled by dampers or bypass |
| **4** | Low cost fans types, like radial, are often used even in clean air applications |
| **5** | Fans are sometimes located on the dirty side of the process |
| **6** | Fans are sometimes oversized for the present load |
| **7** | Variable speed drives or variable inlet vanes are sometimes proposed as a solution for flow control |
| **8** | Motors of all sizes are routinely rewound multiple times instead of replaced |
| **9** | 10% or less of the installed motors are high efficiency--either EPAct or EFF1 equivalent |
| No. | **MEDIUM Efficiency Base Case Scenario** |
| **1** | ~30% fan systems representing 60% of the connected fan load have been assessed for system energy efficiency |
| **2** | Maintenance is a routine part of operations and includes some preventative actions |
| **3** | System operators take steps to avoid controlling flow via dampers or bypass |
| **4** | Airfoil or backward curved impellers are used in clean air handling applications |
| **5** | Fans are located on the clean side of the process whenever possible |
| **6** | Fans are chosen to efficiently serve a given condition |
| **7** | Variable speed drives or variable inlet vanes are frequently proposed as a solution for flow control |
| **8** | Motors ≥ 37 kW are typically rewound multiple times, while smaller motors may be replaced |
| **9** | ~25% of the installed motors are high efficiency--either EPAct or EFF1 equivalent |
| No. | **HIGH Efficiency Base Case Scenario** |
| **1** | ~50% fan systems representing 80% of the connected fan load have been assessed for system efficiency |
| **2** | Both routine and predictive maintenance are commonly practiced |
| **3** | Flow is not controlled by dampers or bypass except in emergencies |
| **4** | Fans are located on the clean side of the process whenever possible |
| **5** | Variable speed drives are one of several flow control strategies commonly applied to increase efficiency |
| **6** | Fans types are chosen based on the highest efficient type to serve a given condition |
| **7** | Fans are selected and procured so that typical process flow and pressure requirements are at or near Best Efficiency Point |
| **8** | Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (typ <45 kW) |
| **9** | 50% or more of the installed motors are high efficiency--either EPAct or EFF1 equivalent |

**Table A.3. Characteristics of LOW-MEDIUM-HIGH efficiency base-case scenarios for compressed air systems**

| No. | **LOW Efficiency Base Case Scenario** |
|---|---|
| **1** | Less than 10% of compressed air systems have been assessed for system energy efficiency (both supply and demand side assessment) |
| **2** | Maintenance is limited to what is required to support operations |
| **3** | Compressor control is coordinated but poorly and a single trim compressor operates inefficiently |
| **4** | System pressure profile, supply / demand balance, and storage partially optimized |
| **5** | Leaks are ≥ 25%, but < 35% and are fixed irregularly |
| **6** | There is widespread inappropriate use of compressed air |
| **7** | Motors of all sizes are routinely rewound multiple times instead of replaced |
| No. | **MEDIUM Efficiency Base Case Scenario** |
| **1** | ~20% of compressed air systems have been assessed for system energy efficiency (both supply and demand side assessment) |
| **2** | Maintenance is a routine part of operations and includes some preventative actions |
| **3** | Compressor control is coordinated and a single trim compressor operates efficiently |
| **4** | Variable speed drives are frequently proposed as a solution for flow control |
| **5** | Leaks are ≥ 15%, but < 25% and are fixed periodically |
| **6** | Inappropriate end use of compressed air has been reduced |
| **7** | Motors ≥ 37 kW are typically rewound multiple times, while smaller motors may be replaced |
| No. | **HIGH Efficiency Base Case Scenario** |
| **1** | ~30% or more of compressed air systems have been assessed for system energy efficiency (both supply and demand side assessment) |
| **2** | Both routine and predictive maintenance are commonly practiced |
| **3** | Compressor controls and storage are used to efficiently match supply to demand |
| **4** | System pressure profile from supply to end use has been optimized |
| **5** | Leaks < 15%; Leaks management is ongoing |
| **6** | Inappropriate end use of compressed air has been minimized |
| **7** | Most facilities have a written rewind/replace policy that prohibits rewinding smaller motors (typ <37 kW) |

**Table A.4. Consolidated system efficiency for LOW-MED-HIGH efficiency baselines**

| | Pump System Efficiency | | |
|---|---|---|---|
| | low end (%) | high end (%) | Average (%) - used in the analyses |
| Low level of efficiency | 20% | 40% | 30% |
| Medium level of efficiency | 40% | 60% | 50% |
| High level of efficiency | 60% | 75% | 68% |

**Table A.5. Consolidated system efficiency for LOW-MED-HIGH efficiency baselines**

| | Fan System Efficiency | | |
|---|---|---|---|
| | low end (%) | high end (%) | Average (%) - used in the analyses |
| Low level of efficiency | 15% | 30% | 23% |
| Medium level of efficiency | 30% | 50% | 40% |
| High level of efficiency | 50% | 65% | 58% |

**Table A.6. Consolidated system efficiency for LOW-MED-HIGH efficiency baselines**

| | Compressed Air System Efficiency | | |
|---|---|---|---|
| | low end (%) | high end (%) | Average (%) - used in the analyses |
| Low level of efficiency | 2.0% | 5.0% | 3.5% |
| Medium level of efficiency | 4.8% | 8.0% | 6.4% |
| High level of efficiency | 8.0% | 13.0% | 10.5% |