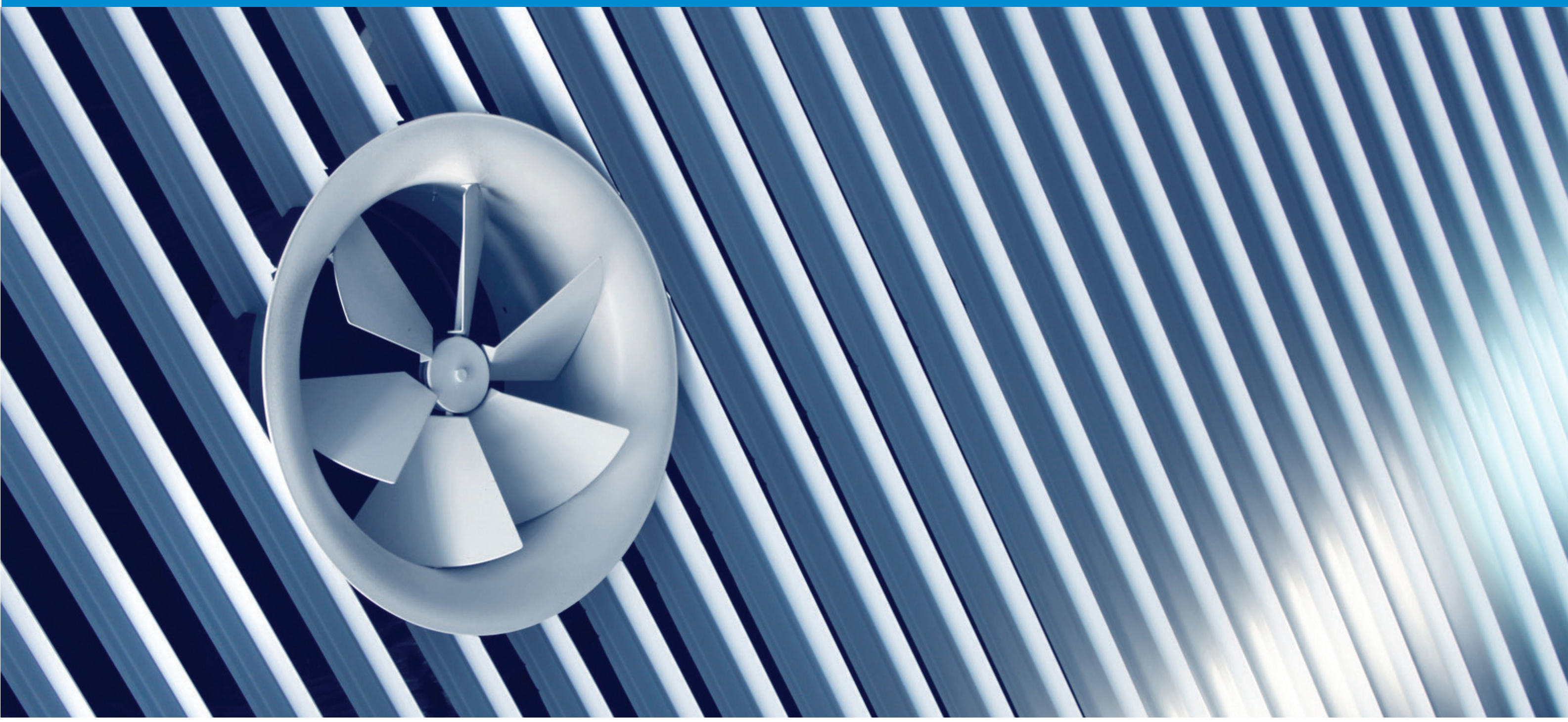

Motor Systems Efficiency Supply Curves

UNITED NATIONS
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December 2010

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Acknowledgements

The principal authors, Aimee McKane and Ali Hasanbeigi of Lawrence Berkeley National Laboratory, gratefully acknowledge the helpful guidance and insightful comments provided by Dolf Gielen and Sanjaya Shrestha of UNIDO. They would also like to thank Manuel Welsch and Morgan Bazilian of UNIDO for their assistance during this project.

Motor System Experts
This work could not have been completed without the contributions and guidance of the motor system experts listed below. Their knowledge of the subject matter, patience with the iterative process of developing a new research framework, and generosity in finding time in extremely busy schedules are gratefully acknowledged.

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Executive Summary

Motor-driven equipment accounts for approximately 60% of manufacturing final electricity use and are ubiquitous in industrial facilities worldwide. Motor systems, such as compressed air, pumping, and fan systems, represent a largely untapped, cost-effective source for industrial energy efficiency savings that could be realized with existing technologies. Although motor systems have the potential to contribute substantial energy savings, on the order of 2.58 EJ in final energy use, this potential is largely unrealized (IEA 2007).

A major barrier to effective policymaking, and to more global acceptance of the energy efficiency potential of motor systems, is the lack of a transparent methodology for quantifying this potential based on sufficient data to document the magnitude and cost-effectiveness of these energy savings by country and by region. It is far easier to quantify the incremental energy savings of substituting an energy efficient motor for a standard motor than it is to quantify energy savings of applying energy efficiency practices to an existing motor system. The former is dependent on the appropriate matching of the replacement motor, but reasonable assumptions can be made that an *incremental benefit against current practice* will occur. The latter is based on the concept of *changing current practice* by applying commercially available technologies in the most energy efficient manner, and requires onsite evaluation to maximize system energy efficiency.

This report and supporting analyses represent an initial effort to address this barrier, thus supporting greater global acceptance of the energy efficiency potential of motor systems, through the construction of a series of motor system efficiency supply curves, by motor system and by country studied. It is important to note, however, the limitations of this initial study. *The purpose of this research is to provide guidance for national policy makers and is not a substitute for a detailed technical assessment of the motor* *system energy efficiency opportunities of a specific site.*[1]

The research framework created to conduct the analyses supporting this Phase I report is based on a combination of expert input and available data. While it is important to acknowledge that the methodology employed blurs real variations that may exist in system performance from one industrial sector to another within a country, it is consistent with the level of precision possible with the available data. The report is meant to be a beginning, not an end unto itself. The authors and sponsors of this research seek to initiate an international dialogue with others having an interest in the energy efficiency potential of motor systems. Through this dialogue, it is hoped that the initial framework for quantifying motor system energy efficiency potential created for this report will be refined based on additional input and data.

Study Scope and Methodology

For these Phase I analyses, six countries/region were selected that represent varying sizes and levels of industrial development, and for which industrial energy use by sector and some information about motor system efficiency practices were available. These initial six are the United States, Canada, the European Union, Thailand, Vietnam, and Brazil.

The first step was a literature review to develop a baseline of information. Next a data collection framework was developed to obtain expert input to supplement the existing data. Input was received from thirteen motor system experts, including at least four experts for each of the three systems analyzed (compressed air, fans, and pumping). Information was sought from these experts on the % of system energy use by industrial sector, the 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. Several cycles of input, analyses, and review were performed to better refine these expert inputs.

The final installed costs for the measures analyzed were adjusted for variations in labor costs across the six countries (see Labor Adjustment Factor, page 32). No such adjustment was made for materials/equipment costs due to limited data; however, materials/equipment costs can vary widely from country to country based on import taxes, tax credits, availability, and other factors. These variations in cost would benefit from further study. Also, it should be mentioned that the full cost of the measures are used in this report rather than the incremental cost of energy efficient measures. (see Section 3.2 for further details).

Country-specific data was collected in parallel with the motor system expert consultation. After receiving expert input and completing collection of the country-specific data, the Motor System Efficiency Supply Curves were constructed. Details of the methodology and research framework are provided in Section 3 of this report.

A summary of the inputs to the supply curves is included in Table ES-1 below.

[1] In addition to literature describing the system assessment included in the bibliography of this report, the American National Standards Institute (ASME) has recently published standards and guidance on conducting energy system assessments. See http://catalog.asme.org/ EA-1 through EA-4

This table summarizes the relative effect of a range of inputs on the cost-effectiveness of the selected measures. Some inputs, such as energy savings, useful life and cost of individual measures, account for the variation between the cost effectiveness of measures, whereas others, such as the base case assumption, the electricity price, and the estimated motor system energy use, account for the variation in results between countries. The same discount rate of 10% was used for all countries studied, although a sensitivity analysis for a range of discount rates was conducted. A sensitivity analysis was also conducted for electricity prices. (See Section 4.5 for details of these analyses). A study of the relative impact of load factors and hours of operation would also be a useful subject for further research.

Key Findings

Based on expert input, ten energy-efficiency technologies and measures for pumping systems, ten measures for the fan systems and sixteen measures for compressed air systems were selected for analysis. Using the bottom-up energy efficiency supply curve model, the cost-effective electricity efficiency potentials for these motor systems were estimated for the six countries in the analyses. Total technical electricity-saving potentials were also estimated for 100% penetration of the measures in the base year. An overview of the cost effectiveness of these measures by country is illustrated in Table ES-2.

Table ES-1: Inputs to the Construction of Supply Curves

Parameter	Account for variation of results between countries	Account for variation of results between EE measures
Base Case Assumption	X	
Typical % Improvement in Energy Efficiency Over Current Pump System Efficiency Practice		X
Typical Installed Cost		X
Labor Adjustment Factor	X	
Expected Useful Life of Measure		X
Discount Rate	Same discount rate was used for all measures and countries. A change of discount rate, would change the CCE in all measures and countries.	
Electricity Price	X	
Average Hours of Operation by Horsepower for the Motor System	X	
Distribution of Industrial Motors by Part Load for the Motor System	X	
The motor System Energy Use (GWh/Yr) by Horsepower (Weighted Average for Total Industry)	X	

Table ES-2: Cost Effective Measures in the Efficiency Supply Curves by Motor System and Country (Cost-Effective Measures are Marked with an "X")

Table ES-2 provides a convenient summary of results from the analyses, but is not meant to be a substitute for more detailed study of the cost-effectiveness of individual measures under site-specific conditions. Measures listed below as not meeting the cost effectiveness threshold for the purposes of these analyses, often have highly favorable simple paybacks for site specific installations based on a detailed assessment of system optimization opportunities.

No.	Pump system efficiency measures	US	Canada	EU	Thailand	Vietnam	Brazil
1.1.1	Fix Leaks, damaged seals, and packing			X	X	X	X
1.1.2	Remove scale from components such as heat exchangers				X	X	
1.1.3	Remove sediment/scale buildup from piping				X	X	X
1.2.1	Use pressure switches to shut down unnecessary pumps	X		X	X	X	X
1.2.2	Isolate flow paths to non-essential or non-operating equipment	X	X	X	X	X	X
1.3.1	Trim or change impeller to match output to requirements	X	X	X	X	X	X
1.4.1	Install variable speed drive	X	X	X	X	X	X
1.5	Replace pump with more energy efficient type						X
1.6	Replace motor with more energy efficient type						X
1.7	Initiate predictive maintenance program						X

No.	Compressed air system efficiency measures*	US	Canada	EU	Thailand	Vietnam	Brazil
2.1.1	Fix Leaks, adjust compressor controls, establish ongoing plan	X	X	X	X	X	X
2.1.2	Replace existing condensate drains with zero loss type			X	X	X	X
2.1.3	Correct compressor intake problems/replace filter			X	X	X	X
2.2.1	Address restrictive end use drops and connections, faulty FRLs	X		X	X	X	X
2.2.2	Reconfigure branch header piping to reduce critical pressure loss				X	X	X
2.2.3	Correct excessive pressure drops in main line distribution piping				X		X
2.2.4	Correct excessive supply side pressure drop; i.e., treatment equipment				X		X
2.3.1	Eliminate inappropriate compressed air uses	X	X	X	X	X	X
2.3.2	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	X	X	X	X	X	X
2.3.3	Eliminate artificial demand with pressure optimization/control/storage	X		X	X	X	X
2.4.1	Install dedicated storage with metered recovery						X
2.5.1	Install sequencer	X	X	X	X	X	X
2.5.2	Improve trim compressor part load efficiency; i.e. variable speed drive						
2.6	Match air treatment to demand side needs						X
2.7	Size replacement compressor to meet demand						
2.8	Initiate predictive maintenance program	X	X	X	X	X	X

NOTE: Heat recovery excluded- see Section 3.2.2 for details

No.	Fan system efficiency measures	US	Canada	EU	Thailand	Vietnam	Brazil
3.1.1	Fix Leaks and damaged seals	X	X	X	X	X	X
3.1.2	Repair or replace inefficient belt drives	X	X	X	X	X	X
3.1.3	Remove sediment/scale buildup from fans and system surfaces	X	X	X	X	X	X
3.1.4	Correct damper problems	X	X	X	X	X	X
3.2.1	Isolate flow paths to nonessential or non-operating equipment	X	X	X	X	X	X
3.2.2	Correct poor airflow conditions at fan inlets and outlets	X	X	X	X	X	X
3.3.1	Replace oversized fans with more efficient type			X	X		X
3.4.1	Install variable speed drive	X		X	X	X	X
3.5	Replace motor with more energy efficient type				X		X
3.6	Initiate predictive maintenance program	X	X	X	X	X	X

A summary of the results of the cost-effective and technical energy savings for all motor systems and countries studied are presented in Table ES-3. Using the average CO_2 emission factor of the electricity grid in each country, the CO_2 emission reduction associated with the electricity saving potentials was also calculated.

The share of *total technical* electricity saving potential for pumping systems as compared to the total pumping system energy use in studied industries for the base year varies between 43% and 57%. The 57% value is for Vietnam, which has the LOW efficiency base case and a correspondingly higher technical saving potential. The share of total technical electricity saving potential for compressed air systems as compared to the total compressed air system energy use in studied industries for the base year varies between 29% and 56%. Thailand, Vietnam and Brazil have higher technical saving potentials since their compressed air systems are classified in LOW efficiency base case. The share of total technical electricity saving potential for fan systems as compared with the total fan system energy use in studied industries in the base year varies between 27% and 46%. Thailand, Vietnam and Brazil have higher technical saving potentials because their fan systems are classified as LOW efficiency base case.

The share of *cost-effective* electricity saving potential as compared to the total motor system energy use in the base case varies between 27% and 49% for the pumping system, 21% and 47% for the compressed air system, and 14% and 46% for the fan system. Overall, Thailand, Vietnam and Brazil have a higher percentage for cost-effective potential as compared to total motor systems energy use. There are two reasons for this. First, the three developing countries have the LOW efficiency base case, so the efficiency improvement over the base case is higher for each measure, resulting in a lower CCE. Second, the application of a labor

Table ES-3: Total Annual Electricity Saving and CO_2 Emission Reduction Potential in Industrial Pump, Compressed Air, and Fan Systems

	Total Annual Electricity Saving Potential in Industrial Pump, Compressed Air, and Fan System (GWh/yr)		Share of Saving from Electricity use in Pump, Compressed Air, and Fan Systems in Studied Industries in 2008		Total Annual CO_2 Emission Reduction Potential in Industrial Pump, Compressed Air, and Fan System (kton CO_2/yr)	
	Cost Effective	Technical	Cost Effective	Technical	Cost Effective	Technical
U.S	71,914	100,877	25%	35%	43,342	60,798
Canada	16,461	27,002	25%	40%	8,185	13,426
EU	58,030	76,644	29%	39%	25,301	33,417
Thailand	8,343	9,659	43%	49%	4,330	5,013
Vietnam	4,026	4,787	46%	54%	1,973	2,346
Brazil	13,836	14,675	42%	44%	2,017	2,140
Total (sum of 6 countries)	**172,609**	**233,644**	**28%**	**38%**	**85,147**	**117,139**

* In calculation of energy savings, equipment 1000 hp or greater are excluded

adjustment factor in the calculation of CCE for Thailand, Vietnam and Brazil reduced the CCE; thus allowing more measures to fall below the electricity price line.

A further study was conducted of the relative dependence on regular maintenance of energy savings from the measures studied and this result was compared to the cost-effectiveness of these measures (see Section 4.4 Maintenance and Persistence of Energy Savings). The dependence of many of the cost effective motor system energy efficiency measures on effective maintenance is one indicator of the potential benefits from implementing an Energy Management System (EnMS), and hints at the potential impact from implementation of the future International Organization for Standardization (ISO) 50001- Energy Management System. A principal goal of the ISO 50001 standard is to foster continual and sustained energy performance improvement through a disciplined approach to operations and maintenance practices.

Finally, it should be noted that some energy efficiency measures provide productivity, environmental, and other benefits in addition to energy savings, but it is difficult to quantify those benefits. Including quantified estimates of other benefits can decrease the cost of conserved energy and, thus, increase the number of cost-effective efficiency measures (Worrell, et al. 2003). This could be the subject of further research.

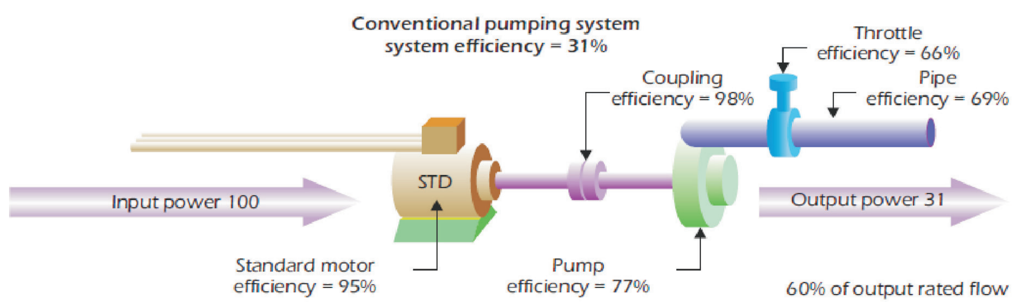
The approach used in this study and the model developed should be viewed as a screening tool to present energy-efficiency measures and capture the energy-saving potential in order to help policy makers understand the potential of savings and design appropriate energy-efficiency policies. However, the energy-saving potentials and the cost of energy-efficiency measures and technologies will vary in accordance with country- and plant-specific conditions. Finally, effective energy-efficiency policies and programs are needed to realize the cost effective potentials and to exceed those potentials in the future.

1 Introduction

Motor-driven equipment accounts for approximately 60% of manufacturing final electricity use and are ubiquitous in industrial facilities worldwide. Motor systems, such as compressed air, pumping, and fan systems, represent a largely untapped, cost-effective source for industrial energy efficiency savings that could be realized with existing technologies. Although motor systems have the potential to contribute substantial energy savings, on the order of 2.58 EJ in final energy use, this potential is largely unrealized (IEA 2007).

Motor systems are made up of a range of components centered on a motor-driven device such as a compressor, pump or fan. Figure 1 provides a schematic of a conventional pumping system with a system efficiency of 31%.

Figure 1: Conventional Pumping System Schematic (Almeida, et al., 2005.)



The motor systems included in this study are: compressed air, fan, and pumping systems. There are three primary barriers to improving motor system energy efficiency:

- lack of awareness of the energy savings opportunity,
- lack of support from management to undertake motor system energy efficiency projects, and
- limited understanding by consulting engineers and service providers on how to identify and implement system energy efficiency improvement opportunities in new and existing motor-driven systems.

The United Nations Development Organization (UNIDO) has undertaken a global initiative on industrial energy efficiency, focused on energy management and systems optimization, which is designed to address these barriers. With the support of the host countries and the Global Environmental Facility, a series of projects at the national and facility level are engaging a range of stakeholders in the industrial energy efficiency market toward that end: government, regulators, factory personnel, industry managers, service providers and equipment vendors. While these efforts are extremely important, more needs to be done to provide a framework for effective national and international decision-making on industrial energy efficiency policy as it relates to motor systems.

A major barrier to effective policymaking, and to more global acceptance of the energy efficiency potential of motor system, is the lack of a transparent methodology for quantifying this potential based on sufficient data to document the magnitude and cost-effectiveness of these energy savings by country and by region. It is far easier to quantify the incremental energy savings of substituting an energy efficient motor for a standard motor than it is to quantify energy savings of applying energy efficiency practices to an existing motor system. The former is dependent on the appropriate matching of the replacement motor, but reasonable assumptions can be made that an *incremental benefit against current practice* will occur. The latter is based on the concept of *changing current practice* by applying commercially available technologies in the most energy efficient manner, and requires onsite evaluation to maximize system efficiency. Based on documented results from hundreds of system optimization projects, the difference in savings potential between motor replacement and motor system optimization is on the order of 2% - 5% for motors versus 20% - 30% for motor systems. Providing a framework for quantifying motor system energy efficiency potential that moves beyond case studies of individual applications is needed.

2

Approach

This report and the supporting analyses is an initial effort to begin to meet the need for a framework for quantifying motor system energy efficiency potential by developing a transparent methodology for constructing a motor system efficiency supply curve.

The approach used is a combination of available data and expert opinion. The intent of this Phase I report is to:

- document the methodology used,
- apply it to six countries/regions including developed, emerging, and developing countries,
- invite comment from a community of technical and policy experts,
- refine these analyses based on comments received, and
- invite participation in a Phase II effort involving additional countries.

Although comprehensive data on motor system energy use does not exist for most countries, industrial energy use data by sector is available for a number of countries and energy efficiency professionals in those countries are often aware of current motor system practices. This report builds on previous efforts to quantify the energy saving potential of motor systems by the International Energy Agency (IEA), the U.S. Department of Energy BestPractices and Save Energy Now initiatives, the E.U. Motor Challenge and SAVE initiatives, Natural Resources Canada, Federal University of Rio de Janeiro in Brazil, Programa País de Eficiencia Energética-Chile, ISI Fraunhofer, and others. It is the goal of this report to create sufficient interest in the benefits of collecting and analyzing these data to develop broader international participation from policymakers and energy efficiency professionals for a Phase II Report.

Target Countries

For this Phase I analysis, six countries/region were selected that represent varying sizes and levels of industrial development, and for which industrial energy use by sector and some information about motor system efficiency practices were available. These initial six are the United States, Canada, the European Union, Thailand, Vietnam, and Brazil. In addition, Chile provided useful data on motor system practices, but will be included in Phase II rather than Phase I due to some uncertainty associated with the results of a recent national industrial energy use survey.

3

Methodology

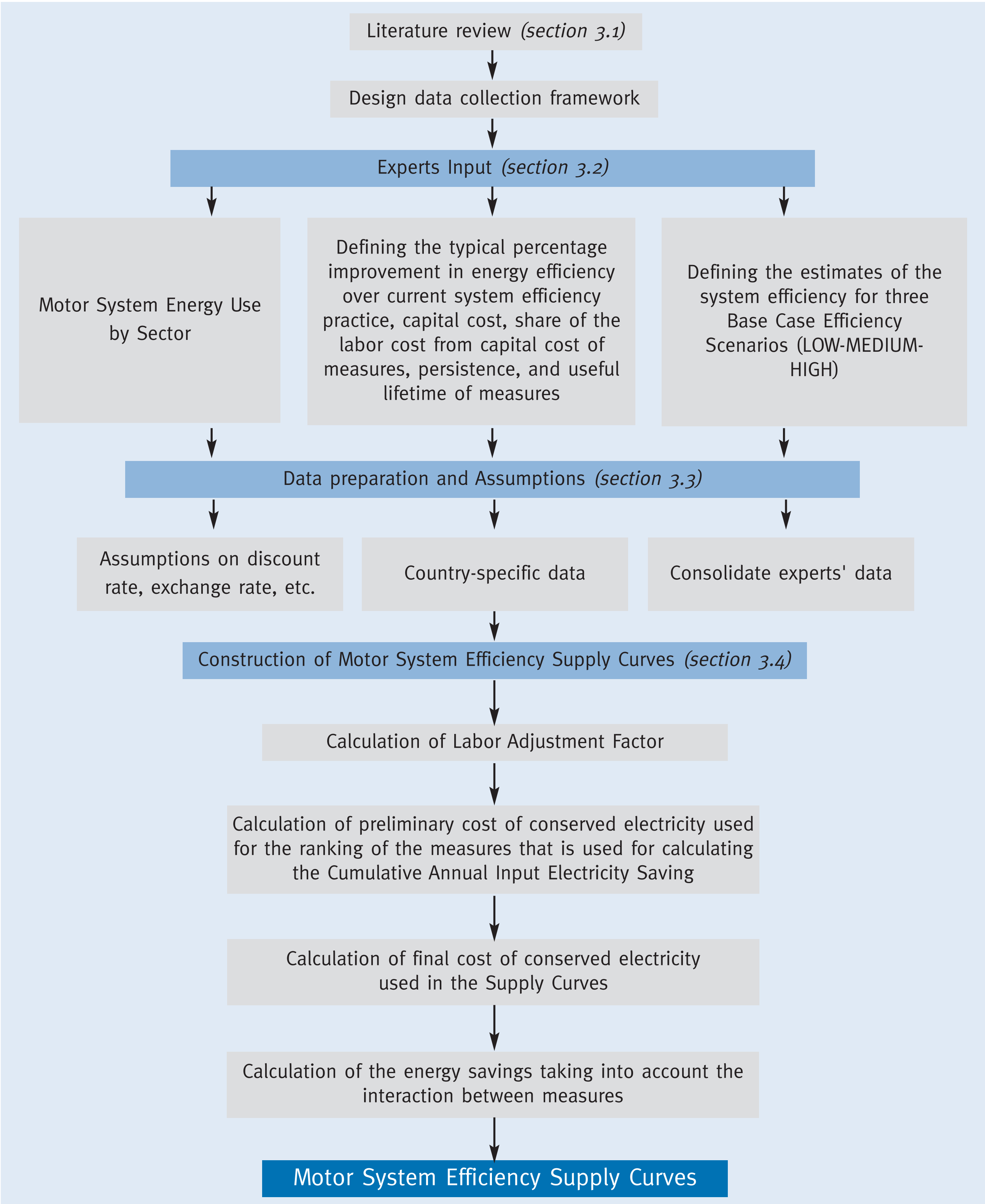
Figure 2 shows a schematic of the methodology used for this study. The first step was a literature review (see References) to develop a baseline of information. Next a data collection framework was developed to obtain expert input to supplement the existing data. Input was sought from a total of seventeen motor system experts known to the authors and responses were received from thirteen of them. At least four experts responded for each of the three systems analyzed (compressed air, fans, and pumping), with one expert providing input on two systems. Information was sought from these experts on: the % of system energy use as compared to total energy use by industrial sector; the 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. Several cycles of input, analyses, and review were performed to better define these inputs into the resulting Motor System Efficiency Supply Curve. Details concerning this expert input are provided in Section 3.2

Country-specific data was collected in parallel with the motor system expert consultation. After receiving expert input and completing collection of the country-specific data, the Motor System Efficiency Supply Curves were constructed based on the methodology explained below.

3 .1. Literature Review

The literature review included a comprehensive scan for relevant reports, publications, and papers on industrial energy use in the six countries targeted in Phase I. In addition, the authors drew from existing sources, including both published and unpublished documents, for information on motor system energy use and energy efficiency opportunities. These references are provided at the end of this report. Notable sources of information on motor systems included: US DOE (2002), US DOE (2004), IEA (2007), de Almeida et al. (2003), and Fraunhofer ISI (2009).

Figure 2: Schematic of the Methodology used for this Study



3.2. Experts Input

3.2.1. Defining Three Base Case System Efficiency Scenarios (LOW-MEDIUM-HIGH)

The approach used was to establish three base case efficiency scenarios (LOW-MEDIUM-HIGH) for each of three system types—pumping, compressed air, and fan systems based on previous research and the experts' opinion. There was a remarkable degree of agreement among the experts concerning the range of efficiency for each system type that could be expected from these base case scenarios. After defining the base cases, "base case" values were assigned to each country of study for the purpose of providing a reference point for the current (pumping, compressed air, or fan) system performance in that country, based on the information available for that country. While it is important to acknowledge that this approach blurs the real variations that may exist in system performance from one industrial sector to another within a country, it is consistent with the level of precision possible with the available data. It is hoped that this approach can be fine-tuned as part of a Phase II effort.

The first step in establishing a base case was to create a unique list of system energy efficiency practices representative of each of three efficiency scenarios for each system type. The initial lists for each system type were created by the authors and reviewed and revised by an expert in each system type before circulating the list for further expert review. Tables 1-3 provide the list of practices defined for each base-case efficiency level.

The experts were asked to review the list of proposed energy efficiency practices for each of the three efficiency scenarios (LOW-MEDIUM-HIGH) and to either approve or make recommendations to improve the groupings provided. The experts were then asked to provide a low to high estimated range of the system energy efficiency (expressed as a %) they would expect to see when auditing a system in an industrial market with the characteristics given for each efficiency scenario. A range of efficiency was requested, rather than a single value to better align with the variations that are likely to be found in industrial settings.

Table 1: Characteristics of LOW-MEDIUM-HIGH Efficiency Base Case Scenarios for Pumping Systems

No.	LOW Efficiency Base Case Scenario
1	Few pumping systems have ever 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 in excess of actual system needs is common
5	Variable speed drives are not commonly used
6	Motors of all sizes are routinely rewound multiple times instead of replaced
7	5% or less of the installed motors are high efficiency--either EPAct or EFF1 equivalent

No.	MEDIUM Efficiency Base Case Scenario
1	~15% of pumping 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 taken to efficiently match supply with demand
5	Variable speed drives are proposed as a solution for flow control
6	Motors ≥ 37 kW are typically rewound multiple times, while 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% pumping 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 2: Characteristics of LOW-MEDIUM-HIGH Efficiency Base Case Scenarios for Compressed Air Systems

No.	LOW Efficiency Base Case Scenario
1	Few compressed air systems have ever been assessed for system energy efficiency
2	Maintenance is limited to what is required to support operations
3	Compressors are independently controlled; energy use of partly loaded compressor(s) not known
4	System pressure profile, supply/demand balance, and storage, not optimized
5	Leaks are greater than 35%, and there are no plans to fix them
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	~15% of compressed air systems have been assessed for system energy efficiency
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 proposed as a solution for flow control
5	Leaks are ≥ 20%, but < 35% and are fixed periodically
6	There is widespread inappropriate use of compressed air
7	Motors ≥ 37 kW are typically rewound multiple times, while smaller motors may be replaced
No.	**HIGH Efficiency Base Case Scenario**
1	~30% compressed air systems have been assessed for system energy efficiency
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 < 20%; 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 3: Characteristics Defined of LOW-MEDIUM-HIGH Efficiency Base Case Scenarios for Fan Systems

No.	LOW Efficiency Base Case Scenario
1	Few fan systems have ever been assessed for system energy efficiency
2	Maintenance is limited to what is required to support operations
3	Flow is typically controlled by dampers or bypass
4	Low cost fans types, like radial, are often used even in clean air applications
5	Fans are often located on the dirty side of the process
6	Fans are oversized for the present load
7	Variable speed drives or variable inlet vanes are not commonly used
8	Motors of all sizes are routinely rewound multiple times instead of replaced
9	5% 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	Fans are located on the clean side of the process whenever possible
5	Airfoil or backward curved impellers are used in clean air handling applications
6	Fans are chosen to efficiently serve a given condition
7	Variable speed drives or variable inlet vanes are 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 energy efficiency
2	Both routine and predictive maintenance are commonly practiced
3	Flow is not controlled by dampers or bypass except in emergencies
4	Variable speed drives are one of several flow control strategies commonly applied to increase system efficiency
5	Fans are located on the clean side of the process whenever possible
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

3.2.2. Determining the Impact of Energy Efficiency Measures

For this purpose, a list of potential measures to improve system energy efficiency was developed for each system type and sent to the experts for review. For each group of measures, we asked experts to provide their opinion on energy savings likely to result from implementation of each measure, taken as an independent action, expressed as a % improvement over each of the LOW-MED-HIGH base cases,. The percentage efficiency improvement by the implementation of each measure over the LOW base case will be greater than that of the MEDIUM base case, which will in turn be greater than the value given for the HIGH base case. For instance, since the LOW base case is defined by limited maintenance, the % improvement from maintenance-related measures would be expected to be greater than that of the HIGH base case, for which both routine and predictive maintenance are common. The experts were also asked to critique the list of measures. Based on the responses received, some edits were made to the list of measures, requiring a second round of review to validate the % efficiency improvement values.

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 (US DOE, 2002). For the purpose of this study, the term "motor system size" refers to the aggregate motor HP or KW for that system. In addition to the energy efficiency improvement cost, the experts were also asked to provide the useful lifetime of the measures, disaggregated into two categories of operating hours (between 1000 hrs and 4500 hrs per year and more than 4500 hrs per year). Finally, the experts were asked to indicate the degree to which the energy saving achieved by each measure is dependent on the future maintenance practices (limited, moderately, or highly dependent).

The experts provided a % improvement for each measure over the base case scenarios using a 0-100% scale. Thus, for instance, if 30% of the compressed air is lost to leaks and the leak rate is reduced to 10%, then that is a 20% improvement over the base case. So experts would enter 20% in the space provided for measure 2.1.1 for compressed air system (fix leaks, adjust compressor controls, establish ongoing plan).

In some instances, the initial list of measures included several measures that would be unlikely to be implemented together—it is more likely that one would be selected. For example, it is likely that matching pumping system supply to demand would include one of the measures below, rather than all three.

- *1.4.1 Trim or Change Impeller to Match Output to Requirements*
- *1.4.2 Install Pony Pump*
- *1.4.3 Install New Properly Sized Pump*

For this reason, in situations for which there appear to be groupings of several proposed solutions to address a specific problem, during the second round of review, the experts were asked:

- Are these measures "either, or" rather than "and" solutions?
- If the measures are "either, or" (in other words they are alternative measures and cannot be implemented at the same time), as a very general statement, we asked experts which one is the most typical or common?

For compressed air systems, heat recovery can be extremely beneficial to improving the energy efficiency of the system because this measure has the potential to address the energy lost through heat of compression (typically 80% of input energy). Despite this potential, its applicability is dependent on a suitable use for the resulting low grade heat. Because compressed air system heat recovery would need to be added to the base case rather than applied as a % improvement and consensus could not be reached concerning its potential across countries and climates, the measure was not included in the final analyses. It should be noted, however, that with appropriate application, *compressed air system heat recovery has the potential to increase overall system efficiency more than any other compressed air measure listed.*

Information was also sought concerning the dependence of energy savings resulting from implementation of each measure on maintenance practices. As an example, persistence of savings from fixing compressed air leaks is Highly Dependent, whereas replacing a motor with a more efficient type would be categorized as Limited Dependent. The purpose of including these data was to assess the relative importance of an energy management system in sustaining the energy efficiency resulting from these measures. A detailed discussion of the results is included in Section 4.4 of this report.

In addition to dependence on maintenance practices, energy savings and the cost-effectiveness of individual system optimization measures can be significantly affected by human behavior. The experts involved in this report have all witnessed the impact on system efficiency of practices such as bypassed controls or "adjustments" made to return to a previous (and more familiar) mode of operation after an energy efficiency improvement is made. In some instances, potentially cost-effective approaches such as preventative maintenance programs can become an end in themselves, as the original purpose of the program is lost in the paperwork process. The importance of proper training and work instructions to support new operating procedures as well as the need to share the goals for these procedures with personnel responsible for their successful implementation cannot be overstated. This is a key feature of an effective energy management system.

For typical capital cost, rough estimates were sought for each measure in US $ for six categories of motor size ranges. Experts were further given the opportunity to indicate that a measure was no-cost/low-cost (Table 4-6). For systems larger than 1000 hp (745kW), the system is usually custom-designed and the cost is highly variable. This was further compounded by having no upper bound for this size category. The cost data given by experts for this size of systems varied so much that it was imposing additional uncertainty on the final results. For these reasons, we decided to exclude systems larger than 1000 hp (745kW) from the final analysis. A more extensive dialogue with experts on the cost of larger systems might permit their inclusion in future analyses.

The systems larger than 1000 hp account for 3%–8% of the total electricity use by pumping system, 8%–28% of the total electricity use by fan system, and 15%–44% of the total electricity use by compressed air system (all sizes) in industry in the studied countries. The share of energy use by systems larger than 1000 hp compared to the total energy use (all sizes) by each motor system type (pumping, fan, compressed air) in industry in the countries/region studied is shown the table below. As can be seen, exclusion of pumping systems larger than 1000 hp will not affect the total energy use of the systems covered in our analysis. However, for compressed air and, to a lesser extent, fans, systems larger than 1000hp account for a significant share of their total energy use in industry. *The exclusion of these systems from the analysis resulted in a proportional decrease in the total system energy use in the analysis, and a corresponding decrease in the energy savings resulting from the energy efficiency measures analyzed.* This limitation should be considered when reviewing the results of the analysis presented in this report.

This report uses the estimated full cost of the measures analyzed rather than the incremental cost for energy efficient measures. This was driven by the goal of the analysis, to assess the total potential for energy efficiency in industrial motor systems in the base year assuming 100% penetration rate. Therefore, *the energy savings is based on the assumption that all the measures are installed in the base year.* In this case, the full cost of the measures should be applied since the existing systems are not all at the end of their lifetime. However, for other type of studies, such as a supply curve used to develop future scenarios, the use of incremental cost makes a better sense, since new stock can be installed at the end of the lifetime of the existing ones.

Table 4: The Share of Energy Use by System Larger than 1000 hp (745 kW) Compared to the Total Energy Use by Motor System Type

Country/Region	Pumping Energy	Fan Energy	Compressed Air Energy
US	8%	19%	44%
Canada	4%	28%	22%
EU	5%	15%	19%
Thailand	3%	8%	11%
Vietnam	3%	9%	10%
Brazil	4%	21%	24%

Using the % energy efficiency improvement and the typical costs provided, an extensive cross-check was conducted of simple paybacks for the list of measures intended as input into the cost curves. This analysis was very useful in identifying sensitivities in the data leading to further consultation with the experts.

Tables 7-9 in Section 3.3 include the results of analysis of the expert input for energy efficiency improvement and cost by measure and by system. A discussion of other factors affecting cost, including equipment and labor cost variations by country can also be found in Section 3.3.

3.2.3. Motor System Energy Use by Sector

US DOE (2002), US DOE (2004), and de Almeida (2003) all presented different values for the percentage of electricity use by the motor system type (pumping, fan, compressed air) in a selection of 15 industrial sectors, expressed in relationship to the total electricity use in each sector. Since the values given in these three studies can vary significantly, the experts were also asked to give their best estimate of the typical percentage of electricity used by the system type (pumping, compressed air, or fan) as compared to the electricity use for 15 industrial sectors.

To assist the experts in this effort, and to give them an idea of the range of data currently available, a table was provided for motor system total electricity use (not disaggregated by the system type) as the % of total electricity use in each industrial sector as reported in three sources: US DOE (2002), US DOE (2004), and de Almeida (2003). We requested that experts estimate:

a) the system electricity use as % of overall electricity use in the sector

   OR

b) System electricity use as % of motor system electricity use in the sector

The results from the experts were compared with the three studies and a final estimate was developed for each industrial sector. (See the Appendices for additional information).

3.3. Data Preparation and Assumptions

As mentioned before, the experts were asked to assign system efficiency, expressed as a range, for LOW-MED-HIGH efficiency base cases. Table 5 is the consolidated results, including the baseline values used in calculating the cost curves. *There was a high degree of agreement among experts for each system type regarding the range of system energy efficiency that would be expected to result from the list of characteristics assigned to the three base cases.* As can be seen, for the compressed air and fan system, we used the average values (average of low and high values) for the LOW-MED-HIGH efficiency baseline. However, for the pump system, we used the low end of the values because application of the energy efficiency measures to the low end values provided a outcome more consistent with experts opinion for each of the baselines than using the average values. This helped to compensate for lack of interactivity between measures in the analysis, which seemed to be a particular issue for the pumping system measures. It was assumed that a 10 year period would typically be required to move a market from LOW to MEDIUM or MEDIUM to HIGH.

Table 5: Consolidated System Efficiency for LOW-MED-HIGH Efficiency Baselines

	System Efficiency			
Motor System Type	Low End (%)	High End (%)	Average (%)	Used in our Analysis
Pumping Systems				
Low level of efficiency	20.0%	40.0%	30.0%	20.0%
Medium level of efficiency	40.0%	60.0%	50.0%	40.0%
High level of efficiency	60.0%	75.0%	67.5%	60.0%
Compressed Air Systems				
Low level of efficiency	2.0%	5.0%	3.5%	3.5%
Medium level of efficiency	4.8%	8.0%	6.4%	6.4%
High level of efficiency	8.0%	13.0%	10.5%	10.5%
Fan Systems				
Low level of efficiency	15.0%	30.0%	22.5%	22.5%
Medium level of efficiency	30.0%	50.0%	40.0%	40.0%
High level of efficiency	50.0%	65.0%	57.5%	57.5%

After defining the baseline efficiencies for each motor system, we assigned a "base case" to each country of study for the purpose of providing a reference point for the current (pumping, compressed air, or fan) system performance in that country based on the information available for that country. Expert judgment was used for this purpose. Table 6 shows the base case efficiencies assigned to each country for each motor system type.

Table 6: Base Case Efficiencies Assigned to Each Country for Each Motor System Type

	Pumping	Fan	Compressed air
US	MED	MED	MED
Canada	MED	MED	MED
EU	MED	MED	MED
Brazil	MED	LOW	LOW
Thailand	MED	LOW	LOW
Vietnam	LOW	LOW	LOW

Table 7 to Table 9 depict the typical % improvement in efficiency over each baseline efficiency (LOW-MED-HIGH) as well as an estimated typical capital cost of the measure, differentiated by system size. The actual installed cost of some system measures can be highly variable and dependent on site conditions, such as the number and type of end uses. The need to add or modify physical space to accommodate new equipment can also be a factor. Finally, in developing countries, the cost of imported equipment, especially energy efficient equipment, can be higher due to scarcity, shipping, and/or import fees.

The base year for all countries/region except the EU was 2008. For the EU, year 2007 was used as the base year. This was because we could obtain the 2008 energy use data for the industrial sectors for all countries, but for the EU the most recent data we could collect was 2007 energy use for the EU industrial sectors.

Country-specific data was collected from various sources. Electricity use for industrial sub-sectors in each country was available. Also collected were the: average unit price of electricity for industry in each country, emission factor for grid electricity in the base year of the study in each country, weighted average net generation efficiency of fossil fuel-fired power plants in the country[2], and average transmission and distribution losses of the electricity grid in the country in the base year. The latter two were used to calculate the conversion factor to convert electricity from final to primary energy.

US DOE (2002) data as well as expert input data were used to determine

1) the motor systems electricity use as a % of total electricity use in each industrial sector and
2) each system (pump, compressed air, and fan) electricity use as % of overall motor system electricity use in the sector. The data received was consolidated and used in the analysis for all countries. For all countries except Canada, the industrial classification was different from the one used in US DOE (2002). In these cases, the data was mapped over the sectors in US DOE (2002) in a way that best represented the industry sectors given for these countries. The consolidated data for the electricity use in each manufacturing sector included in the study is given in the Appendices.

[2] It should be noted that in some countries the share of non-fossil fuel power generation is significant. For instance, in Brazil electricity generation mix is 87% hydropower, 3% nuclear, and 10% fossil fuel. In this study, however, the net generation efficiency of fossil fuel-fired power plants is used for converting electricity consumption from final to primary energy in all countries.

Table 7: Expert Input: Energy Efficiency Measures, % Efficiency Improvement and Cost for Pumping Systems

No.	Energy Efficiency Measure	Typical % Improvement in Energy Efficiency Over Current Pumping System Efficiency Practice			Expected Useful Life of Measure (Years)	Typical Capital Cost (US$)				
		% Improvement over LOW eff. base case	% Improvement over MED eff. base case	% Improvement over HIGH eff. base case		≤ 50 hp	>50 hp ≤ 100 hp	> 100 hp ≤ 200 hp	>200 hp ≤ 500 hp	>500 hp ≤ 1000 hp
1.1	**Upgrade System Maintenance**									
1.1.1	Fix Leaks, damaged seals, and packing	3.5%	2.5%	1.0%	5	$1,000	$1,500	$2,000	$2,500	$3,000
1.1.3	Remove scale from components such as heat exchangers and strainers	10.0%	5.0%	2.0%	4	$6,000	$6,000	$9,000	$12,000	$15,000
1.1.3	Remove sediment/scale buildup from piping	12.0%	7.0%	3.0%	4	$3,500	$3,500	$7,000	$10,500	$14,000
1.2	**Eliminate Unnecessary Uses**									
1.2.1	Use pressure switches to shut down unnecessary pumps	10.0%	5.0%	2.0%	10	$3,000	$3,000	$3,000	$3,000	*
1.2.2	Isolate flow paths to no-nessential or non-operating equipment	20.0%	10.0%	5.0%	15	$0	$0	$0	$0	$0
1.3	**Matching Pump System Supply to Demand**									
1.3.1	Trim or change impeller to match output to requirements	20.0%	15.0%	10.0%	8	$5,000	$10,000	$15,000	$20,000	$25,000
1.4	**Meet variable flow rate requirement w/o throttling or bypass****									
1.4.1	Install variable speed drive	25.0%	15.0%	10.0%	10	$4,000	$9,000	$18,000	$30,000	$65,000
1.5	**Replace pump with more energy efficient type**	25.0%	15.0%	5.0%	20	$15,000	$30,000	$40,000	$65,000	$115,500
1.6	**Replace motor with more energy efficient type**	5.0%	3.0%	1.0%	15	$2,200	$4,500	$8,000	$21,000	$37,500
1.7	**Initiate predictive maintenance program**	12.0%	9.0%	3.0%	5	$8000	$8,000	$10,000	$10,000	$12,000

* This measure is not typical for large pumps, but it is a good practice for all pumps in parallel applications.

** For pumping systems dominated by static head, multiple pumps may be a more appropriate way to efficiently vary flow

Table 8: Expert Input: Energy Efficiency Measures, % Efficiency Improvement and Cost for Compressed Air Systems

No	Energy Efficiency Measure	Typical % improvement in energy efficiency over current Compressed Air system efficiency practice			Expected Useful Life of Measure (Years)	Typical Capital Cost (US$)				
		% Improvement over LOW eff. base case	% Improvement over MED eff. base case	% Improvement over HIGH eff. base case		≤ 50 hp ≤ 37 kW	>50 hp ≤ 100 hp > 37kW ≤ 75kW	>100 hp ≤ 200 hp > 75kW ≤ 150kW	>200 hp ≤ 500 hp > 150kW ≤ 375kW	> 500 hp ≤ 1000 hp > 375kW ≤ 745kW
2.1	**Upgrade System Maintenance**									
2.1.1	Fix Leaks, adjust compressor controls, establish ongoing plan	20.0%	15.0%	10.0%	8	1250	3000	5000	5000	5000
2.1.2	Replace existing condensate drains with zero loss type	5.0%	3.0%	1.0%	10	1750	2000	2000	4000	4000
2.1.3	Correct compressor intake problems/replace filter	2.0%	1.0%	0.0%	5	150	400	1000	2000	3000
2.2	**Improve system pressure profile/reduce supply side target pressure**									
2.2.1	Address restrictive end use drops and connections, faulty FRLs	5.0%	4.0%	2.0%	5	1000	1250	1750	2750	3500
2.2.2	Reconfigure branch header piping to reduce critical pressure loss	4.0%	3.0%	1.0%	15	2000	3000	6000	10000	15000
2.2.3	Correct excessive pressure drops in main line distribution piping	5.0%	3.0%	0.5%	15	2000	3000	6000	10000	12000
2.2.4	Correct excessive supply side pressure drop; i.e., treatment equipment	5.0%	3.0%	1.0%	10	1500	3000	5000	12000	18000
2.3	**Reduce compressed air waste**									
2.3.1	Eliminate inappropriate compressed air uses	20.0%	13.0%	3.0%	5	2000	4000	7000	12000	15000
2.3.2	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	12.0%	8.0%	3.0%	4	1000	1500	2000	7000	10000
2.3.3	Eliminate artificial demand with pressure optimization/control/storage *	10.0%	7.0%	3.0%	10	2500	4000	6000	10000	15000
2.4	**Isolate high pressure and intermittent high volume uses****									
2.4.1	Install dedicated storage with metered recovery	5.0%	3.0%	2.0%	15	2000	4000	5500	8500	14000

No	Energy Efficiency Measure	Typical % improvement in energy efficiency over current Compressed air system efficiency practice			Expected Useful Life of Measure (Years)	Typical Capital Cost (US$)				
		% Improvement over LOW eff. base case	% Improvement over MED eff. base case	% Improvement over HIGH eff. base case		≤ 50 hp ≤ 37 kW	>50 hp ≤ 100 hp > 37kW ≤ 75kW	>100 hp ≤ 200 hp > 75kW ≤ 150kW	>200 hp ≤ 500 hp > 150kW ≤ 375kW	> 500 hp ≤ 1000 hp > 375kW ≤ 745kW
2.5	**Balance supply with demand and improve control strategy**									
2.5.1	Install sequencer	15.0%	8.0%	2.0%	10	0	5000	7500	15000	20000
2.5.2	Improve trim compressor part load efficiency; i.e. variable speed drive	20.0%	15.0%	5.0%	15	12000	20000	40000	70000	100000
2.6	**Match air treatment to demand side needs**	8.0%	6.0%	2.0%	10	3500	7500	10000	20000	25000
2.7	**Size replacement compressor to meet demand**	18.0%	13.0%	9.0%	15	12000	25000	40000	70000	120000
2.8	**Initiate predictive maintenance program**	10.0%	5.0%	1.0%	5	500	1000	2000	5000	10000

* Eliminating artificial demand can be addressed to some extent with manual, low cost approaches; more expensive automated approaches may yield higher savings depending on the variability of system demand and other factors

** There are several ways to efficiently address a high volume intermittent uses, including booster compressors and dedicated compressors, and metered storage

Note 1: Compressed Air System Heat Recovery is the only measure with the potential to address the energy lost through heat of compression (typically 80% of input energy), and thus can greatly increase energy efficiency. It was not included in these analyses because

- *its applicability is dependent on a use for the low grade heat and*
- *it must be treated differently by adding it the base case rather than applied as a % improvement*

Note 2: Compressed air system problems are highly varied, therefore solutions are also varied—not all captured here

Table 9: Expert Input: Energy Efficiency Measures, % Efficiency Improvement and Cost for Fan Systems

No	Energy Efficiency Measure	Typical % improvement in energy efficiency over current Fan system efficiency practice			Expected Useful Life of Measure (Years)	Typical Capital Cost (US$)				
		% Improvement over LOW eff. base case	% Improvement over MED eff. base case	% Improvement over HIGH eff. base case		≤ 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
3.1	**Upgrade System Maintenance***									
3.1.1	Fix Leaks and damaged seals	5.0%	3.0%	2.0%	5	175	325	600	1375	2650
3.1.2	Repair or replace inefficient belt drives	4.5%	2.5%	0.5%	2	200	750	1000	N/A	N/A
3.1.2	Remove sediment/scale buildup from fans and system surfaces	2.5%	1.5%	0.5%	2	100	110	135	580	1090
3.1.3	Correct damper problems	5.0%	3.0%	1.0%	4	200	250	300	400	450
3.2	**Correct System Flow Problems**									
3.2.1	Isolate flow paths to nonessential or non-operating equipment	12.0%	8.0%	2.0%	15	1150	2250	2625	3550	4700
3.2.2	Correct poor airflow conditions at fan inlets and outlets	10.0%	5.0%	1.0%	20	1000	2000	3000	5000	10000
3.3	**Correct Fan Size/Type/Position to Increase Efficiency****									
3.3.1	Replace oversized fans with more efficient type	18.0%	11.0%	2.0%	20	8000	15000	25000	50000	100000
3.4	**Efficiently meet variable flow requirement (w/o dampers or bypass)*****									
3.4.1	Install variable speed drive	35.0%	20.0%	8.0%	10	8000	15000	30000	80000	150000
3.5	**Replace motor with more energy efficient type**	5.0%	3.0%	1.0%	15	2200	4500	8000	21000	35000
3.6	**Initiate predictive maintenance program**	3.0%	2.0%	1.0%	5	260	260	1000	2000	5000

* Vibration analysis and addressing bearing maintenance are important for system operation, but are more of a reliability issue

** Relocating a fan to the clean side of a process can increase energy efficiency, but is more of a design issue for new systems and is rarely possible in existing systems

*** Use controls to shut down or slow down unnecessary fans.

3.4. Construction of Motor System Efficiency Supply Curves

3.4.1. Introduction to the Conservation Supply Curve

The Conservation Supply Curve (CSC) is an analytical tool that captures both the engineering and the economic perspectives of energy conservation. The curve shows the energy conservation potential as a function of the marginal Cost of Conserved Energy. The Cost of Conserved Energy can be calculated from Equation 1.

Cost of Conserved Energy (CCE) = (Annualized capital cost + Annual change in O&M costs) /Annual energy savings (Eq. 1)

The annualized capital cost can be calculated from Equation 2.

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

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

After calculating the CCE for all energy efficiency measures, the measures are ranked in ascending order of CCE. In CSCs 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 for 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 cost of conserved energy.

The CSC gives us some very useful information. It presents the cost of conserved energy (CCE), annualized cost of energy efficiency measures, annualized energy cost saving, annualized net cost saving, and annualized energy saving by each individual technology or a group of technologies. The calculation of CCE is explained above. If dE is the energy saving by a technology/measure, then the annualized cost of the energy efficiency measure, annualized energy cost saving, and the annualized net cost saving of that technology can be calculated from:

AC = dE*CCE (Eq. 3)

AECS= dE*P (Eq. 4)

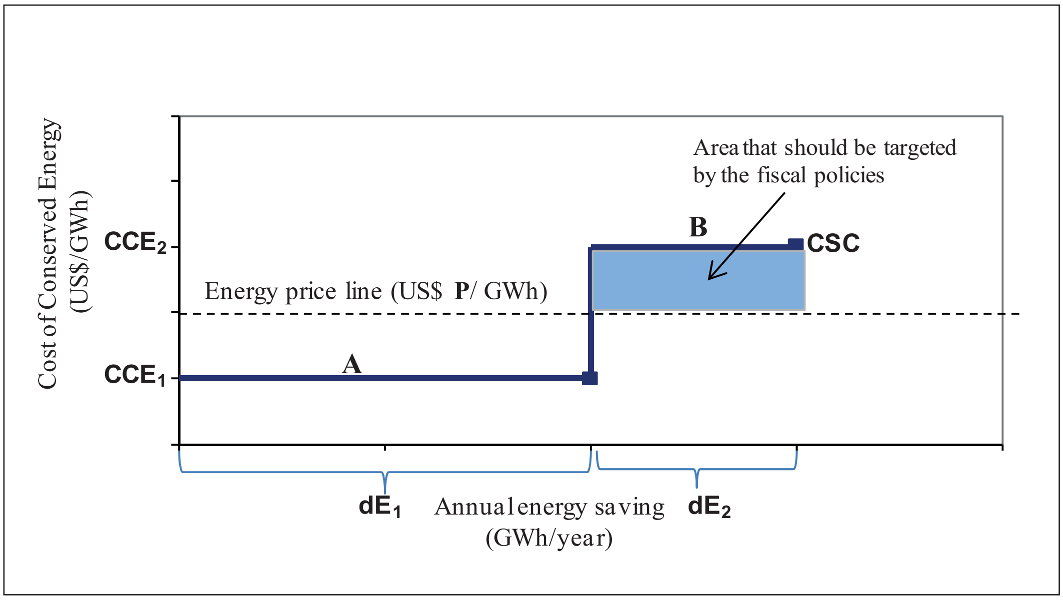
ANC = AC - AECS = dE*(P-CCE) (Eq. 5)

Where:

AC: Annualized Cost of Energy Efficiency Measure (US$), AECS: Annualized Energy Cost Saving (US$), ANC: Annualized Net Cost Saving (US$), P: Energy Price, and dE: Energy Saving in CSC.

For the cost-effective energy-efficiency measures in the CSC, the annual net cost saving is positive, but for the measures whose CCE is above the energy cost line, the annualized net cost saving is negative. That is, for cost-effective measures, net annual revenue results from implementing those measures from the energy cost saving, whereas for non-cost effective measures the annualized cost of implementing the measures is higher than the annualized cost saving. Thus, the annual net cost saving for non-cost effective measures is negative. However, it should be emphasized that even in the case of non-cost effective measures, the significant cost saving occurs from energy saving which is equal to dE*P as mentioned above. *Therefore, from an energy policy point of view, any fiscal policy for non-cost effective energy*

Figure 3: Schematic View of a Conservation Supply Curve (CSC)



efficiency measures should target the annualized net cost saving of the measure which is the area between the CSC and the energy price line. Figure 3 shows a schematic of a CSC that helps the visualization of the above discussion. For measure A which is cost effective, the annual net cost saving is positive, whereas for measure B which is non-cost effective the annual net cost saving is negative. For measure B, the area between energy price line and CSC should be targeted by the fiscal policies.

3.4.2 Discount Rate

In this study, a real discount rate of 10% was assumed for the analysis. However, since it is one of the key variables used in the cost of conserved energy calculation, Section 4.5 presents a sensitivity analysis of the final results with varying discount rates. It should be noted that the choice of the discount rate also depends on the purpose of the analysis 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 equally to our own, but they also may cause relatively certain, near-term effects to be ignored in favor of more uncertain, long-term effects (NEPO/DANCED 1998).

A descriptive approach (also called private-sector or industry perspective), however, uses relatively high discount rates between 10% and 30% in order to reflect the existence of barriers to energy efficiency investments (Worrell et al. 2004). These barriers include perceived risk, lack of information, management concerns about production and other issues, capital constraints, opportunity cost, and preference for short payback periods and high internal rates of return (Bernstein, et al. 2007 and Worrell, et al.

2000). Hence, the 10% discount rate used for these analyses is at the higher end of discount rates used from social perspective and lower end of the discount rates used from private-sector or industry perspective. The sensitivity analysis of the results with respect to the discount rate will show how the movement towards each of these two perspectives will influence the results. In addition, since the energy efficiency measures for the motor systems are cross-cutting technologies/measures, the selection of a discount rate is further influenced by the assumption of fewer barriers to the implementation of these measures compared to process-specific capital intensive technologies in each industrial sector (i.e. installation of an efficient grinding mill or kiln system in the cement industry). Thus, the lower discount rate used for these cross-cutting measures is consistent with a private-sector or industry perspective.

Other industrial sector analyses use varying real discount rates. Carlos (2006) used the range of 10% to 16% discount rate in the financial analysis for cogeneration projects in Thailand. Garcia et al. (2007) used three discount rates of 12%, 15%, and 22% in three different investment scenarios for high efficiency motors in Brazil. McKinsey & Company used a 7% social discount rate for developing Conservation Supply Curves and GHG abatement cost curve for the US (McKinsey&Company, 2007 and 2009a and a 4% social discount rate for developing a GHG abatement cost curve for China (McKinsey & Company, 2009b). ICF developed an abatement cost curve for the cement industry in Brazil and Mexico in 2015 using a 10% discount rate (ICF International, 2009a, b). In the Asia Least-cost Greenhouse Gas Abatement Strategy (ALGAS) project, 10% real discount rate is assumed for the calculation of GHG emissions abatement scenarios for various economic sectors including industry in Thailand (ADB/GEF 1998).

3.4.3. Calculation of the Annual Energy Savings

The calculation and data analysis methodology used was the same for all three motor system types included in these analyses (i.e. pumping, fan, and compressed air systems). The example provided here for pumping systems is also illustrative of the methodology used for the other two systems.

For the calculation of energy saving achieved by the implementation of each efficiency measure for the pumping system, the following inputs were available:

- The efficiency base case scenarios for pumping systems (HIGH, MEDIUM, LOW), as developed from expert input. As previously described, each country was then assigned a base case efficiency for pumping systems, based on the authors' judgment and expert consultation;
- For each pumping system measure, the experts provided a typical % improvement in energy efficiency over each base case efficiency scenario;
- Electricity use in the manufacturing sectors of each country;
- The percentages of the pump system electricity use as compared to the total electricity use in each manufacturing sectors studied. Using these

percentages and the electricity use of each sector, the total electricity use by the pump system in each sector was calculated. The total value of all the electricity use for the sectors studied in the given country could then be calculated and used to calculate the potential electricity savings.

- From the above information, the annual electricity saving from the implementation of each individual efficiency measure for the pumping system in the industry *where measures are treated Individually and can be implemented regardless of the implementation of other measures* can be calculated following the steps given below:

  1. Annual Input energy for the pumping system (MWh/yr) = Pump system energy use in industry in the base year
  2. Annual Useful energy used in the pumping system with base case efficiency = Annual Input energy for the pump (MWh/yr) * Base Case Efficiency of the pumping System
  3. New system efficiency after the implementation of the efficiency measure = Base case efficiency of the pumping system* (1+ % system efficiency improvement by the implementation of the measure)
  4. Annual Useful energy used in the pumping system with NEW efficiency = Annual Input energy for the pumping system (MWh/yr)* New system efficiency
  5. Annual Useful energy saving = Annual Useful energy used in the pumping system with NEW efficiency - Annual Useful energy used in the pumping system with base case efficiency
  6. Annual Input energy saving = Annual Useful energy saving / New system efficiency after the implementation of the efficiency measure

In the procedure explained above, Input energy use is the energy that is supplied to the system as input. This is equal to the typical energy use data given for the industry/system in the statistics. The Useful energy use, however, is the energy that is converted to the actual service through the system. The Useful energy is the energy that does the work intended to be done by the system at the end use. Hence, the Useful energy use is calculated by taking into account the system efficiency and multiplying that by Input energy use. Since the system efficiency is always lower than 100%, the Useful energy use is always less than the Input energy use.

In practice, the implementation of one measure can influence the efficiency gain by the next measure implemented. When one measure is implemented the base case efficiency is improved. Therefore, the efficiency improvement by the second measure will be less than if the second measure was implemented first or was considered alone. If the annual electricity saving is calculated from the implementation of each individual efficiency measure for the pumping system in the industry *when measures are treated individually and can be implemented regardless of the implementation of other measures,* the total saving achieved by the implementation of all measures will be very high and for some countries even higher than annual electricity use in the industry. Since this is not feasible, it was clear that the measures could not be treated as isolated actions and the resulting energy saving as a sum of these actions.

To overcome this problem, the methodology was refined. The measures were treated in relation with each other (as a group). In other words, the efficiency improvement by the implementation of one measure depends on the efficiency improvement achieved by the previous measures implemented. The refined method used is as follow:

1. Annual Input Energy for the Pump System (MWh/yr) = Pumping System Energy Use in Industry in the Base Year
2. Annual Useful Energy Used in the Pumping System with Base Case Efficiency = Annual Input Energy for the Pump (MWh/yr)* Base Case Efficiency of the Pumping System
3. *Cumulative* New System Efficiency after the Implementation of the Efficiency Measure = Base Case Efficiency of the Pumping System* **(1+ Sum of the % Efficiency Improvement by the Implementation of the Measure and all the Previous Measures Implemented)**
4. *Cumulative* Annual Useful energy used in the pumping system with NEW efficiency = Annual Input energy for the pumping system (MWh/yr) * New system efficiency
5. *Cumulative* Annual Useful energy saving = Annual Useful energy used in the pumping system with NEW efficiency - Annual Useful energy used in the pumping system with base case efficiency
6. *Cumulative* Annual Input energy saving = Annual Useful energy saving / New system efficiency after the implementation of the efficiency measure

In this method, the *Cumulative* Electricity Saving is calculated by taking into account the additive effect of the measures, rather than treating the measures completely in isolation from each other. For instance, when calculating the Cumulative Annual Electricity Saving achieved by the implementation of measure #3 and all the previous measures (measures #1 and #2), the *Sum of the % Efficiency Improvement by the Implementation of Measure Number 1, 2, and 3* is used in the above calculation.

The calculation of the cumulative saving rather than individual savings is also desirable since the cumulative electricity saving will be used in the construction of the Motor System Efficiency Supply Curves. However, *the ranking of the measures significantly influence the energy saving achieved by each measure.* In other words, given a fixed % improvement of efficiency for each individual measure, the higher the rank of the measure, the larger the energy saving contribution of that measure to the cumulative savings. To define the ranking of the efficiency measures before calculating the cumulative energy saving from the method described above, the preliminary Cost of Conserved Electricity (CCE) was calculated (see below for the explanation on CCE calculation) for each measure assuming that the measures are independent of each other (i.e. treating them in isolation without taking into account any additive effect). Then, these measures were ranked based on their Preliminary CCE. This ranking was used to calculate the Final Cumulative annual energy saving as well as the Final CCE.

3.4.4. Calculation of the Cost of Conserved Electricity

Since the capital cost data received from the experts was for the implementation of only one unit of each measure/technology, the Cost of Conserved Electricity (CCE) was calculated assuming the implementation of only one unit of each measure under each efficiency base case, taken separately. Since each efficiency base case has a different value, calculations were performed separately for each base case (LOW, MED, HIGH). Later, the CCE was calculated under the base case scenario assigned to each country (see Table 6) and the system was used in developing the corresponding efficiency supply curve. The CCE is calculated as follows:

for the analysis, as previously discussed. The lifetime of the measures were provided by the experts for each efficiency measure.

- Because only one type of cost (capital cost) was available for each measure, the capital cost was used for the calculation of the CCE without regard for any change in operations and maintenance (O&M) cost (given in

Size range (hp)	≤ 50 hp	› 51 hp ≤ 100 hp	› 101 hp ≤ 200 hp	› 201 hp ≤ 500 hp	› 501 hp ≤ 1000 hp
Size range (kW)	≤ 37 kW	› 38kW ≤ 75kW	› 76kW ≤ 150kW	› 151kW ≤ 375kW	› 376kW ≤ 746kW
Size used in the analysis (hp)	50	75	150	350	750

- Capital cost data was provided in bins based on a range of motor sizes, expressed in horsepower (hp). The average hp value of each range was used as a representative size in the analyses, except for the first and last category for which the boundary values are assumed. The size ranges are shown in the table below.
- The Annualized capital cost of implementing one unit of each measure could then be calculated using the following equations:

  Annualized Capital Cost = Capital Cost*CRF (Eq. 6)

  and

  Capital Recovery Factor (CRF) = $(d/ (1-(1+d)^{-n})$ (Eq. 7)

  d: discount rate,

  n: lifetime of the energy efficiency measure.

- The discount rate of 10% was assumed

Eq. 1). Some of the measures themselves are improvement in maintenance practices. Therefore, the cost of conserved energy can be calculated from the following formula:

Cost of Conserved Energy=

$$\frac{\text{Annualized capital cost}}{\text{Annual Input Energy Savings}} \quad \text{(Eq. 8)}$$

- For calculating the energy saving achieved by the implementation of one unit of each measure, it was necessary to combine the information from above concerning the cost of implementing one unit of each measure with some assumptions for the load and operation hours for the motor systems for each representative size for which the CCE is calculated.
- For the hours of operation, the values for each motor system type and power range from USDOE's motor market assessment report were used (US DOE, 2002).

Table 10: Distribution of Industrial Motors by Part Load (Experts Estimate)

Part Load (Estimated % of full load)	Pump	Compressed Air	Fan
25%	10	20	10
50%	25	35	20
75%	50	25	50
100%	15	20	20
Total	100%	100	100%
Weighted Average	68%	61%	70%

- For the load factor, the experts were asked to provide the **Distribution of Industrial Motors by Part Load** (part loads: 25%, 50%, 75%, 100%) for each motor system type. The following table shows the consolidate results of the experts input for this data.
- The annual energy saving for *one unit* of each measure under each base case scenario was calculated (separately) using the following approach:

  1. Annual Input Energy for One Unit of System (MWh/yr) = (hp*hours Used per year* load* 0.746)/Motor Efficiency
  2. Annual Useful Energy Used in One Unit of System with Base Case Efficiency = Annual Input Energy for One Unit of System (MWh/yr)* Base Case Efficiency of the Pumping System
  3. New System Efficiency After the Implementation of the Efficiency Measure = Base Case Efficiency of the Pumping System* (1+ % System Efficiency Improvement by the Implementation of the Measure)
  4. Annual Useful Energy Used in One Unit of System with NEW Efficiency = Annual Input Energy for One Unit of System (MWh/yr)* New System Efficiency
  5. Annual Useful Energy Saving for One Unit of System = Annual Useful Energy Used in one Unit of System with NEW Efficiency - Annual Useful Energy Used in One Unit of System with Base Case Efficiency
  6. Annual Input Energy Saving for One Unit of System = Annual Useful Energy Saving for One Unit of System/New System Efficiency After the Implementation of the Efficiency Measure

- Having the annual cost and annual electricity saving calculated above for one unit of the system, the cost of conserved electricity (CCE) could be calculated for each representative motor size (5 CCE for 5 sizes).
- Only one CCE value can be displayed on the Supply Curves. Therefore, the CCEs calculated for different motor sizes needed to be consolidated. To consolidate the CCEs of all power ranges for each measure, the Motor System Energy Use (GWh/Yr) by Horsepower (for each type of system, i.e. pumping, fan, compressed air) was used to calculate the weighted average CCE. One CCE resulted for each

efficiency measure under each base case scenario. Motor System Energy Use (GWh/Yr) by Horsepower was calculated for each country based on the data was provided in US DOE (2002) for the U.S. It is hoped that the availability of additional data would permit greater refinement of these assumptions for future analyses.

The CCE calculated above is the *Preliminary CCE* since in the calculation of this CCE the additive effect is not taken into account. This Preliminary CCE was used for the ranking of the measures before the final calculation of the Cumulative Energy Saving could be done in which the additive effect of the measures is taken into account (see section 2.4.3).

Once the measures are ranked based on the Preliminary CCE, we can calculate the Final CCE from the followings:

1. Annual Input Energy for One Unit of System (MWh/yr) = (hp*hours used per year* load* 0.746)/Motor Efficiency

We assumed the average motor efficiency of 93% across all sizes.

2. *Cumulative* New System Efficiency after the Implementation of the Efficiency Measure = Base Case Efficiency of the Pumping System* **(1+ Sum of the % Efficiency Improvement by the Implementation of the Measure and all the Previous Measures Implemented)**

However, unlike the energy saving that is shown as cumulative saving on the Supply Curve (x-axis), the CCE for each individual measure is shown separately on the supply curve. In other words, the y-axis on the supply curve shows the CCE for the individual measure. Therefore, the *Cumulative* Input Energy saving for one unit of system cannot be used in the calculation of Final CCE. For the calculation of Final CCE, it is necessary to determine the *Individual* Input Energy saving for one unit of system for each measure. This is done, for example for measure number (i) from the following equations:

3. *Cumulative* Annual Useful Energy used in one Unit of System with *Cumulative* New Efficiency after the Implementation of the Efficiency Measure (i) = Annual Input Energy for One Unit of System (MWh/yr)* *Cumulative* New System Efficiency after the Implementation of the Efficiency Measure (i)
4. *Cumulative* Annual Useful Energy Used in One Unit of System with *Cumulative* New Efficiency After the Implementation of the Efficiency Measure (i-1) = Annual Input Energy for One Unit of System (MWh/yr) * *Cumulative* New System Efficiency After the Implementation of the Efficiency Measure (i-1)
5. *Individual* Annual Useful Energy Saving for One unit of System for Measure (i) = *Cumulative* Annual Useful energy Used in One Unit of System with *Cumulative* New Efficiency after the Implementation of the Efficiency Measure (i) - *Cumulative* Annual Useful Energy Used in One Unit of System with *Cumulative* New Efficiency After the Implementation of the Efficiency Measure (i-1)
6. *Individual* Annual Input Energy Saving for One unit of System Measure (i) = *Individual* Annual Useful Energy Saving for One Unit of System/*Cumulative* Annual Useful Energy Used in One Unit of System with *Cumulative* New Efficiency After the Implementation of the Efficiency Measure (i)
7. Final Cost of Conserved Electricity of Measure (i) = Annualized Capital Cost of

Measure (i)/ *Individual* Annual Input Energy Saving for One Unit of System for Measure (i)

The *Final CCE* is used for the construction of Motor Systems Efficiency Supply Curve along with the *Cumulative* Annual Input Energy Saving explained in section 2.4.3. **It should be noted that on the Supply Curves presented in the next section, the CCE is the Final CCE for each individual measure.**

It should also be noted that the purpose of these analyses is to identify the cost effectiveness and to estimate the total electricity savings potential for the industrial motor systems studied. This study does not address scenario analysis based on the assumption of different penetration rates of the measures in the future, but rather seeks to identify the magnitude of the total saving potential and the associated cost. The scenario analysis and study on the penetration of the efficiency measures could be a topic for future research.

Labor Adjustment Factor for the Cost of Measures

Typical capital costs of installing the selected measures were acquired from several experts for each motor system type. These costs include both materials and labor. However, most of these experts are in the U.S., Canada, and European countries and based their cost estimates on the typical costs for those locations. Since most of the energy efficiency measures considered in this study are system improvement measures, a significant portion of the cost is the labor for implementing the measures. There is a large gap between the labor cost in the developed and developing countries studied in this report. To address this disparity in labor costs, a Labor Adjustment Factor (LAF) was created for the three developing countries/emerging economies, i.e. Thailand, Vietnam, and Brazil. This LAF was calculated for each energy efficiency measure.

The first step was to ask the system experts about the share of labor cost as a fraction of the total cost in the U.S. for each energy efficiency measure analyzed for the three systems. Experts provided a range (low end and high end) for this share and the median value of the range was used for the calculation of LAF (See Table 11-13). We assumed a skilled industrial labor cost in the developed countries (U.S., EU. And Canada) equal to US$20.00/hr (US DOL, 2009), in Thailand and Vietnam equal to US$1.20/hr (Barrow, 2005; Runckel, 2005) and in Brazil equal to US$5.00/hr (US DOL, 2009). Because of the limited data available, the materials/equipment costs were not adjusted and were assumed to be equivalent across all countries studied. As previously stated, materials/equipment costs can vary widely from country to country based on import taxes, tax credits, and availability. These variations in cost would benefit from further study.

The following is the procedure for the calculation of LAF:

- Labor cost of the measure in the developed country = Total capital cost in developed countries* share of the labor cost from the total capital cost
- Capital cost of the measure excluding labor cost (Materials/equipment cost)=

Total capital cost - Labor cost of the measure in the developed country

- Number of hours required for labor = Labor cost of the measure in the developed country / hourly rate of labor in the developed country (i.e. US$20/hr)
- Labor cost of the measure in the developing countries = Number of hours required for labor * hourly rate of labor in the developing country
- Total capital cost in developing countries = Materials/equipment cost of the measure + Labor cost of the measure in the developing country
- Labor Adjustment Factor (LAF) = Total capital cost in developing countries / Total capital cost in developed countries

The calculated LAFs for Thailand, Vietnam and Brazil are shown in Table 11-13 for the three motor systems. The LAF was multiplied by the calculated CCE (both preliminary and final). This resulted in lower CCEs for the measures in the three developing countries compared to that of developed countries. The results after applying the LAF appear to more closely approximate to real world conditions.

Table 11: The Share of Labor Cost from the Total Cost and Labor Adjustment Factors for Energy Efficiency Measures in Pumping Systems

No.	Energy Efficiency Measure	Average Labor Cost as % of Total Costs	Labor Adjustment Factor for Thailand and Vietnam	Labor Adjustment Factor for Brazil
1.1.1	Fix Leaks, damaged seals, and packing	70%	0.34	0.48
1.1.2	Remove scale from components such as heat exchangers and strainers	85%	0.20	0.36
1.1.3	Remove sediment/scale buildup from piping	85%	0.20	0.36
1.2.1	Use pressure switches to shut down unnecessary pumps	50%	0.53	0.63
1.2.2	Isolate flow paths to non-essential or non-operating equipment	N/A	N/A	N/A
1.3.1	Trim or change impeller to match output to requirements	50%	0.53	0.63
1.4.1	Install variable speed drive	50%	0.53	0.63
1.5	Replace pump with more energy efficient type	30%	0.72	0.78
1.6	Replace motor with more energy efficient type	20%	0.81	0.85
1.7	Initiate predictive maintenance program	70%	0.34	0.48

Table 12: The Share of Labor Cost from the Total Cost and Labor Adjustment Factors for Energy Efficiency Measures in Compressed Air Systems

No.	Energy Efficiency Measure	Average Labor Cost as % of Total Costs	Labor Adjustment Factor for Thailand and Vietnam	Labor Adjustment Factor for Brazil
2.1.1	Fix leaks, adjust compressor controls, establish ongoing plan	70%	0.34	0.48
2.1.2	Replace existing condensate drains with zero loss type	45%	0.58	0.66
2.1.3	Correct compressor intake problems/replace filter	50%	0.53	0.63
2.2.1	Address restrictive end use drops and connections, faulty FRLs	70%	0.34	0.48
2.2.2	Reconfigure branch header piping to reduce critical pressure loss	60%	0.44	0.55
2.2.3	Correct excessive pressure drops in main line distribution piping	40%	0.62	0.70
2.2.4	Correct excessive supply side pressure drop; i.e., treatment equipment	50%	0.53	0.63
2.3.1	Eliminate inappropriate compressed air uses	40%	0.62	0.70
2.3.2	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	60%	0.44	0.55
2.3.3	Eliminate artificial demand with pressure optimization/control/storage	30%	0.72	0.78
2.4.1	Install dedicated storage with metered recovery	30%	0.72	0.78
2.5.1	Install sequencer	40%	0.62	0.70
2.5.2	Improve trim compressor part load efficiency; i.e. variable speed drive	35%	0.67	0.74
2.6	Match air treatment to demand side needs	30%	0.72	0.78
2.7	Size replacement compressor to meet demand	35%	0.67	0.74
2.8	Initiate predictive maintenance program	N/A	N/A	N/A

Table 13: The Share of Labor Cost from the Total Cost and Labor Adjustment Factors for Energy Efficiency Measures in Fan Systems

No.	Energy Efficiency Measure	Average Labor Cost as % of Total Costs	Labor Adjustment Factor for Thailand and Vietnam	Labor Adjustment Factor for Brazil
3.1.1	Fix Leaks and damaged seals	60%	0.44	0.55
3.1.2	Repair or replace inefficient belt drives	80%	0.25	0.40
3.1.3	Remove sediment/scale buildup from fans and system surfaces	70%	0.34	0.48
3.1.4	Correct damper problems	55%	0.48	0.59
3.2.1	Isolate flow paths to non-essential or non-operating equipment	70%	0.34	0.48
3.2.2	Correct poor airflow conditions at fan inlets and outlets	50%	0.53	0.63
3.3.1	Replace oversized fans with more efficient type	20%	0.81	0.85
3.4.1	Install variable speed drive	25%	0.77	0.81
3.5	Replace motor with more energy efficient type	25%	0.77	0.81
3.6	Initiate predictive maintenance program	70%	0.34	0.48

4

Results and Discussion

Based on the methodology explained in Chapter 3, an Efficiency Supply Curves were constructed for the pumping, fan and compressed air systems for the industrial sector in six studied countries, to separately capture the cost-effective and total technical potential for electricity efficiency improvement in these industrial motor systems. Furthermore, the CO_2 emission reduction potential associated with the electricity savings was calculated. It should be noted that these potentials are the total existing potentials for the energy efficiency improvement in the studied motor systems in the base year. In other words, the potential presented here is for the 100% penetration rate. The authors are aware that 100% penetration rate is not likely and, in any event, values approaching a high penetration rate would only be possible over a period of time. Although conducting the scenario analysis by assuming different penetration rates for the energy efficiency measures was beyond the scope of this study, it could be the subject of a follow up study.

4.1. Pumping System Efficiency Supply Curves

Figure 4 to Figure 9 show the Pumping System Efficiency Supply Curves for the six countries/region studied. The name of the measures related to each number on the supply curve is given in the following table each figure along with the cumulative annual electricity saving potential, final CCE of each measure, cumulative annual primary energy saving potential, and cumulative CO_2 emission reduction potential (Tables 14-25). **In the tables, the energy efficiency measures that are shaded in lighter color are cost-effective (i.e. their CCE is less than the unit price of electricity) and the efficiency measures that are shaded in darker color are not cost effective.** As can be seen from the pumping system efficiency supply curves, in the developed countries (U.S., Canada, and EU) out of 10 energy efficiency measures only 3 to 5 measures are cost effective, i.e. their cost of conserved energy is less than the average unit price of electricity in those countries.

On the other hand, in the developing countries, more energy efficiency measures fall below the electricity price line (7 to 9 measures). This is mainly because of the application of labor adjustment factor to the cost of the measures for the developing countries which will reduce the CCE significantly.

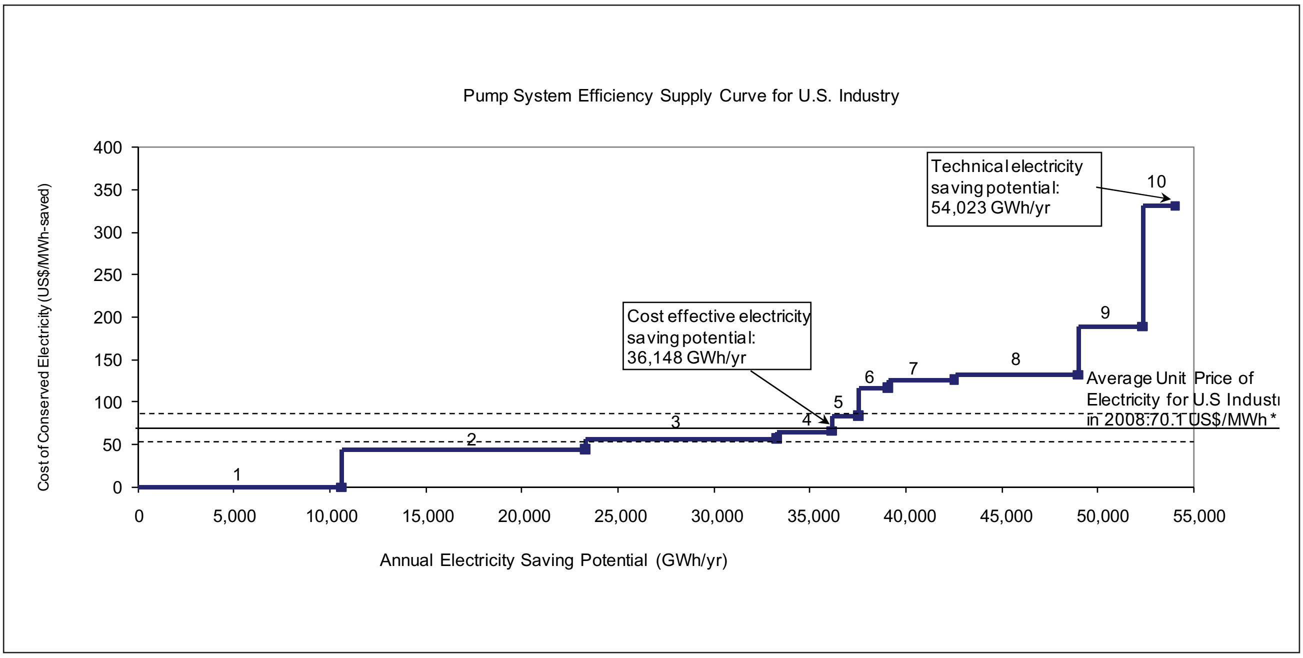
"Isolate flow paths to non-essential or non-operating equipment" is the most cost-effective measure for the pumping system across all studied countries followed by "Install variable speed drive" in U.S. EU, Canada, and Brazil, while the second most cost-effective measure in Thailand and Vietnam is "Remove sediment/scale buildup from piping". On the other hand, "Remove scale from components such as heat exchangers" is ranked last in all countries and has the highest CCE except in Thailand and Vietnam in which "Replace pump with more energy efficient type" has the highest CCE. While both measures have substantial energy savings potential, they are relatively more expensive to implement. Again, the differences in their position in the CCE ranking can be attributed to the application of the labor adjustment factor, with labor comprising a higher proportion of the cost for removing sediment from piping than for a pump replacement.

Furthermore, tables show that in all countries studied except Vietnam, the total technical energy saving potential is around 45% of the total pumping system energy use in the base year for the industries analyzed. The reason for this similarity is that all countries except Vietnam fall into the MEDIUM base case efficiency (see Table 6). Because Vietnam falls into LOW base case efficiency (see Table 6), the share of total technical energy efficiency potential compared to the total pumping system energy use is higher than that of the other five countries/region, at approximately 57%.

For cost-effective potential, however, the story is different. The three developed countries have the cost-effective potential of 27% - 29% of the total pumping system energy use in the base year for the industries analyzed. Although Thailand and Brazil have a MEDIUM base case efficiency (similar to the developed countries), their cost-effective potential is higher - equal to 36% and 43%, respectively - due to the application of a labor adjustment factor in the calculation of CCE. As a result, the CCE is lower, thus allowing more measures to fall below the electricity price line. For Vietnam, the cost-effective potential is much higher than other countries (49%) due to the combination of a LOW efficiency baseline and the application of labor adjustment factor.

The relative cost-effectiveness of the pumping system energy efficiency measures across all countries are generally consistent with what could be expected based on field experience. There are some interesting findings. For example, replacing either the pump or the motor with a more energy efficient type, a commonly implemented measure, is frequently not cost-effective. There are two notable findings that are not consistent with what one might expect based on field experience. First, the relative cost effectiveness of a preventive maintenance program is much lower for pumping systems than for compressed air or fan systems, which may warrant further investigation. Second, removing scale from heat exchangers is often cost-effective for cooling loops, a common pumping application, as it can reduce the tendency to pump excess fluid in an attempt to overcome the inability of a compromised heat exchanger to maintain design temperature, thus reducing pump operating time. The relatively low cost effectiveness result for this measure is an indicator of the limitations of these analyses, which are by necessity based on a generalization of the benefits of each energy efficiency measure across a wide variety of system type and operating conditions. While this lack of granularity may be suitable to support policymaking needs, it is no substitute for individualized assessments of motor system opportunities.

Figure 4: US Pumping System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

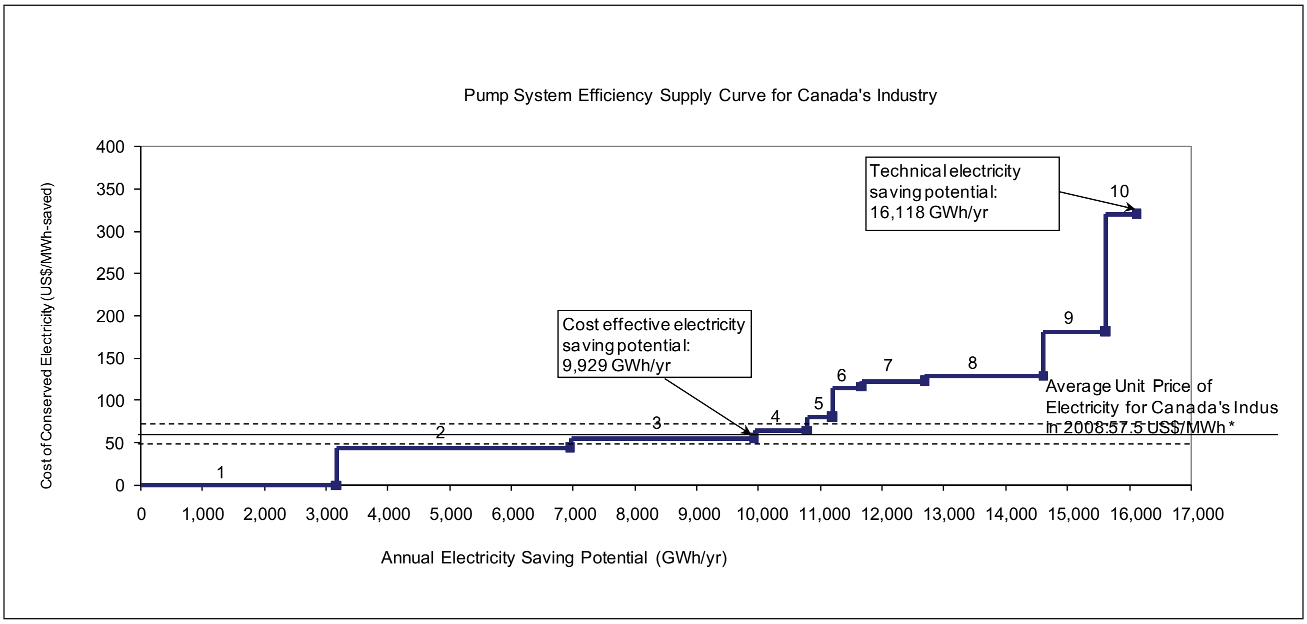
Table 14: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Pumping System Efficiency Measures in the US Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
1	Isolate flow paths to non-essential or non-operating equipment	10,589	0.0	116,265	6,382
2	Install variable speed drive	23,295	44.5	255,784	14,040
3	Trim or change impeller to match output to requirements	33,279	57.0	365,405	20,057
4	Use pressure switches to shut down unnecessary pumps	36,148	65.7	396,905	21,786
5	Fix leaks, damaged seals, and packing	37,510	84.1	411,855	22,607
6	Replace motor with more energy efficient type	39,084	116.9	429,138	23,555
7	Remove sediment/scale buildup from piping	42,523	126.3	466,906	25,628
8	Replace pump with more energy efficient type	48,954	132.2	537,516	29,504
9	Initiate predictive maintenance program	52,302	189.0	574,280	31,522
10	Remove scale from components such as heat exchangers and strainers	54,023	330.9	593,171	32,559

Table 15: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for US Industrial Pumping Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in US industry (GWh/yr)	36,148	54,023
Share of saving from the total pumping system energy use in studied industries in US in 2008	29%	43%
Share of saving from total electricity use in studied industries in US in 2008	4%	6%
Annual primary energy saving potential for pumping system in US industry (TJ/yr)	396,905	593,171
Annual CO_2 emission reduction potential from US industry (kton CO_2 /yr)	21,786	32,559

Figure 5: Canada's Pumping System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

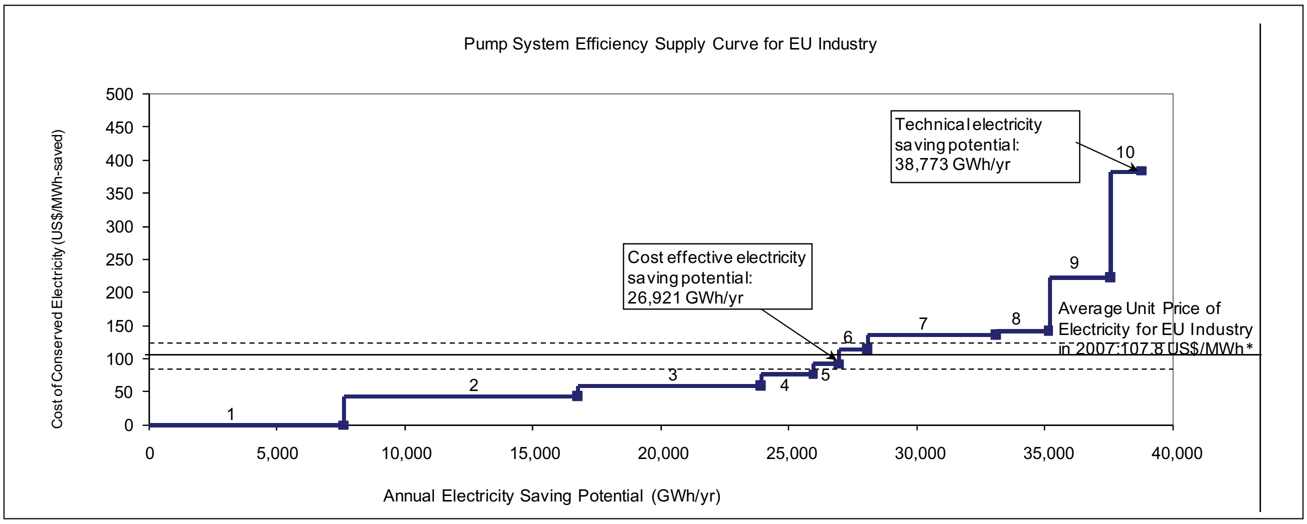
Table 16: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for the Pumping System Efficiency Measures in Canada Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
1	Isolate flow paths to nonessential or non-operating equipment	3,159	0.0	39,357	1,571
2	Install variable speed drive	6,950	44.2	86,586	3,456
3	Trim or change impeller to match output to requirements	9,929	55.5	123,694	4,937
4	Use pressure switches to shut down unnecessary pumps	10,785	64.5	134,357	5,363
5	Fix leaks, damaged seals, and packing	11,191	81.4	139,418	5,565
6	Replace motor with more energy efficient type	11,661	116.2	145,269	5,798
7	Remove sediment/scale buildup from piping	12,687	123.2	158,054	6,308
8	Replace pump with more energy efficient type	14,606	129.1	181,956	7,262
9	Initiate predictive maintenance program	15,605	182.0	194,401	7,759
10	Remove scale from components such as heat exchangers and strainers	16,118	320.3	200,796	8,014

Table 17: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for the Canada's Industrial Pumping System

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in Canadian industry (GWh/yr)	9,929	16,118
Share of saving from the total pumping system energy use in studied industries in Canada in 2008	27%	45%
Share of saving from total electricity use in studied industries in Canada in 2008	6%	9%
Annual primary energy saving potential for pumping system in Canadian Industry (TJ/yr)	123,694	200,796
Annual CO_2 emission reduction potential from Canadian industry (kton CO_2 /yr)	4,937	8,014

Figure 6: EU's Pumping System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the regional level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

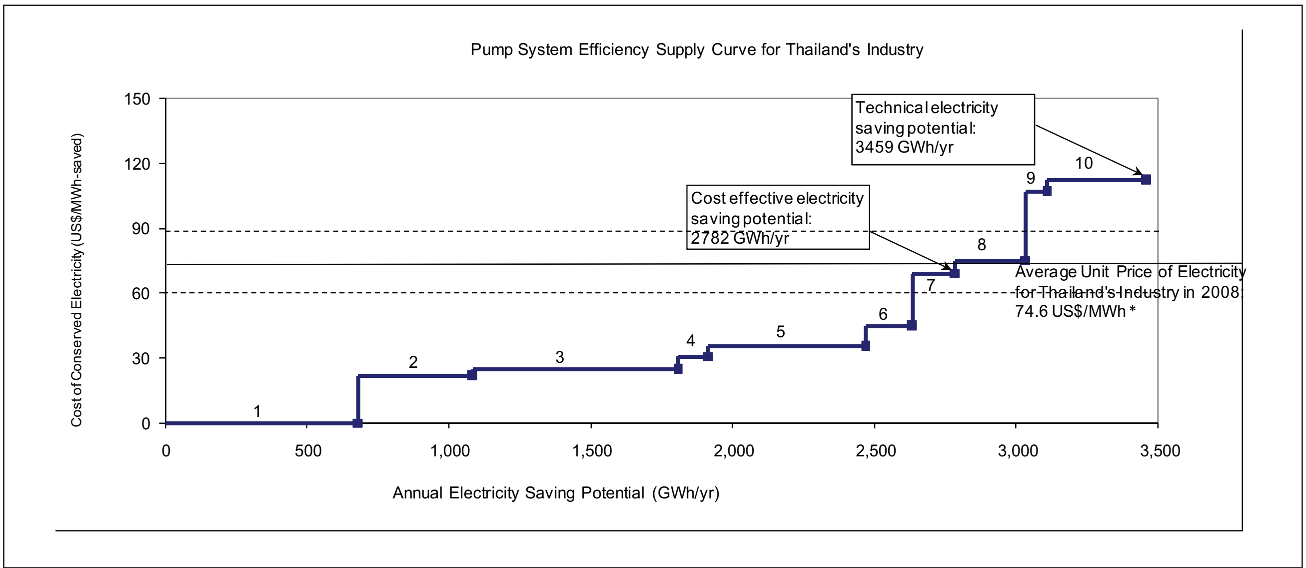
Table 18: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Pumping System Efficiency Measures in EU Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Isolate flow paths to non-essential or non-operating equipment	7,600	0.0	71,406	3,313
2	Install variable speed drive	16,719	43.7	157,094	7,290
3	Trim or change impeller to match output to requirements	23,885	59.3	224,420	10,414
4	Use pressure switches to shut down unnecessary pumps	25,944	76.6	243,767	11,312
5	Fix leaks, damaged seals, and packing	26,921	92.6	252,948	11,738
6	Replace motor with more energy efficient type	28,051	115.0	263,563	12,230
7	Replace pump with more energy efficient type	33,085	137.1	310,866	14,425
8	Remove sediment/scale buildup from piping	35,135	142.8	330,125	15,319
9	Initiate predictive maintenance program	37,538	223.1	352,704	16,367
10	Remove scale from components such as heat exchangers and strainers	38,773	383.7	364,306	16,905

Table 19: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for the EU's Industrial Pumping Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in EU's Industry (GWh/yr)	26,921	38,773
Share of saving from the total pumping system energy use in studied industries in EU in 2008	30%	44%
Share of saving from total electricity use in studied industries in EU in 2008	5%	7%
Annual primary energy saving potential for pumping system in EU's Industry (TJ/yr)	252,948	364,306
Annual CO_2 emission reduction potential from EU's Industry (kton CO_2 /yr)	11,738	16,905

Figure 7: Thailand's Pumping System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

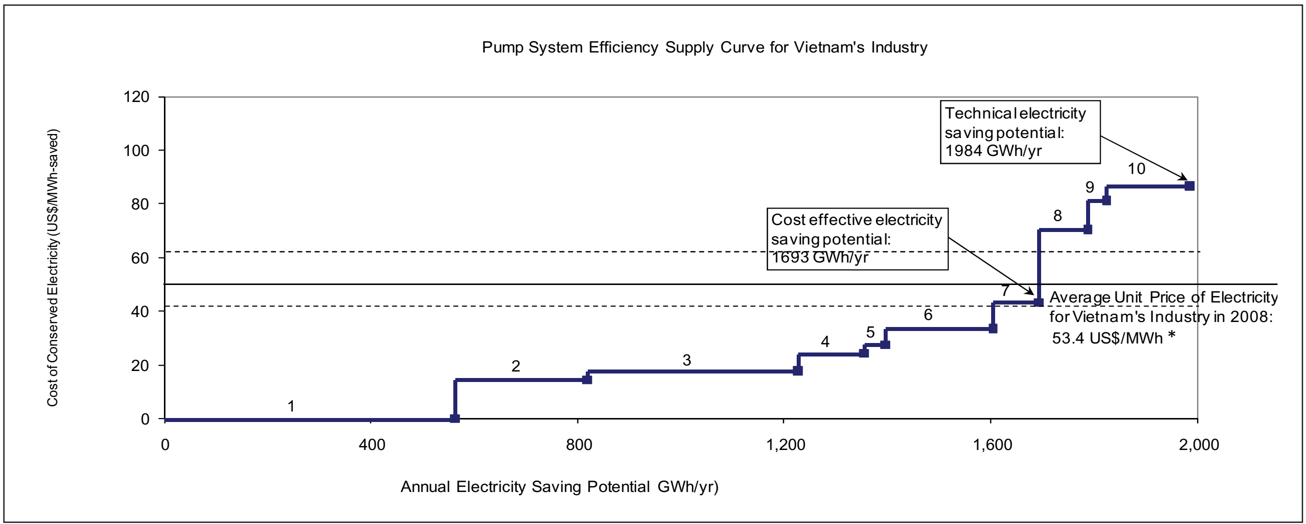
Table 20: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Pumping System Efficiency Measures in Thailand Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Isolate flow paths to nonessential or non-operating equipment	678	0.0	6,823	352
2	Remove sediment/scale buildup from piping	1,084	22.0	10,905	562
3	Install variable speed drive	1,808	24.9	18,194	938
4	Fix Leaks, damaged seals, and packing	1,913	30.6	19,251	993
5	Trim or change impeller to match output to requirements	2,469	35.5	24,849	1,282
6	Use pressure switches to shut down unnecessary pumps	2,631	45.1	26,474	1,365
7	Remove scale from components such as heat exchangers and strainers	2,782	69.1	27,997	1,444
8	Initiate predictive maintenance program	3,032	75.0	30,510	1,574
9	Replace motor with more energy efficient type	3,109	107.3	31,289	1,614
10	Replace pump with more energy efficient type	3,459	112.4	34,809	1,795

Table 21: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Education Potential for Thailand's Industrial Pumping Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in Thai Industry (GWh/yr)	2,782	3,459
Share of saving from the total pumping system energy use in studied industries in Thailand in 2008	36%	45%
Share of saving from total electricity use in studied industries in Thailand in 2008	5%	6%
Annual primary energy saving potential for pumping system in Thai Industry (TJ/yr)	27,997	34,809
Annual CO_2 emission reduction potential from Thai Industry (kton CO_2 /yr)	1,444	1,795

Figure 8: Vietnam's Pumping System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

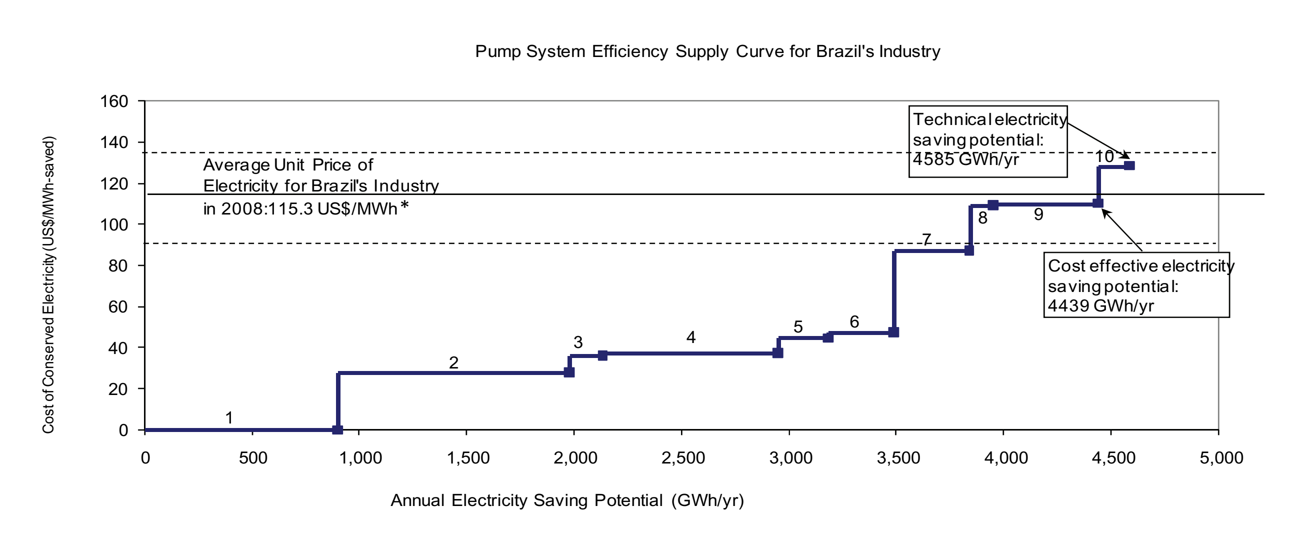
Table 22: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Pumping System Efficiency Measures in Vietnam Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Isolate flow paths to non-essential or non-operating equipment	563	0.0	8,040	276
2	Remove sediment/scale buildup from piping	819	14.5	11,694	401
3	Install variable speed drive	1,226	17.7	17,514	601
4	Use pressure switches to shut down unnecessary pumps	1,355	24.3	19,354	664
5	Fix leaks, damaged seals, and packing	1,396	27.5	19,947	684
6	Trim or change impeller to match output to requirements	1,604	33.6	22,917	786
7	Remove scale from components such as heat exchangers and strainers	1,693	43.3	24,180	829
8	Initiate predictive maintenance program	1,788	70.6	25,539	876
9	Replace motor with more energy efficient type	1,824	81.4	26,061	894
10	Replace pump with more energy efficient type	1,984	86.7	28,347	972

Table 23: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Vietnam's Industrial Pumping Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in Vietnam's Industry (GWh/yr)	1,693	1,984
Share of saving from the total pumping system energy use in studied industries in Vietnam in 2008	49%	57%
Share of saving from total electricity use in studied industries in Vietnam in 2008	6%	7%
Annual primary energy saving potential for pumping system in Vietnam's Industry (TJ/yr)	24,180	28,347
Annual CO_2 emission reduction potential from Vietnam's Industry (kton CO_2 /yr)	829	972

Figure 9: Brazil's Pumping System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 24: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Pumping System Efficiency Measures in Brazil Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
1	Isolate flow paths to nonessential or non-operating equipment	899	0.0	10,030	131
2	Install variable speed drive	1,977	27.8	22,066	288
3	Fix Leaks, damaged seals, and packing	2,132	36.2	23,797	311
4	Trim or change impeller to match output to requirements	2,949	37.2	32,906	430
5	Use pressure switches to shut down unnecessary pumps	3,184	44.7	35,530	464
6	Remove sediment/scale buildup from piping	3,487	47.6	38,919	508
7	Initiate predictive maintenance program	3,840	87.3	42,850	560
8	Replace motor with more energy efficient type	3,949	109.4	44,066	576
9	Replace pump with more energy efficient type	4,439	110.2	49,543	647
10	Remove scale from components such as heat exchangers and strainers	4,585	128.5	51,172	669

Table 25: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Brazil's Industrial Pumping Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for pumping system in Brazil's Industry (GWh/yr)	4,439	4,585
Share of saving from the total pumping system energy use in studied industries in Brazil in 2008	43%	45%
Share of saving from total electricity use in studied industries in Brazil in 2008	3%	3%
Annual primary energy saving potential for pumping system in Brazil's Industry (TJ/yr)	49,543	51,172
Annual CO_2 emission reduction potential from Brazil's Industry (kton CO_2 /yr)	647	669

Table 26 below shows the snapshot of which energy efficiency measure for pumping system is cost-effective for each country for a quick comparison

Table 26: Cost-effectiveness of Energy Efficiency Measure for Pumping Systems in Each Country (Note: Cost Effective Measures are Marked with "X")

No.	Energy efficiency measure	US	Canada	EU	Thailand	Vietnam	Brazil
1.1.1	Fix leaks, damaged seals, and packing			X	X	X	X
1.1.2	Remove scale from components such as heat exchangers				X	X	
1.1.3	Remove sediment/scale buildup from piping				X	X	X
1.2.1	Use pressure switches to shut down unnecessary pumps	X		X	X	X	X
1.2.2	Isolate flow paths to nonessential or non-operating equipment	X	X	X	X	X	X
1.3.1	Trim or change impeller to match output to requirements	X	X	X	X	X	X
1.4.1	Install variable speed drive	X	X	X	X	X	X
1.5	Replace pump with more energy efficient type						X
1.6	Replace motor with more energy efficient type						X
1.7	Initiate predictive maintenance program						X

4.2. Compressed Air System Efficiency Supply Curves

Figure 10 to Figure 15 depict the Compressed Air System Efficiency Supply Curves for the six countries/region studied. The name of the measures related to each number on the supply curve is given in the table below each figure along with the cumulative annual electricity saving potential, final CCE of each measure, cumulative annual primary energy saving potential, and cumulative CO2 emission reduction potential (Tables 27-38). *In the tables, the energy efficiency measures that are shaded in lighter color are cost-effective (i.e. their CCE is less than the unit price of electricity) and the efficiency measures that are shaded in darker color are not cost-effective*. As can be seen from the compressed air system efficiency supply curves and the tables, "Fix leaks, adjust compressor controls, establish ongoing plan" and "predictive maintenance program" are the top two most cost-effective measures for the compressed air system across studied countries, except for the EU for which "sequencer" displaces "predictive maintenance program" in the top two. On the other hand, "Size replacement compressor to meet demand" is ranked last with the highest CCE across all countries studied.

Furthermore, tables show that for Canada and the EU, each with a MEDIUM base case efficiency, the total technical energy saving potential is well-aligned at 41% and 38%, respectively, of the total compressed air system energy use in the base year for the industries analyzed. Although the U.S. base case efficiency for compressed air systems is also MEDIUM, the total technical potential is only 29% of the total compressed air system energy use for the industries analyzed based on 2008 data. A major reason for this difference seems to be in the relative share of energy use by compressed air system larger than 1000 hp, *excluded* from these analyses, as compared to the total energy use of compressed air systems, which *includes* these larger systems. This share in the U.S. is 44%, whereas in Canada and EU is only 22% and 19%, respectively (see Table 4). This difference in technical potential seems to occur because the savings potential is divided by the total energy use of the compressed air system, resulting in a lower percentage for the total technical potential (Table 28a) due to the proportionally larger exclusion of the "systems bigger than 1000 hp from the total energy use" from U.S compressed air energy use.

An investigation was undertaken to validate or refute the theory about the effect of exclusion of "systems bigger than 1000 hp from the total energy use" in the construction of efficiency supply curve for the compressed air system in the U.S. For this purpose, compressed air systems bigger than 1000 hp were included in the analyses and a new supply curve was developed. The result is presented in Table 28b. Inclusion of compressed air systems greater than 1000 hp resulted in an increase in the total technical energy saving potential from 29% to 52%, thus supporting the theory. A US technical potential of 29% appears to be understated.

For Thailand, Vietnam, and Brazil with LOW base case efficiency (see Table 6), the share of total technical energy efficiency potential for industrial compressed air systems relative to total compressed air energy use is higher than that of developed countries. Within this group, this share is relatively lower for Brazil than for Thailand and Vietnam, most likely for the same reason for the relative difference given above for the U.S. For both the U.S. and Brazil, there are relatively higher proportions of large compressed air systems due to the mix of industries.

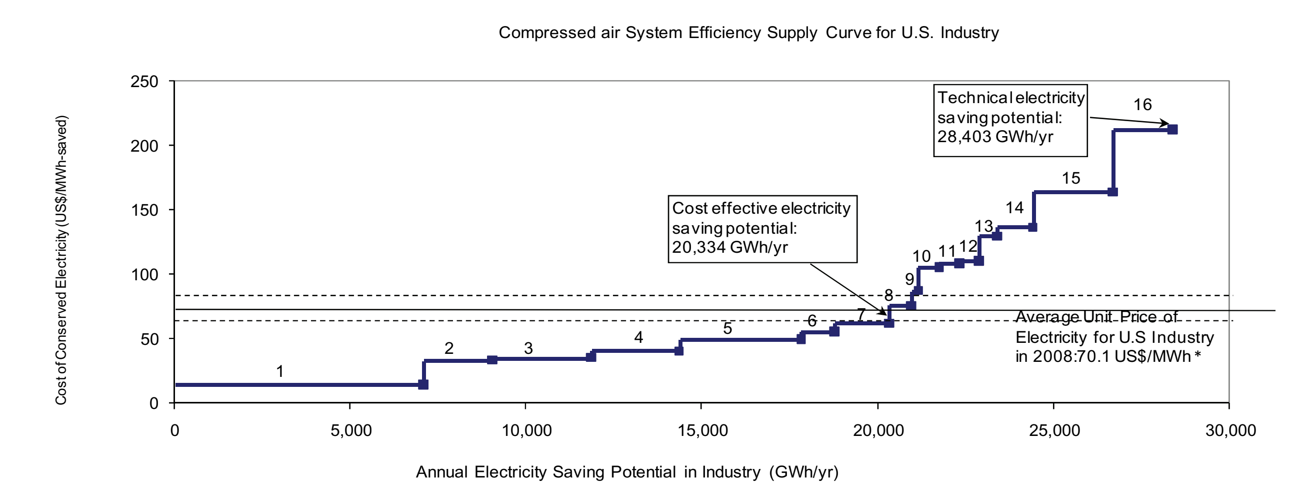
The three developed countries have the cost-effective potential of 21% - 28% of the total compressed air system energy use in the base year for the industries analyzed compared to the three developing countries with a cost-effective potential of 42% - 47%. These results can be attributed for two reasons. First, the three developing countries have a LOW efficiency baseline; hence the percentage improvement of efficiency over the base case efficiency for each measure is higher, resulting in a correspondingly lower CCE. Second reason is the application of labor adjustment factor in the calculation of CCE for Thailand, Vietnam and Brazil, which also lowers the CCE, thus allowing more measures to fall below the electricity price line. It should be noted that electricity price is one of the key factors determining the cost-effectiveness of a measure in a country. The higher the electricity price, the greater the number of measures that fall below the energy price line and thus become cost-effective.

As expected, most of the compressed air system energy efficiency measures identified as cost effective require limited capital investment. Leaks are routinely cited as the most cost-effective measure among compressed air system experts, but *it is extremely important to note that the energy savings for this measure are contingent on the adjustment of compressor controls once the leaks are fixed.* Moreover, the useful life of this measure is based on the implementation of an ongoing leak management program. Without either of these related actions, this measure would be significantly less cost-effective. This is worth mentioning because they are often omitted, thus producing a disappointing outcome.

The importance of looking at the demand side of the system and not just the operation of the compressor room is supported by the cost-effectiveness of improving end use efficiency, eliminating inappropriate compressed air uses, and addressing restrictive end use drops and connections and faulty filter-regulators-lubricators, or FRLs. While the installation of a sequencer for systems with more than one compressor is a highly cost-effective measure in most situations, sizing a replacement compressor to meet demand is typically not cost-effective.

As with pumping systems, there are limitations of these analyses, which are by necessity based on a generalization of the benefits of each energy efficiency measure across a wide variety of system type and operating conditions. For instance, there are situations in which correcting a pressure drop across compressed air treatment equipment or replacing a compressor intake filter can be highly cost-effective and may result in the ability to turn off a compressor or the avoidance of premature equipment failure. While this lack of granularity may be suitable to support policymaking needs, it is no substitute for individualized assessments of motor system opportunities.

Figure 10: US Compressed Air System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 27: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Compressed Air System Efficiency Measures in US Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
1	Fix leaks, adjust compressor controls, establish ongoing plan	7,073	14.4	77,658	4,263
2	Initiate predictive maintenance program	9,037	33.4	99,230	5,447
3	Install sequencer	11,862	35.3	130,239	7,149
4	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	14,353	40.4	157,600	8,651
5	Eliminate inappropriate compressed air uses	17,832	49.9	195,796	10,747
6	Address restrictive end use drops and connections, faulty FRLs	18,783	55.7	206,242	11,321
7	Eliminate artificial demand with pressure optimization/control/storage	20,334	62.0	223,267	12,255
8	Replace existing condensate drains with zero loss type	20,958	75.7	230,116	12,631
9	Correct compressor intake problems/replace filter	21,161	87.3	232,343	12,753
10	Correct excessive pressure drops in main line distribution piping	21,755	105.5	238,864	13,111

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
11	Install dedicated storage with metered recovery	22,328	108.8	245,156	13,457
12	Reconfigure branch header piping to reduce critical pressure loss	22,881	110.9	251,229	13,790
13	Correct excessive supply side pressure drop; i.e., treatment equipment	23,415	129.7	257,095	14,112
14	Match air treatment to demand side needs	24,431	136.6	268,248	14,724
15	Improve trim compressor part load efficiency; i.e. variable speed drive	26,699	164.1	293,156	16,091
16	Size replacement compressor to meet demand	28,403	212.7	311,865	17,118

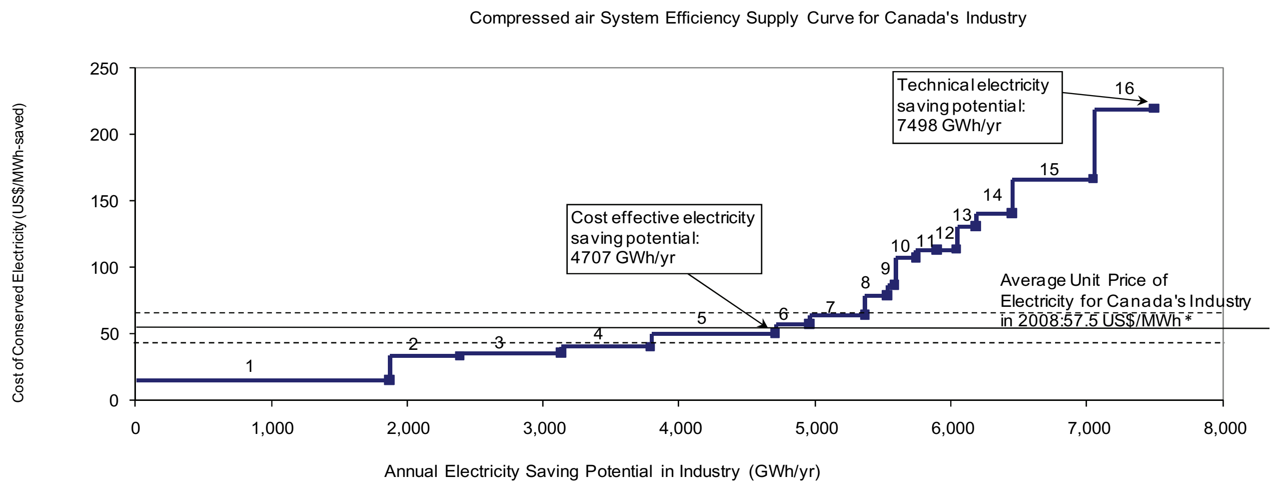
Table 28a: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for US Industrial Compressed Air Systems Excluding Systems Larger than 1000 hp

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in US Industry (excludes systems larger than 1000hp) (GWh/yr)	20,334	28,403
Share of saving from the total compressed air system energy use in studied industries in US in 2008	21%	29%
Share of saving from total electricity use in studied industries in US in 2008	2%	3%
Annual primary energy saving potential for compressed air system in US Industry (TJ/yr)	223,267	311,865
Annual CO_2 emission reduction potential from US Industry (kton CO_2 /yr)	12,255	17,118

Table 28b: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for US Industrial Compressed Air Systems, Including Systems Larger than 1000 hp

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in US Industry (includes systems larger than 1000hp) (GWh/yr)	36,535	51,033
Share of saving from the total compressed air system energy use in studied industries in US in 2008	38%	52%
Share of saving from total electricity use in studied industries in US in 2008	4%	6%
Annual primary energy saving potential for compressed air system in US Industry (TJ/yr)	401,154	560,342
Annual CO_2 emission reduction potential from US Industry (kton CO_2/yr)	22,019	30,757

Figure 11. Canada's Compressed Air System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 29: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Compressed Air System Efficiency Measures in Canada Ranked by their Final CCE

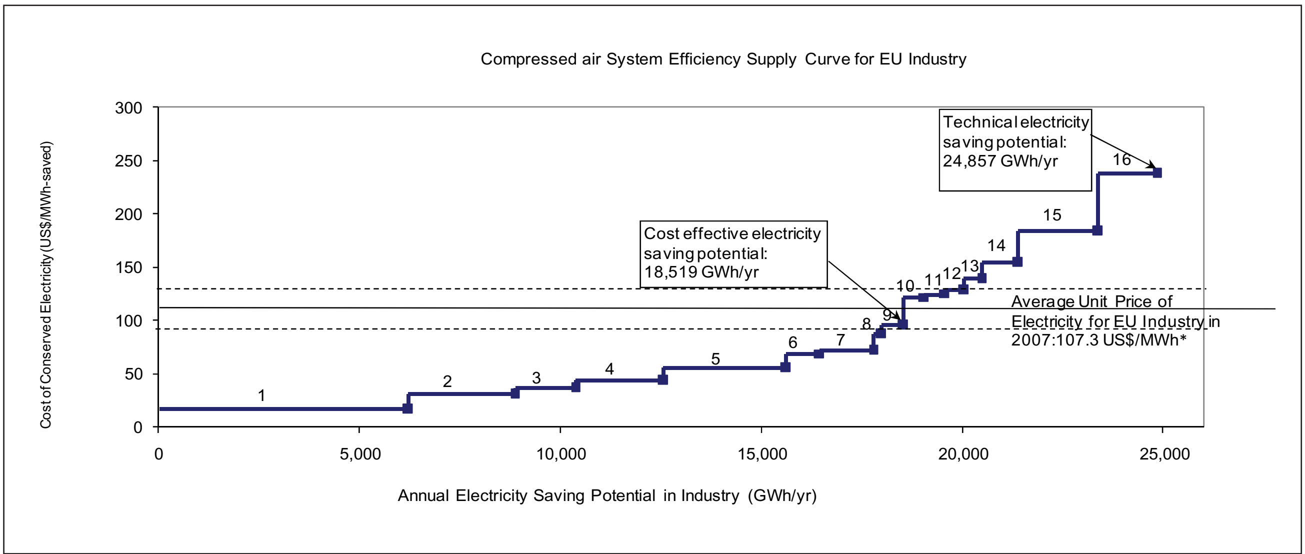
No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Fix leaks, adjust compressor controls, establish ongoing plan	1,867	15.1	23,258	928
2	Initiate predictive maintenance program	2,386	33.7	29,719	1,186
3	Install sequencer	3,131	36.0	39,006	1,557
4	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	3,789	40.4	47,201	1,884
5	Eliminate inappropriate compressed air uses	4,707	51.0	58,640	2,340
6	Address restrictive end use drops and connections, faulty FRLs	4,958	57.9	61,769	2,465
7	Eliminate artificial demand with pressure optimization/control/storage	5,368	64.3	66,868	2,669

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
8	Replace existing condensate drains with zero loss type	5,532	78.8	68,919	2,751
9	Correct compressor intake problems/replace filter	5,586	86.9	69,586	2,777
10	Correct excessive pressure drops in main line distribution piping	5,743	107.3	71,539	2,855
11	Reconfigure branch header piping to reduce critical pressure loss	5,894	113.2	73,424	2,931
12	Install dedicated storage with metered recovery	6,040	113.9	75,242	3,003
13	Correct excessive supply side pressure drop; i.e., treatment equipment	6,181	130.9	76,999	3,073
14	Match air treatment to demand side needs	6,449	140.6	80,339	3,207
15	Improve trim compressor part load efficiency; i.e. variable speed drive	7,048	166.9	87,799	3,504
16	Size replacement compressor to meet demand	7,498	219.8	93,403	3,728

Table 30: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Canada's Industrial Compressed Air Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in Canada's Industry (GWh/yr)	4,707	7,498
Share of saving from the total compressed air system energy use in studied industries in Canada in 2008	26%	41%
Share of saving from total electricity use in studied industries in Canada in 2008	3%	4%
Annual primary energy saving potential for compressed air system in Canada's Industry (TJ/yr)	58,640	93,403
Annual CO_2 emission reduction potential from Canada's Industry (kton CO_2 /yr)	2,340	3,728

Figure 12: EU's Compressed Air System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the regional level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 31: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Compressed Air System Efficiency Measures in EU Ranked by their Final CCE

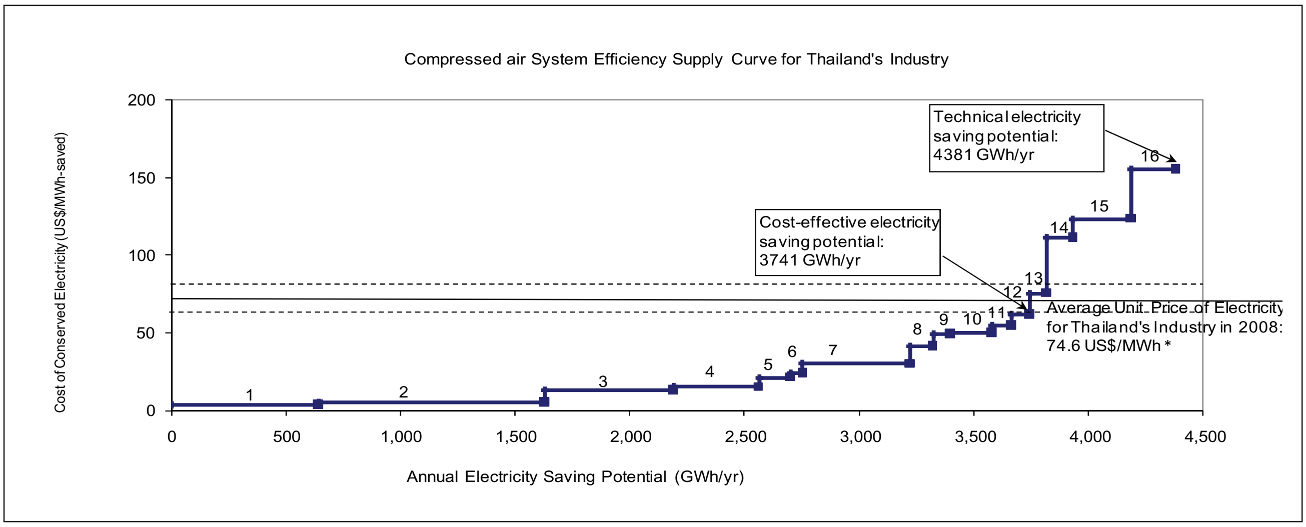
No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Fix Leaks, adjust compressor controls, establish ongoing plan	6,190	17.0	58,158	2,699
2	Install sequencer	8,874	31.7	83,375	3,869
3	Initiate predictive maintenance program	10,381	36.9	97,535	4,526
4	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	12,561	44.1	118,026	5,477
5	Eliminate inappropriate compressed air uses	15,606	56.3	146,631	6,804
6	Address restrictive end use drops and connections, faulty FRLs	16,438	68.5	154,454	7,167
7	Eliminate artificial demand with pressure optimization/control/storage	17,795	73.0	167,204	7,759

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
8	Correct compressor intake problems/replace filter	17,980	87.6	168,935	7,839
9	Replace existing condensate drains with zero loss type	18,519	96.2	174,001	8,074
10	Correct excessive pressure drops in main line distribution piping	19,039	121.5	178,885	8,301
11	Reconfigure branch header piping to reduce critical pressure loss	19,540	124.8	183,596	8,519
12	Install dedicated storage with metered recovery	20,024	129.1	188,144	8,730
13	Correct excessive supply side pressure drop; i.e., treatment equipment	20,492	139.9	192,538	8,934
14	Match air treatment to demand side needs	21,381	154.9	200,889	9,322
15	Improve trim compressor part load efficiency; i.e. variable speed drive	23,366	184.7	219,543	10,188
16	Size replacement compressor to meet demand	24,857	238.8	233,554	10,838

Table 32: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for the EU's Industrial Compressed Air Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in EU's Industry (GWh/yr)	18,519	24,857
Share of saving from the total compressed air system energy use in studied industries in EU in 2008	28%	38%
Share of saving from total electricity use in studied industries in EU in 2008	3%	4%
Annual primary energy saving potential for compressed air system in EU's Industry (TJ/yr)	174,001	233,554
Annual CO_2 emission reduction potential from EU's Industry (kton CO_2 /yr)	8,074	10,838

Figure 13. Thailand's Compressed Air System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 33: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Compressed Air System Efficiency Measures in Thailand Ranked by their Final CCE

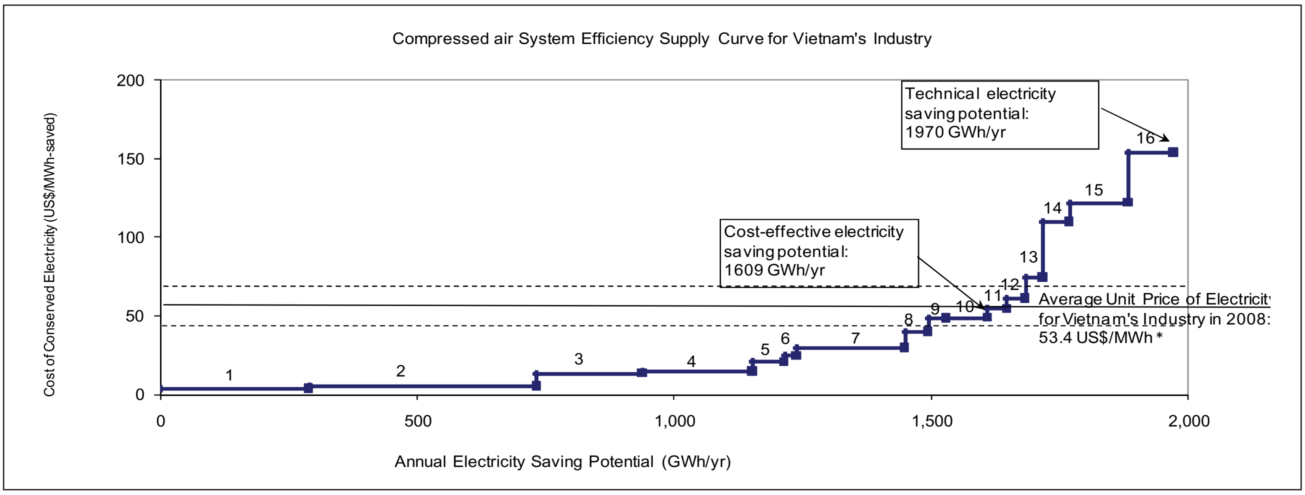
No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Initiate predictive maintenance program	641	4.0	6,451	333
2	Fix Leaks, adjust compressor controls, establish ongoing plan	1,627	5.4	16,376	845
3	Install sequencer	2,189	13.2	22,023	1,136
4	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	2,560	15.4	25,763	1,329
5	Address restrictive end use drops and connections, faulty FRLs	2,699	21.6	27,158	1,401
6	Correct compressor intake problems/replace filter	2,752	24.6	27,693	1,428
7	Eliminate inappropriate compressed air uses	3,219	30.3	32,396	1,671
8	Replace existing condensate drains with zero loss type	3,321	41.8	33,416	1,724

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
9	Reconfigure branch header piping to reduce critical pressure loss	3,398	49.5	34,194	1,764
10	Eliminate artificial demand with pressure optimization/control/storage	3,578	50.2	36,006	1,857
11	Correct excessive supply side pressure drop; i.e., treatment equipment	3,662	55.2	36,846	1,900
12	Correct excessive pressure drops in main line distribution piping	3,741	62.4	37,647	1,942
13	Install dedicated storage with metered recovery	3,817	75.9	38,411	1,981
14	Match air treatment to demand side needs	3,932	111.6	39,563	2,041
15	Improve trim compressor part load efficiency; i.e. variable speed drive	4,185	123.9	42,116	2,172
16	Size replacement compressor to meet demand	4,381	155.5	44,083	2,274

Table 34: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Thailand's Industrial Compressed Air Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in Thai Industry (GWh/yr)	3,741	4,381
Share of saving from the total compressed air system energy use in studied industries in Thailand in 2008	47%	55%
Share of saving from total electricity use in studied industries in EU in 2008	6%	7%
Annual primary energy saving potential for compressed air system in Thai Industry (TJ/yr)	37,647	44,083
Annual CO_2 emission reduction potential from Thai Industry (kton CO_2 /yr)	1,942	2,274

Figure 14: Vietnam's Compressed Air System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 35: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Compressed Air System Efficiency Measures in Vietnam Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Initiate predictive maintenance program	288	4.0	4,119	141
2	Fix Leaks, adjust compressor controls, establish ongoing plan	732	5.4	10,455	359
3	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	938	13.6	13,400	460
4	Install sequencer	1,151	15.0	16,448	564
5	Address restrictive end use drops and connections, faulty FRLs	1,214	20.9	17,339	595
6	Correct compressor intake problems/replace filter	1,238	24.8	17,680	606
7	Eliminate inappropriate compressed air uses	1,448	30.0	20,683	709
8	Replace existing condensate drains with zero loss type	1,493	40.1	21,334	732
9	Reconfigure branch header piping to reduce critical pressure loss	1,528	48.7	21,831	749

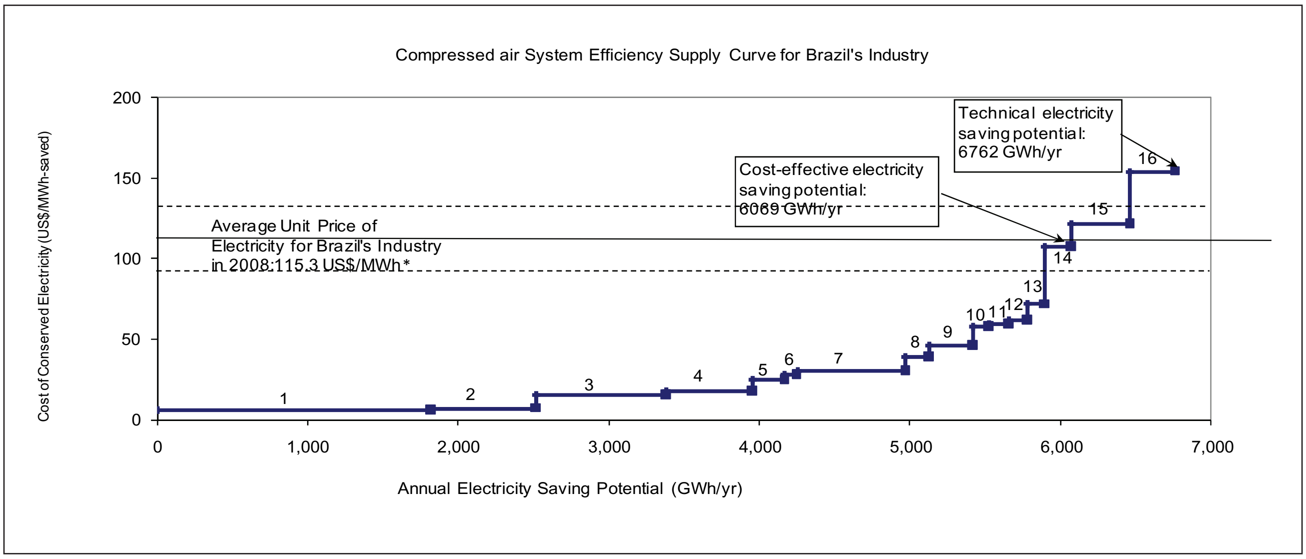
Table 35: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Compressed Air System Efficiency Measures in Vietnam Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
10	Eliminate artificial demand with pressure optimization/control/storage	1,609	49.1	22,987	788
11	Correct excessive supply side pressure drop; i.e., treatment equipment	1,647	54.8	23,524	807
12	Correct excessive pressure drops in main line distribution piping	1,682	61.3	24,035	824
13	Install dedicated storage with metered recovery	1,717	74.7	24,523	841
14	Match air treatment to demand side needs	1,768	110.1	25,259	866
15	Improve trim compressor part load efficiency; i.e. variable speed drive	1,882	122.3	26,888	922
16	Size replacement compressor to meet demand	1,970	153.9	28,144	965

Table 36: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Vietnam's Industrial Compressed Air Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in Vietnam's Industry (GWh/yr)	1,609	1,970
Share of saving from the total compressed air system energy use in studied industries in Vietnam in 2008	47%	55%
Share of saving from total electricity use in studied industries in Vietnam in 2008	6%	7%
Annual primary energy saving potential for compressed air system in Vietnam's Industry (TJ/yr)	22,987	28,144
Annual CO_2 emission reduction potential from Vietnam's Industry (kton CO_2 /yr)	788	965

Figure 15: Brazil's Compressed Air System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 37: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Compressed Air System Efficiency Measures in Brazil Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Fix leaks, adjust compressor controls, establish ongoing plan	1,814	6.1	20,247	265
2	Initiate predictive maintenance program	2,512	7.4	28,034	366
3	Install sequencer	3,378	15.6	37,701	493
4	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	3,952	17.9	44,105	576
5	Address restrictive end use drops and connections, faulty FRLs	4,166	25.1	46,493	607
6	Correct compressor intake problems/replace filter	4,248	28.1	47,408	619
7	Eliminate inappropriate compressed air uses	4,970	30.4	55,459	725
8	Replace existing condensate drains with zero loss type	5,126	39.5	57,206	747

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
9	Eliminate artificial demand with pressure optimization/control/storage	5,416	46.2	60,436	790
10	Reconfigure branch header piping to reduce critical pressure loss	5,523	58.1	61,639	805
11	Correct excessive pressure drops in main line distribution piping	5,652	60.0	63,077	824
12	Correct excessive supply side pressure drop; i.e., treatment equipment	5,775	62.0	64,448	842
13	Install dedicated storage with metered recovery	5,892	72.0	65,756	859
14	Match air treatment to demand side needs	6,069	107.7	67,729	885
15	Improve trim compressor part load efficiency; i.e. variable speed drive	6,461	121.9	72,099	942
16	Size replacement compressor to meet demand	6,762	154.4	75,466	986

Table 38: Total Annual cost-Effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Brazil's Industrial Compressed Air Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for compressed air system in Brazil's Industry (GWh/yr)	6,069	6,762
Share of saving from the total compressed air system energy use in studied industries in Brazil in 2008	42%	47%
Share of saving from total electricity use in studied industries in Brazil in 2008	4%	5%
Annual primary energy saving potential for compressed air system in Brazil's Industry (TJ/yr)	67,729	75,466
Annual CO_2 emission reduction potential from Brazil's Industry (kton CO_2 /yr)	885	986

Table 39 below shows the snapshot of which energy efficiency measure for compressed air system is cost-effective for each country for a quick comparison

Table 39: Cost-effectiveness of Energy Efficiency Measure for Compressed Air Systems in Each Country

No.	Energy efficiency measure	US	Canada	EU	Thailand	Vietnam	Brazil
2.1.1	Fix leaks, adjust compressor controls, establish ongoing plan	X	X	X	X	X	X
2.1.2	Replace existing condensate drains with zero loss type			X	X	X	X
2.1.3	Correct compressor intake problems/replace filter			X	X	X	X
2.2.1	Address restrictive end use drops and connections, faulty FRLs	X		X	X	X	X
2.2.2	Reconfigure branch header piping to reduce critical pressure loss				X	X	X
2.2.3	Correct excessive pressure drops in main line distribution piping				X		X
2.2.4	Correct excessive supply side pressure drop; i.e., treatment equipment				X		X
2.3.1	Eliminate inappropriate compressed air uses	X	X	X	X	X	X
2.3.2	Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.	X	X	X	X	X	X
2.3.3	Eliminate artificial demand with pressure optimization/control/storage	X		X	X	X	X
2.4.1	Install dedicated storage with metered recovery						X
2.5.1	Install sequencer	X	X	X	X	X	X
2.5.2	Improve trim compressor part load efficiency; i.e. variable speed drive						
2.6	Match air treatment to demand side needs						X
2.7	Size replacement compressor to meet demand						
2.8	Initiate predictive maintenance program	X	X	X	X	X	X

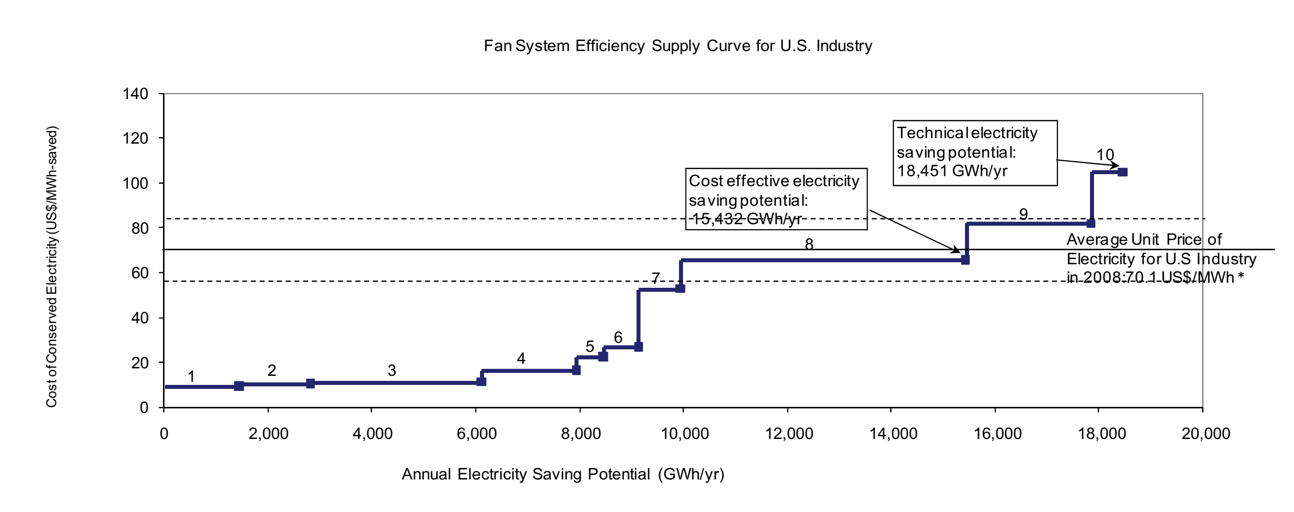
4.3. Fan System Efficiency Supply Curves

Figure 16 to Figure 21 show the Fan System Efficiency Supply Curves for the six countries/region studied. As can be seen from the fan system efficiency supply curves and the tables below them, "Correct damper problems", "Fix leaks and damaged seals" and "Isolate flow paths to non-essential or non-operating equipment" are the top three most cost-effective measures for fan systems across the studied countries. "Replace motor with more energy efficient type" and "Replace oversized fans with more efficient type" are the least cost-effective across all countries studied.

Tables 40 - 51 show that U.S., Canada and EU with MEDIUM base case efficiency have a total technical energy saving potential of 27% - 30% as compared with total fan system energy use in the base year for the industries analyzed. Thailand, Vietnam, and Brazil, with LOW base case efficiency (see Table 6), have a higher percentage of total energy saving technical potential (40% - 46%) as compared with total fan system energy use in the base year for the industries analyzed. This is because these three developing countries have the LOW efficiency base case, hence the percentage improvement of efficiency over the base case efficiency for each measure is higher, resulting in higher technical saving potential. *In the tables, the energy efficiency measures that are shaded in lighter color are cost-effective (i.e. their CCE is less than the unit price of electricity) and the efficiency measures that are shaded in darker color are not cost-effective.* The three developed countries also have a lower cost-effective potential of 14% - 28% of total fan system energy use in the base year for the industries analyzed, as compared to the cost-effective potential of 40% - 46% for the developing countries. There are two reasons for this. First, the three developing countries have the LOW efficiency baseline; hence the percentage improvement of efficiency over the baseline efficiency for each measure is higher for these three countries, resulting in lower CCE. Second, the application of labor adjustment factor in the calculation of CCE for Thailand, Vietnam and Brazil reduced the CCE; thus allowing more measures to fall below the electricity price line.

Another point to highlight is the difference between the cost-effective energy saving potential for fan systems in the U.S. and Canada. The main reason for this is that the cost-effectiveness of measure number 8 (install variable speed drive or VSD). This measure has the highest energy saving potential and is marginally cost-effective in U.S., but not cost-effective in Canada. This variation is the result of the difference in average electricity price for industry in these two countries. The relatively higher cost of electricity in U.S means that VSDs fall below the energy price line in the supply curve and are cost-effective. While field experience in Canada would support the cost-effectiveness of VSDs in specific industrial facilities, studying this measure using national averages illustrates the important role of the electricity price in cost-effectiveness of a measure both within and across countries. There is less variation in the cost effectiveness of the fan system measures analyzed than in the pumping and compressed air system measures. Most fan system measures analyzed are cost-effective in all countries studied. In addition, for Thailand and Brazil all fan system measures are cost-effective. Potential causes for this outcome are a combination of the fact that the fan system for these two countries are in LOW base case, the application of labor adjustment factor, and the higher electricity cost compared to Vietnam, which also has the LOW base case and labor adjustment factor. As with pumping and compressed air systems, the larger capital investments attributed to equipment replacement (fans, motors) with more energy efficient types, resulted in these measures appearing as the least cost effective of the ten measures analyzed.

Figure 16: US Fan System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

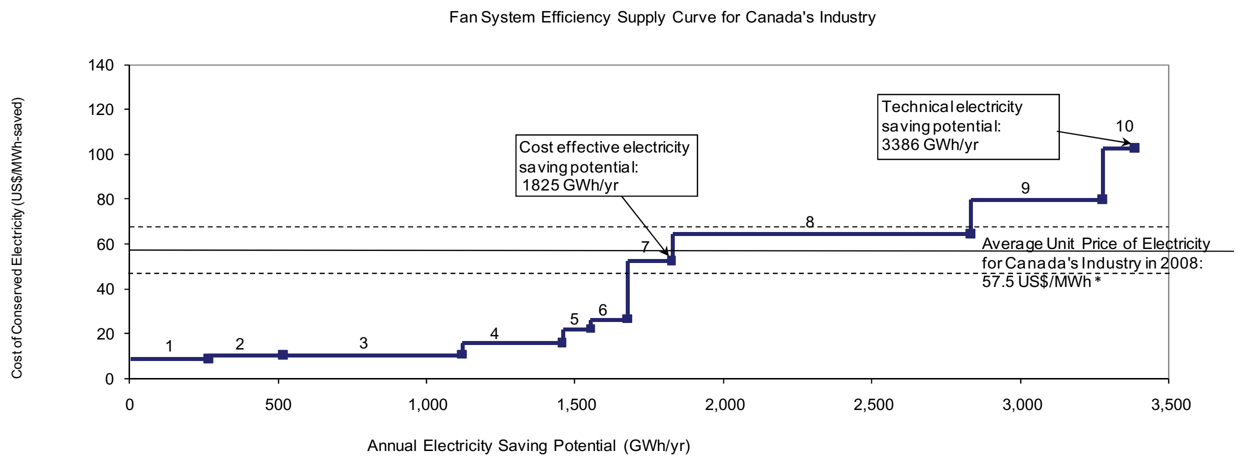
Table 40: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Fan System Efficiency Measures in US Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Correct damper problems	1,448	9.5	15,902	873
2	Fix Leaks and damaged seals	2,815	10.6	30,904	1,696
3	Isolate flow paths to non-essential or non-operating equipment	6,106	11.3	67,049	3,680
4	Correct poor airflow conditions at fan inlets and outlets	7,939	16.7	87,171	4,785
5	Remove sediment/scale buildup from fans and system surfaces	8,459	22.5	92,882	5,098
6	Initiate predictive maintenance program	9,133	26.9	100,280	5,504
7	Repair or replace inefficient belt drives	9,945	52.9	109,193	5,994
8	Install variable speed drive	15,432	65.6	169,438	9,300
9	Replace oversized fans with more efficient type	17,850	81.9	195,988	10,758
10	Replace motor with more energy efficient type	18,451	104.9	202,592	11,120

Table 41: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for US Industrial Fan Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for fan system in US Industry (GWh/yr)	15,432	18,451
Share of saving from the total fan system energy use in studied industries in US in 2008	25%	30%
Share of saving from total electricity use in studied industries in US in 2008	2%	2%
Annual primary energy saving potential for fan system in US Industry (TJ/yr)	169,438	202,592
Annual CO_2 emission reduction potential from US Industry (kton CO_2/yr)	9,300	11,120

Figure 17: Canada's Fan System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

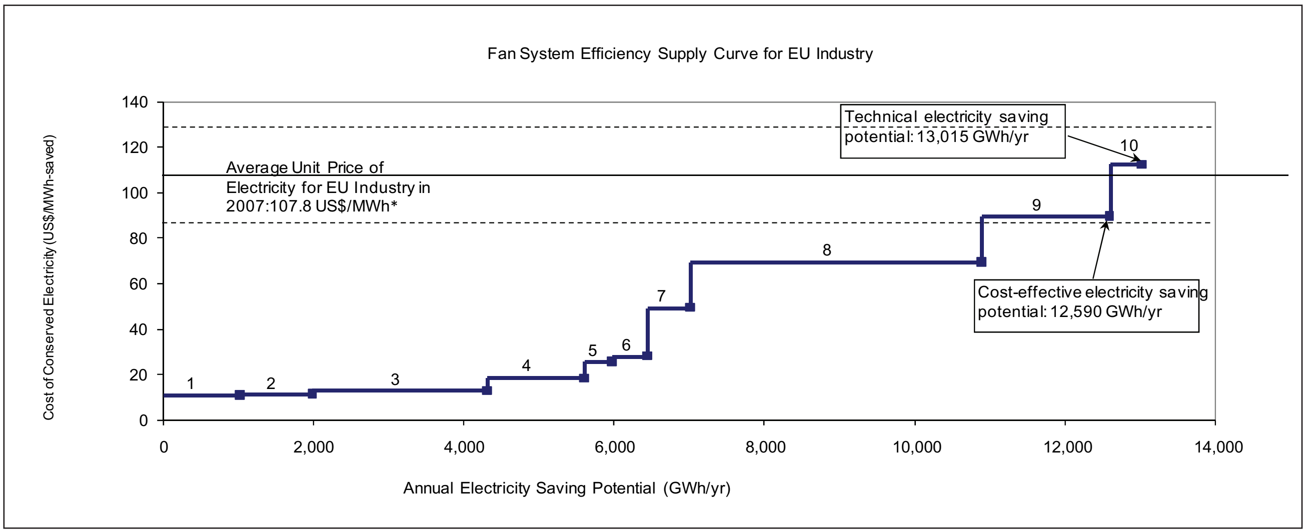
Table 42: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for the Fan System Efficiency Measures in Canada Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Fan System Efficiency Measures in Canada Ranked by their Final CCE	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2/yr)
1	Correct damper problems	266	9.0	3,311	132
2	Fix Leaks and damaged seals	517	10.4	6,434	257
3	Isolate flow paths to nonessential or non-operating equipment	1,121	10.8	13,960	557
4	Correct poor airflow conditions at fan inlets and outlets	1,457	16.2	18,150	724
5	Remove sediment/scale buildup from fans and system surfaces	1,552	22.2	19,339	772
6	Initiate predictive maintenance program	1,676	26.6	20,879	833
7	Repair or replace inefficient belt drives	1,825	52.7	22,735	907
8	Install variable speed drive	2,832	64.8	35,278	1,408
9	Replace oversized fans with more efficient type	3,276	79.9	40,806	1,629
10	Replace motor with more energy efficient type	3,386	102.9	42,181	1,684

Table 43: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Canada's Industrial Fan Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for fan system in Canada's Industry (GWh/yr)	1,825	3,386
Share of saving from the total fan system energy use in studied industries in Canada in 2008	14%	27%
Share of saving from total electricity use in studied industries in Canada in 2008	1%	2%
Annual primary energy saving potential for fan system in Canada's Industry (TJ/yr)	22,735	42,181
annual CO_2 emission reduction potential from Canada's Industry (kton CO_2 /yr)	907	1,684

Figure 18: EU's Fan System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the regional level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

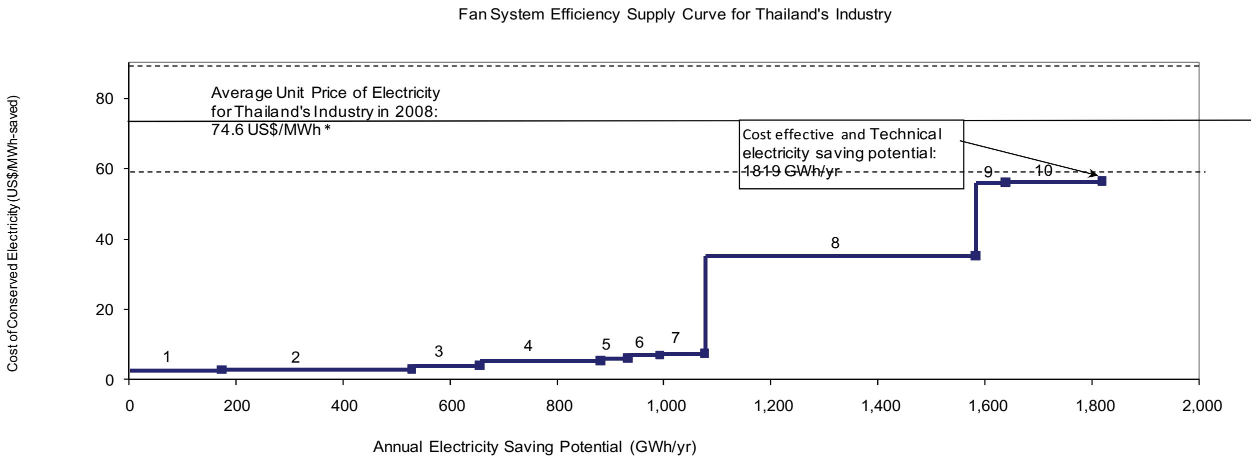
Table 44: Cumulative Annual Electricity Saving and CO2 Emission Reduction for Fan System Efficiency Measures in EU Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Fix Leaks and damaged seals	1,022	11.1	9,598	445
2	Correct damper problems	1,985	11.6	18,653	866
3	Isolate flow paths to non-essential or non-operating equipment	4,307	13.0	40,470	1,878
4	Correct poor airflow conditions at fan inlets and outlets	5,600	18.5	52,616	2,442
5	Remove sediment/scale buildup from fans and system surfaces	5,967	25.8	56,064	2,602
6	Initiate predictive maintenance program	6,442	28.2	60,529	2,809
7	Repair or replace inefficient belt drives	7,015	49.6	65,909	3,058
8	Install variable speed drive	10,885	69.7	102,272	4,746
9	Replace oversized fans with more efficient type	12,590	89.8	118,298	5,489
10	Replace motor with more energy efficient type	13,015	112.5	122,284	5,674

Table 45: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for the EU's Industrial Fan Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for fan system in EU's Industry (GWh/yr)	12,590	13,015
Share of saving from the total fan system energy use in studied industries in EU in 2008	28%	29%
Share of saving from total electricity use in studied industries in EU in 2008	2%	2%
Annual primary energy saving potential for fan system in EU's Industry (TJ/yr)	118,298	122,284
Annual CO_2 emission reduction potential from EU's Industry (kton CO_2/yr)	5,489	5,674

Figure 19: Thailand's Fan System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

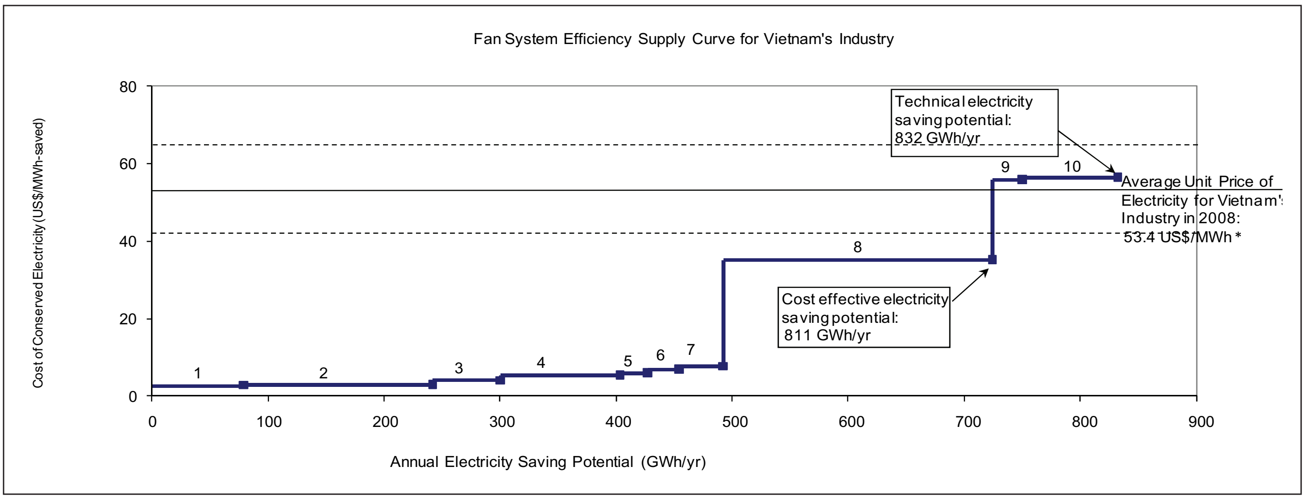
Table 46: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Fan System Efficiency Measures in Thailand Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 emission reduction Potential from Industry (kton CO_2 /yr)
1	Fix Leaks and damaged seals	173	2.9	1,743	90
2	Isolate flow paths to nonessential or non-operating equipment	529	3.1	5,319	274
3	Correct damper problems	656	4.2	6,602	340
4	Correct poor airflow conditions at fan inlets and outlets	882	5.4	8,875	458
5	Remove sediment/scale buildup from fans and system surfaces	933	6.1	9,391	484
6	Initiate predictive maintenance program	992	7.0	9,984	515
7	Repair or replace inefficient belt drives	1,076	7.6	10,828	558
8	Install variable speed drive	1,583	35.3	15,926	821
9	Replace motor with more energy efficient type	1,639	56.0	16,495	851
10	Replace oversized fans with more efficient type	1,819	56.4	18,305	944

Table 47: Total Annual Cost-Effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Thailand's Industrial Fan Systems

	Cost effective Potential	Technical Potential
Annual electricity saving potential for fan system in Thai Industry (GWh/yr)	1,819	1,819
Share of saving from the total fan system energy use in studied industries in Thailand's in 2008	46%	46%
Share of saving from total electricity use in studied industries in Thailand's in 2008	3%	3%
Annual primary energy saving potential for fan system in Thai Industry (TJ/yr)	18,305	18,305
Annual CO_2 emission reduction potential from Thai Industry (kton CO_2/yr)	944	944

Figure 20: Vietnam's Fan System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis- see Section 4.5.
NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

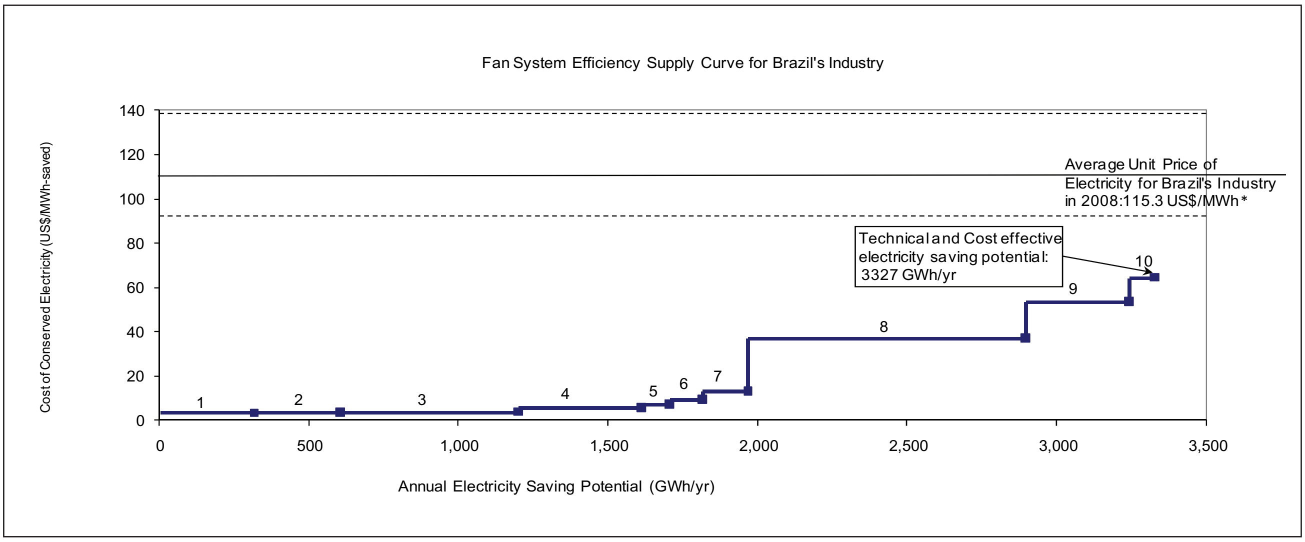
Table 48: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Fan System Efficiency Measures in Vietnam Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO_2 Emission Reduction Potential from Industry (kton CO_2 /yr)
1	Fix Leaks and damaged seals	79	2.9	1,132	39
2	Isolate flow paths to non-essential or non-operating equipment	242	3.1	3,455	119
3	Correct damper problems	300	4.1	4,288	147
4	Correct poor airflow conditions at fan inlets and outlets	404	5.4	5,765	198
5	Remove sediment/scale buildup from fans and system surfaces	427	6.1	6,099	209
6	Initiate predictive maintenance program	454	6.9	6,485	222
7	Repair or replace inefficient belt drives	492	7.8	7,033	241
8	Install variable speed drive	724	35.3	10,344	355
9	Replace motor with more energy efficient type	750	56.0	10,713	367
10	Replace oversized fans with more efficient type	832	56.5	11,889	408

Table 49: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Vietnam's Industrial Fan Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for fan system in Vietnam's Industry (GWh/yr)	724	832
Share of saving from the total fan system energy use in studied industries in Vietnam in 2008	40%	45%
Share of saving from total electricity use in studied industries in Vietnam in 2008	3%	3%
Annual primary energy saving potential for fan system in Vietnam's Industry (TJ/yr)	10,344	11,889
Annual CO_2 emission reduction potential from Vietnam's Industry (kton CO_2/yr)	355	408

Figure 21: Brazil's Fan System Efficiency Supply Curve



* The dotted lines represent the range of price from the sensitivity analysis—see Section 4.5.

NOTE: this supply curve is intended to provide an indicator of the relative cost-effectiveness of system energy efficiency measures at the national level. The cost-effectiveness of individual measures will vary based on site-specific conditions.

Table 50: Cumulative Annual Electricity Saving and CO_2 Emission Reduction for Fan System Efficiency Measures in Brazil Ranked by their Final CCE

No.	Energy Efficiency Measure	Cumulative Annual Electricity Saving Potential in Industry (GWh/yr)	Final CCE (US$/MWh-Saved)	Cumulative Annual Primary Energy Saving Potential in Industry (TJ/yr)	Cumulative Annual CO2 Emission Reduction Potential from Industry (kton CO2 /yr)
1	Fix leaks and damaged seals	317	3.5	3,536	46
2	Correct damper problems	605	3.7	6,751	88
3	Isolate flow paths to non-essential or non-operating equipment	1,200	4.0	13,391	175
4	Correct poor airflow conditions at fan inlets and outlets	1,613	5.9	18,002	235
5	Remove sediment/scale buildup from fans and system surfaces	1,707	7.4	19,048	249
6	Initiate predictive maintenance program	1,815	9.5	20,252	265
7	Repair or replace inefficient belt drives	1,968	13.2	21,964	287
8	Install variable speed drive	2,895	37.2	32,305	422
9	Replace oversized fans with more efficient type	3,242	53.9	36,178	473
10	Replace motor with more energy efficient type	3,327	64.6	37,130	485

Table 51: Total Annual Cost-effective and Technical Energy Saving and CO_2 Emission Reduction Potential for Brazil's Industrial Fan Systems

	Cost Effective Potential	Technical Potential
Annual electricity saving potential for fan system in Brazil's Industry (GWh/yr)	3,327	3,327
Share of saving from the total fan system energy use in studied industries in Brazil in 2008	40%	40%
Share of saving from total electricity use in studied industries in Brazil in 2008	2%	2%
Annual primary energy saving potential for fan system in Brazil's Industry (TJ/yr)	37,130	37,130
Annual CO_2 emission reduction potential from Brazil's Industry (kton CO_2/yr)	485	485

Table 52 below shows the snapshot of which energy efficiency measure for fan system is cost-effective for each country for a quick comparison

Table 52: Cost-effectiveness of Energy Efficiency Measure for Fan Systems in Each Country

No.	Energy Efficiency Measure	US	Canada	EU	Thailand	Vietnam	Brazil
3.1.1	Fix Leaks and damaged seals	X	X	X	X	X	X
3.1.2	Repair or replace inefficient belt drives	X	X	X	X	X	X
3.1.3	Remove sediment/scale buildup from fans and system surfaces	X	X	X	X	X	X
3.1.4	Correct damper problems	X	X	X	X	X	X
3.2.1	Isolate flow paths to non-essential or non-operating equipment	X	X	X	X	X	X
3.2.2	Correct poor airflow conditions at fan inlets and outlets	X	X	X	X	X	X
3.3.1	Replace oversized fans with more efficient type			X	X		X
3.4.1	Install variable speed drive	X		X	X	X	X
3.5	Replace motor with more energy efficient type				X		X
3.6	Initiate predictive maintenance program	X	X	X	X	X	X

(Note: cost effective measures are marked with "X")

4.4. Maintenance and Persistence of Energy Savings

Motor system energy assessments and case studies have illustrated the importance of regular maintenance, or the lack therein, as a critical factor in the persistence of energy savings from measures to improve the energy efficiency of motor systems. Expert opinion was sought to identify the relative dependence on maintenance for the energy efficiency measures included in this study. The experts were asked to select whether a given measure should be classified as Limited, Moderately, or Highly Dependent on maintenance practices. Substantial agreement among experts was reached on these ratings. Measures that were classified as either Highly or Moderately Dependent were then compared to the cost-effective measures as identified by CCE in the motor system supply curves for the six countries studied. Those measures identified as cost-effective for four or more of the six countries are shown in Table 53 in bold, italicized text.

The dependence of so many cost-effective motor system energy efficiency measures on effective maintenance is one indicator of the potential benefits from implementing an energy management system (EnMS), and hints at the potential impact from implementation of the future ISO 50001- Energy management systems. A principal goal of the standard is to foster continual and sustained energy performance improvement through a disciplined approach to operations and maintenance practices.

Table 53: Energy Efficiency Measures Highly or Moderately Dependent on Maintenance Practices for Persistence of Energy Savings, Further Identified by Final CCE as Cost Effective.

No.	Measures	Measure Cost-effective per Efficiency Supply Curve					
	Measures Most Dependent on Maintenance Practices	US	Canada	EU	Thailand	Vietnam	Brazil
	Pumping Systems:						
1.1.1	***Fix leaks, damaged seals, and packing***			X	X	X	X
1.1.2	Remove scale from components such as heat exchangers and strainers				X	X	
1.1.3	Remove sediment/scale buildup from piping				X	X	X
1.7	Initiate predictive maintenance program						X
	Compressed Air Systems:						
2.1.1	***Fix leaks, adjust compressor controls, establish ongoing plan***	X	X	X	X	X	X
2.1.3	***Correct compressor intake problems/replace filter***			X	X	X	X
2.8	***Initiate predictive maintenance program***	X	X	X	X	X	X

No.	Measures	Measure Cost-effective per Efficiency Supply Curve					
	Measures Most Dependent on Maintenance Practices	US	Canada	EU	Thailand	Vietnam	Brazil
	Fan Systems:						
3.1.1	***Fix leaks and damaged seals***	X	X	X	X	X	X
3.1.2	***Repair or replace inefficient belt drives***	X	X	X	X	X	X
3.13	***Remove sediment/scale buildup from fans and system surfaces***	X	X	X	X	X	X
3.6	***Initiate predictive maintenance program***	X	X	X	X	X	X
	Measures Moderately Dependent on Maintenance Practices						
	Pumping Systems:						
1.2.1	***Use pressure switches to shut down unnecessary pumps***	X		X	X	X	X
1.5	Replace pump with more energy efficient type						X
1.6	Replace motor with more energy efficient type						X
	Compressed Air Systems:						
2.1.2	***Replace existing condensate drains with zero loss type***			X	X	X	X
2.2.1	***Address restrictive end use drops and connections, faulty FRLs***			X	X	X	X
	Correct excessive supply side pressure drop, i.e. treatment equipment				X		X
2.3.2	***Improve end use efficiency; shut-off idle equip, engineered nozzles, etc.***	X	X	X	X	X	X
2.5.2	Improve trim compressor part load efficiency						
2.6	Match air treatment to demand side needs						
	Fan Systems:						
	none listed						

Further analysis of the pumping, compressed air, and fan systems reveal interesting differences. Of the seven (7) measures identified by pumping experts as highly or moderately dependent on maintenance, only two (2) or 28% met the cost-effectiveness threshold for four or more countries. Of the nine (9) measures identified by compressed air systems experts as highly or moderately dependent on maintenance, six (6) or 67% met the cost-effectiveness threshold. For fan systems, only four (4) measures were identified as highly or moderately dependent on maintenance and 100% met the cost-effectiveness threshold. Altogether, there were twenty (20) measures identified as highly or moderately dependent on maintenance practices, with 60% (12) of them also meeting the cost-effectiveness threshold for four or more countries.

Based on these results, it could be assumed that energy efficiency measures for pumping systems that are reliant on maintenance are less cost effective than such measures for compressed air or fan systems. These results reveal an interesting variation by system that warrants further study.

4.5 Sensitivity Analysis

In the previous sections, the cost-effective and technical energy efficiency improvement potentials were presented and discussed for the industrial motor systems in the six countries studied. Since several parameters play important roles in the analysis of energy efficiency potentials, it is important to see how changes in some of those parameters can influence the cost effectiveness of the potentials. A sensitivity analysis was conducted for two of the key parameters, the discount rate and the unit price of electricity because they can significantly influence the results. The choice of discount rate can differ based on the purpose of the analysis and the unit price of electricity can vary within the country/region, especially in the U.S. and EU.

In general, the cost of conserved energy has a direct proportional relationship with the discount rate. In other words, reduction of the discount rate will reduce the cost of conserved energy, which will increase the cost-effective energy-saving potential (depending on the energy price). Tables 54-56 illustrate how changes in the discount rate can have a significant effect on the cost-effective energy saving potentials, assuming all the other factors, including the electricity price, are held constant. It should be noted that the non-cost effective measures may not become cost-effective by changing the discount rate, since the electricity price also plays a role in determining cost. The "Sum of Final CCE of all Measures" will decrease with the decline in discount rate regardless. The total technical energy-saving potentials do not change with the variation of the discount rate.

The choice of the discount rate depends on the purpose of the analysis and the approach (prescriptive versus descriptive) used. A prescriptive approach uses lower discount rates (4% to 8%), especially for long-term issues like climate change or public sector projects. Low discount rates have the advantage of treating future generations equally to our own, but they also may cause relatively certain, near-term effects to be ignored in favor of more uncertain, long-term effects. A descriptive approach, however, uses relatively high discount rates between 10% and 30% in order to reflect the existence of barriers to energy efficiency investments (Worrell et al. 2004). The discount rate used for this study is 10%.

Table 54: Sensitivity Analysis for the Cost-effective Electricity Saving Potentials in Industrial Pumping Systems in the Base year with *Different Discount Rates*

Country		Discount Rate			
		5%	10%	15%	20%
U.S	Cost effective Annual Electricity Saving Potential (GWh/yr)	36,148	36,148	33,279	23,295
	Sum of Final CCE of all measures (US$/MWh-saved) **	962	1147	1355	1566
Canada	Cost effective Annual Electricity Saving Potential (GWh/yr)	10,785	9929	6950	3159
	Sum of Final CCE of all measures (US$/MWh-saved)	936	1116	1321	1527
EU	Cost effective Annual Electricity Saving Potential (GWh/yr)	33,085	26,921	26,921	23,885
	Sum of Final CCE of all measures (US$/MWh-saved)	1074	1274	1499	1725
Thailand	Cost effective Annual Electricity Saving Potential (GWh/yr)	3032	2782	2631	2631
	Sum of Final CCE of all measures (US$/MWh-saved)	416	522	638	765
Vietnam	Cost effective Annual Electricity Saving Potential (GWh/yr)	1693	1693	1693	1693
	Sum of Final CCE of all measures (US$/MWh-saved)	320	400	489	583
Brazil	Cost effective Annual Electricity Saving Potential (GWh/yr)	4585	4439	3840	3840
	Sum of Final CCE of all measures (US$/MWh-saved)	520	629	756	890

* The 10% discount rate is the base scenario which is used in the main analysis presented in this report.
** Sum of Final CCE of all Measures is included here to illustrate that although the change in discount rate may not result in a change in cost-effective savings, it will change the CCE in general.

Table 55: Sensitivity Analysis for the Cost-effective Electricity Saving Potentials in industrial Compressed Air Systems in the Base Year with *Different Discount Rates*

Country		Discount Rate			
		5%	10%	15%	20%
U.S	Cost effective Annual Electricity Saving Potential (GWh/yr)	20,958	20,334	18,783	17,832
	Sum of Final CCE of all measures (US$/MWh-saved)**	1110	1422	1769	2141
Canada	Cost effective Annual Electricity Saving Potential (GWh/yr)	5368	4707	3789	3789
	Sum of Final CCE of all measures (US$/MWh-saved)	1136	1457	1812	2194
EU	Cost effective Annual Electricity Saving Potential (GWh/yr)	20,024	18,519	17,980	16,640
	Sum of Final CCE of all measures (US$/MWh-saved)	1254	1605	1997	2415
Thailand	Cost effective Annual Electricity Saving Potential (GWh/yr)	3817	3741	3662	3508
	Sum of Final CCE of all measures (US$/MWh-saved)	648	841	1058	1290
Vietnam	Cost effective Annual Electricity Saving Potential (GWh/yr)	1682	1609	1493	1448
	Sum of Final CCE of all measures (US$/MWh-saved)	639	829	1043	1273
Brazil	Cost effective Annual Electricity Saving Potential (GWh/yr)	6762	6069	5892	5775
	Sum of Final CCE of all measures (US$/MWh-saved)	658	852	1068	1301

* The 10% discount rate is the base scenario which is used in the main analysis presented in this report.
** Sum of Final CCE of all measures is included here to illustrate that although the change in discount rate may not result in a change in cost-effective savings, it will change the CCE in general.

Table 56: Sensitivity Analysis for the Cost-effective Electricity Saving Potentials in Industrial Fan Systems in the Base Year with *Different Discount Rates*

Country		Discount Rate			
		5%	10%	15%	20%
U.S	Cost effective Annual Electricity Saving Potential (GWh/yr)	17,850	15,432	9945	9945
	Sum of Final CCE of all measures (US$/MWh-saved) **	318	403	499	602
Canada	Cost effective Annual Electricity Saving Potential (GWh/yr)	3276	1825	1825	1676
	Sum of Final CCE of all measures (US$/MWh-saved)	312	396	490	590
EU	Cost effective Annual Electricity Saving Potential (GWh/yr)	13,015	12,590	10,885	10,885
	Sum of Final CCE of all measures (US$/MWh-saved)	334	430	534	645
Thailand	Cost effective Annual Electricity Saving Potential (GWh/yr)	1819	1819	1639	1583
	Sum of Final CCE of all measures (US$/MWh-saved)	142	184	234	288
Vietnam	Cost effective Annual Electricity Saving Potential (GWh/yr)	832	724	724	724
	Sum of Final CCE of all measures (US$/MWh-saved)	142	184	234	288
Brazil	Cost effective Annual Electricity Saving Potential (GWh/yr)	3327	3327	3327	3327
	Sum of Final CCE of all measures (US$/MWh-saved)	152	203	251	308

* The 10% discount rate is the base scenario which is used in the main analysis presented in this report.
** Sum of Final CCE of all measures is included here to illustrate that although the change in discount rate may not result in a change in cost-effective savings, it will change the CCE in general.

The energy price can also directly influence the cost-effectiveness of energy saving potentials. A higher energy price will result in more energy efficiency measures being cost-effective, as it may cause the cost of conserved energy to fall below the energy price line in more cases. Tables 57-59 show how the cost-effective energy savings change by the variation of energy prices for all the three motor systems, keeping the discount rate and other parameters unchanged. As can be seen from the tables, in some cases the change in average unit price of electricity for the industry will not change the cost-effective energy saving potentials. This is because the change of the electricity price in that range will not change the position of the CCE of the measures compared to the electricity price line. In other words, no measures will change their ranking in relation to the average unit price of electricity line. The technical energy-savings do not change with the variation of energy prices.

Table 57: Sensitivity Analysis for the Cost-effective Electricity Saving Potentials in Industrial Pumping Systems in the Base year with *Different Electricity Price*

Country		Average Unit Price of Electricity for Industry in the Base Year Minus 20%	Average Unit Price of Electricity for Industry in the Base Year Minus 10%	Average Unit Price of Electricity for Industry in the Base Year	Average Unit Price of Electricity for Industry in the Base Year Plus 10%	Average Unit Price of Electricity for Industry in the Base Year Plus 20%
U.S.	Average unit price of electricity for industry (US$/MWh)	56.1	63.1	70.1	77.1	84.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	23,295	33,279	36,148	36,148	37,510
Canada	Average unit price of electricity for industry (US$/MWh)	46.0	51.8	57.5	63.3	69.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	6950	6950	9929	9929	10,785
EU	Average unit price of electricity for industry (US$/MWh)	86.2	97.0	107.8	118.6	129.4
	Cost effective Annual Electricity Saving Potential (GWh/yr)	25,944	26,921	26,921	28,051	28,051
Thailand	Average unit price of electricity for industry (US$/MWh)	59.7	67.2	74.6	82.1	89.6
	Cost effective Annual Electricity Saving Potential (GWh/yr)	2631	2631	2782	3032	3032
Vietnam	Average unit price of electricity for industry (US$/MWh)	42.7	48.1	53.4	58.7	64.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	1604	1693	1693	1693	1693
Brazil	Average unit price of electricity for industry (US$/MWh)	92.2	103.7	115.3	126.8	138.3
	Cost effective Annual Electricity Saving Potential (GWh/yr)	3840	3840	4439	4439	4585

Table 58: Sensitivity Analysis for the Cost-effective Electricity Saving Potentials in Industrial Compressed Air Systems in the Base Year with *Different Electricity Price*

Country		Average Unit Price of Electricity for Industry in the Base Year Minus 20%	Average Unit Price of Electricity for Industry in the Base Year Minus 10%	Average Unit Price of Electricity for Industry in the Base Year	Average Unit Price of Electricity for Industry in the Base Year Plus 10%	Average Unit Price of Electricity for Industry in the Base Year Plus 20%
U.S.	Average unit price of electricity for industry (US$ /MWh)	56.1	63.1	70.1	77.1	84.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	18,783	20,334	20,334	20,958	20,958
Canada	Average unit price of electricity for industry (US$ /MWh)	46.0	51.8	57.5	63.3	69.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	3789	4707	4707	4958	5368
EU	Average unit price of electricity for industry (US$ /MWh)	86.2	97.0	107.8	118.6	129.4
	Cost effective Annual Electricity Saving Potential (GWh/yr)	17,795	18,519	18,519	18,519	20,024
Thailand	Average unit price of electricity for industry (US$ /MWh)	59.7	67.2	74.6	82.1	89.6
	Cost effective Annual Electricity Saving Potential (GWh/yr)	3662	3741	3741	3817	3817
Vietnam	Average unit price of electricity for industry (US$ /MWh)	42.7	48.1	53.4	58.7	64.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	1493	1493	1609	1647	1682
Brazil	Average unit price of electricity for industry (US$ /MWh)	92.2	103.7	115.3	126.8	138.3
	Cost effective Annual Electricity Saving Potential (GWh/yr)	5892	5892	6069	6461	6461

Table 59: Sensitivity Analysis for the Cost-effective Electricity Saving Potentials in Industrial Fan Systems in the Base Year with *Different Electricity Price*

Country		Average Unit Price of Electricity for Industry in the Base Year Minus 20%	Average Unit Price of Electricity for Industry in the Base Year Minus 10%	Average Unit Price of Electricity for Industry in the Base Year	Average Unit Price of Electricity for Industry in the Base Year Plus 10%	Average Unit Price of Electricity for Industry in the Base Year Plus 20%
U.S.	Average unit price of electricity for industry (US$ /MWh)	56.1	63.1	70.1	77.1	84.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	9945	9945	15,432	15,432	17,850
Canada	Average unit price of electricity for industry (US$ /MWh)	46.0	51.8	57.5	63.3	69.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	1676	1676	1825	1825	2832
EU	Average unit price of electricity for industry (US$ /MWh)	86.2	97.0	107.8	118.6	129.4
	Cost effective Annual Electricity Saving Potential (GWh/yr)	10,885	12,590	12,590	13,015	13,015
Thailand	Average unit price of electricity for industry (US$ /MWh)	59.7	67.2	74.6	82.1	89.6
	Cost effective Annual Electricity Saving Potential (GWh/yr)	1819	1819	1819	1819	1819
Vietnam	Average unit price of electricity for industry (US$ /MWh)	42.7	48.1	53.4	58.7	64.1
	Cost effective Annual Electricity Saving Potential (GWh/yr)	750	750	750	832	832
Brazil	Average unit price of electricity for industry (US$ /MWh)	92.2	103.7	115.3	126.8	138.3
	Cost effective Annual Electricity Saving Potential (GWh/yr)	3327	3327	3327	3327	3327

Conclusion

This report and supporting analyses represent an initial effort to address a major barrier to effective policymaking, and to more global acceptance of the energy efficiency potential of motor systems. That barrier is the lack of a transparent methodology for quantifying the energy efficiency potential of these systems based on sufficient data to document the magnitude and cost-effectiveness of the resulting energy savings by country and by region. The research framework created to conduct the analyses supporting this Phase I report is meant to be a beginning, not an end unto itself.

The annual cost-effective and technical energy saving potential in industrial motor systems for the countries included in these analyses is summarized below and in Table 60 on the following pages.

The authors and sponsors of this research seek to initiate an international dialogue with others having an interest in the energy efficiency potential of motor systems. Through this dialogue, it is hoped that the initial framework for quantifying motor system energy efficiency potential created for this report with a combination of expert opinion and limited data will be refined and the availability of data increased. A Phase II report which includes these refinements and which encompasses a greater number of countries is anticipated.

Summary of Research and Findings

Efficiency Supply Curves were constructed for this report for pumping, fan, and compressed air systems in the U.S., Canada, EU, Thailand, Vietnam, and Brazil. The purpose of the analyses were to determine the potentials and costs of improving the energy-efficiency of these industrial motor systems by taking into account the costs and energy savings of different energy efficiency measures. Many cost-effective opportunities for energy efficiency improvement in the motor systems in the six countries have been identified but frequently not adopted, leading to what is called an "efficiency gap" (Jaffe and Stavins, 1994). This is explained by the existence of various obstacles especially non-monetary barriers to energy-efficiency improvement.

Ten energy-efficiency technologies and measures for pumping systems, ten measures for the fan systems and sixteen measures for compressed air systems were analyzed. Using the bottom-up energy efficiency supply curve model, the cost-effective electricity efficiency potentials for these motor systems were estimated for the six countries in the analyses. Total technical electricity-saving potentials were also estimated for 100% penetration of the measures in the base year. The summary of the results for all motor systems and countries studied are presented in Table 60. Using the average CO_2 emission factor of the electricity grid in each country, the CO_2 emission reduction associated with the electricity saving potentials was also calculated. Figure 22 shows the share of energy savings for each motor system as a share of total electricity use in the base year for industries studied in the six selected countries/region.

The share of total technical electricity saving potential for pumping systems as compared to the total pumping system energy use in studied industries for the base year varies between 43% and 57%. The 57% value is for Vietnam, which has the LOW efficiency base case and a correspondingly higher technical saving potential. The share of total technical electricity saving potential for compressed air systems as compared to the total compressed air system energy use in studied industries for the base year varies between 29% and 56%. Thailand, Vietnam and Brazil have higher technical saving potentials since their compressed air systems are classified in LOW efficiency base case. The share of total technical electricity saving potential for fan systems as compared with the total fan system energy use in studied industries in the base year varies between 27% and 46%. Thailand, Vietnam and Brazil have higher technical saving potentials because their fan systems are classified as LOW efficiency base case.

The share of cost-effective electricity saving potential as compared to the total motor system energy use in the base case varies between 27% and 49% for the pumping system, 21% and 47% for the compressed air system, and 14% and 46% for the fan system. Overall, Thailand, Vietnam and Brazil have a higher percentage for cost-effective potential as compared to total motor systems energy use. There are two reasons for this. First, the three developing countries have the LOW efficiency base case, so the efficiency improvement over the base case is higher for each measure, resulting in a lower CCE. Second, the application of a labor adjustment factor in the calculation of CCE for Thailand, Vietnam and Brazil reduced the CCE; thus allowing more measures to fall below the electricity price line.

In general, the cost of conserved energy has a direct proportional relationship with the discount rate. Reductions in the discount rate will produce corresponding reductions in the cost of conserved energy, which will increase the cost-effective energy-saving potential (depending on the energy price). A sensitivity analysis was conducted for a range of discount rates to illustrate these relationships.

A sensitivity analysis was also conducted for the unit price of electricity because it can vary within the country/region, especially in the U.S. and EU. The energy price can also directly influence the cost-effectiveness of energy saving potentials. A higher energy price will result in more energy efficiency measures being cost-effective, as it may cause the cost of conserved energy to fall below the energy price line in more cases. However, it should be noted that, as represented in this analysis, in some cases the change in average unit price of electricity for the industry will not change the cost-effective energy saving potentials.

It should be further noted that some energy efficiency measures provide productivity, environmental, and other benefits in addition to energy savings, but it is difficult to quantify those benefits. Including quantified estimates of other benefits can decrease the cost of conserved energy and, thus, increase the number of cost-effective efficiency measures. This could be the subject of further research. The approach used in this study and the model developed should be viewed as a screening tool to present energy-efficiency measures and capture the energy-saving potential in order to help policy makers understand the potential of savings and design appropriate energy-efficiency policies. However, the energy-saving potentials and the cost of energy-efficiency measures and technologies will vary in accordance with country- and plant-specific conditions. Finally, effective energy-efficiency policies and programs are needed to realize the cost-effective potentials and to exceed those potentials in the future.

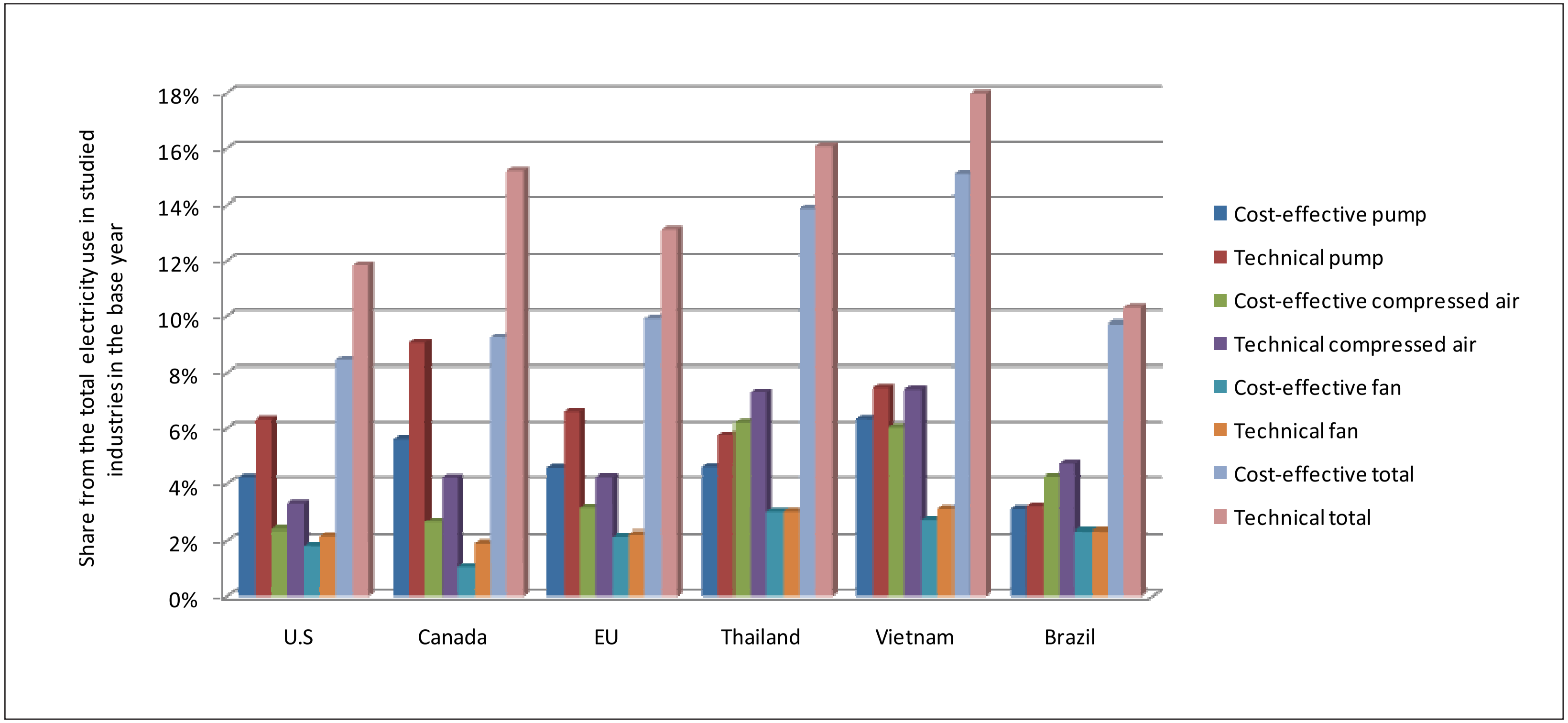
Table 60: Total Annual Cost-effective and Technical Energy Saving Potential in the Industrial Motor Systems in Studied Countries

Country	Annual Electricity Saving Potential in Industrial Pumping Systems (100% Penetration) (GWh/yr)		Share of saving from the total Pumping System Energy Use in Studied Industries in 2008	
	Cost effective	Technical	Cost effective	Technical*
U.S	36,148	54,023	29%	43%
Canada	9,929	16,118	27%	45%
EU	26,921	38,773	30%	44%
Thailand	2,782	3,459	36%	45%
Vietnam	1,693	1,984	49%	57%
Brazil	4,439	4,585	43%	45%

Country	Annual Electricity Saving Potential in Industrial Compressed Air System (100% Penetration) (GWh/yr)		Share of Saving from the Total Compressed Air System Energy Use in Studied Industries in 2008	
	Cost effective	Technical	Cost effective	Technical*
U.S	20,334	28,403	21%	29%
Canada	4,707	7,498	26%	41%
EU	18,519	24,857	28%	38%
Thailand	3,741	4,381	47%	55%
Vietnam	1,609	1,970	46%	56%
Brazil	6,069	6,762	42%	47%
Country	Annual Electricity Saving Potential in Industrial Fan System (100% Penetration) (GWh/yr)		Share of saving from the Total Fan system Energy Use in Studied Industries in 2008	
	Cost effective	Technical	Cost effective	Technical*
U.S	15,432	18,451	25%	30%
Canada	1,825	3,386	14%	27%
EU	12,590	13,015	28%	29%
Thailand	1,819	1,819	46%	46%
Vietnam	750	832	41%	45%
Brazil	3,327	3,327	40%	40%
Country	Total Annual Electricity Saving Potential in Industrial Pump, Compressed Air, and Fan System (GWh/yr)		Share of Saving from Electricity Use in Pump, Compressed Air, and Fan Systems in Studied Industries in 2008	
	Cost effective	Technical	Cost effective	Technical*
U.S	71,914	100,877	25%	35%
Canada	16,461	27,002	25%	40%
EU	58,030	76,644	29%	39%
Thailand	8,343	9,659	43%	49%
Vietnam	4,026	4,787	46%	54%
Brazil	13,836	14,675	42%	44%
Total (sum of 6 countries)	172,609	233,644	28%	38%

* In calculation of energy savings, equipment 1000 hp or greater are excluded.

Figure 22: Energy Savings by Motor System as a Share of Total Electricity Use in the Base Year for Industries Studied in the Six Selected Countries



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APPENDICES

A.1. COUNTRY-SPECIFIC DATA

Country-Specific Data: United States

Industrial Sub-sector	Electricity Consumption in 2008 (GWh)	Motor Systems Electricity Use as the % of Total Electricity Use in Each Industrial Sector	Estimated Pumping System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Pumping System Electricity Use (GWh)	Estimated Fan System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Fan System Electricity Use (GWh)	Estimated Compressed Air System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Compressed Air System Electricity Use (GWh)
Food and Beverage	87483	46.6%	11.9%	10402	6.4%	5564	15.0%	13130
Textiles, Apparel, and Leather	28198	53.7%	13.0%	3658	6.7%	1893	23.4%	6592
Alumina and Aluminum	44906	13.3%	4.8%	2154	2.0%	916	5.5%	2453
Foundries	16798	33.3%	7.1%	1198	5.6%	933	7.0%	1181
Steel Industry	58450	48.0%	11.3%	6613	6.1%	3542	8.6%	5009
Cement	13396	77.8%	15.0%	2009	11.4%	1527	10.1%	1351
Glass and Fiber Glass	18679	40.0%	10.5%	1953	5.5%	1019	7.8%	1450
Chemicals	207107	53.7%	15.8%	32672	7.5%	15555	8.7%	18031
Forest Products (wood products and paper)	151079	69.3%	21.0%	31683	10.1%	15255	12.7%	19186
Petroleum Refineries	56543	74.5%	27.2%	15399	11.2%	6316	9.7%	5465
Fabricated Metal Products	42238	49.4%	11.5%	4850	6.2%	2607	13.5%	5723
Machinery	32733	50.9%	12.1%	3961	5.9%	1937	16.3%	5336
Computers, Electronics, Appliances, Electrical Equipment	40412	29.6%	8.9%	3601	3.4%	1355	13.1%	5292
Plastics and Rubber Products	53423	48.6%	11.3%	6028	6.0%	3211	13.5%	7229
Sum	**851445**			**126180**		**61631**		**97427**
Sum minus 1000hp+	**786,633**			**116477**		**49724**		**54224**

Country-Specific Data : Canada

Industrial Sub-sector	Electricity Consumption in 2008 (GWh)	Motor Systems Electricity Use as the % of Total Electricity Use in Each Industrial Sector	Estimated Pumping System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Pumping System Electricity Use (GWh)	Estimated Fan System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Fan System Electricity Use (GWh)	Estimated Compressed Air System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Compressed Air System Electricity Use (GWh)
Food and Beverage	9,630	46.6%	29.5%	2845	6.4%	613	15.0%	1445
Textiles, Apparel, and Leather	1,255	46.6%	29.7%	373	6.7%	84	23.4%	293
Primary Metal	65,420	33.0%	8.3%	5425	4.5%	2936	7.2%	4705
Non-Metallic Mineral	4,345	55.8%	12.4%	537	7.9%	345	8.7%	379
Chemical	20,837	53.7%	30.8%	6424	7.5%	1565	8.7%	1814
Forest Products (wood products and paper)	54,251	69.3%	31.7%	17172	10.1%	5478	12.7%	6889
Petroleum and Coal Products	6,329	74.5%	27.2%	1724	11.2%	707	9.7%	612
Fabricated Metal	5,210	49.4%	11.5%	598	6.2%	322	13.5%	706
Machinery Manufacturing	2,472	50.9%	12.1%	299	5.9%	146	16.3%	403
Computers, Electronics, Appliances, Electrical Equipment	2,186	29.6%	8.9%	195	3.4%	73	13.1%	286
Plastics and Rubber Products	5,510	48.6%	11.3%	622	6.0%	331	13.5%	746
Sum	**177,446**			**36213**		**12600**		**18280**
Sum minus 1000hp+	**165,775**			**34752**		**9125**		**14314**

Country-Specific Data: European Union

Industrial Sub-sector	Electricity Consumption in 2008 (GWh)	Motor Systems Electricity Use as the % of Total Electricity Use in Each Industrial Sector	Estimated Pumping System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Pumping System Electricity Use (GWh)	Estimated Fan System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Fan System Electricity Use (GWh)	Estimated Compressed Air System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Compressed Air System Electricity Use (GWh)
Food, beverage and tobacco	111,830	46.6%	11.9%	13297	6.4%	7113	15.0%	16784
Iron and steel	138,690	48.0%	11.3%	15690	6.1%	8405	8.6%	11885
Non-metallic mineral	85,069	55.8%	12.4%	10509	7.9%	6752	8.7%	7428
Paper, pulp and print	142,223	69.3%	21.0%	29825	10.1%	14360	12.7%	18061
Chemical	199,531	53.7%	15.8%	31477	7.5%	14986	8.7%	17371
Machinery and metal	158,295	42.9%	10.8%	17027	5.1%	8093	14.2%	22432
Sum	**585,118**			**88,838**		**44191**		**65,292**
Sum minus 1000hp+	**552,921**			**83,597**		**35073**		**47,454**

Country-Specific Data: Thailand

Industrial Sub-sector	Electricity Consumption in 2008 (GWh)	Motor Systems Electricity Use as the % of Total Electricity Use in Each Industrial Sector	Estimated Pumping System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Pumping System Electricity Use (GWh)	Estimated Fan System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Fan System Electricity Use (GWh)	Estimated Compressed Air System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Compressed Air System Electricity Use (GWh)
Food and Beverage	10,583	46.6%	11.9%	1258	6.4%	673	15.0%	1588
Textiles, Apparel, and Leather	7,687	53.7%	13.0%	997	6.7%	516	23.4%	1797
Primary Metal	7,199	33.0%	8.3%	597	4.5%	323	7.2%	518
Non-Metallic Mineral	7,141	55.8%	12.4%	882	7.9%	567	8.7%	624
Chemical, 'Petroleum Refineries, and Plastic Products	9,955	56.5%	17.1%	1699	7.9%	787	9.7%	965
Forest Products (wood products and paper)	3,803	69.3%	21.0%	798	10.1%	384	12.7%	483
Fabricated Metal, 'Machinery, and 'Electrical Machinery	13,735	42.9%	10.8%	1477	5.1%	702	14.2%	1946
Sum	**60,104**			**7,708**		**3,953**		**7,921**
Sum minus 1000hp+	**57,985**			**7,458**		**3,638**		**7,052**

Country-Specific Data : Vietnam

Industrial Sub-sector	Electricity Consumption in 2008 (GWh)	Motor Systems Electricity Use as the % of Total Electricity Use in Each Industrial Sector	Estimated Pumping System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Pumping System Electricity Use (GWh)	Estimated Fan System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Fan System Electricity Use (GWh)	Estimated Compressed Air System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Compressed Air System Electricity Use (GWh)
Food and Beverage	6,565	46.6%	11.9%	781	6.4%	418	15.0%	985
Textiles, Apparel, and Leather	4,409	53.7%	13.0%	572	6.7%	296	23.4%	1031
Primary Metal	3,690	33.0%	8.3%	306	4.5%	166	7.2%	265
Non-Metallic Mineral	4,451	55.8%	12.4%	550	7.9%	353	8.7%	389
Chemical, 'Petroleum Refineries, and Plastic Products	3,786	56.5%	17.1%	646	7.9%	299	9.7%	367
Forest Products (wood products and paper)	2,140	69.3%	21.0%	449	10.1%	216	12.7%	272
Fabricated Metal, 'Machinery, and 'Electrical Machinery	1,593	42.9%	10.8%	171	5.1%	81	14.2%	226
Sum	**26,634**			**3,474**		**1,829**		**3,534**
Sum minus 1000hp+	**25,730**			**3,377**		**1,665**		**3,171**

Country-Specific Data: Brazil

Industrial Sub-sector	Electricity Consumption in 2008 (GWh)	Motor Systems Electricity Use as the % of Total Electricity Use in Each Industrial Sector	Estimated Pumping System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Pumping System Electricity Use (GWh)	Estimated Fan System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Fan System Electricity Use (GWh)	Estimated Compressed Air System Electricity Use as % of Overall Electricity Use in the Sector	Estimated Compressed Air System Electricity Use (GWh)
Food and Beverage	23,080	56.0%	11.9%	1536.7	6.4%	1468	15.0%	3464
Textiles	7,813	51.7%	13.0%	524.5	6.7%	525	23.4%	1826
Non-ferrous metals	39,144	27.3%	4.8%	512.3	2.0%	799	5.5%	2138
Ferro alloys	8,737	2.6%	7.1%	16.3	5.6%	485	7.0%	614
Pig iron and Steel	18,622	75.2%	11.3%	1584.2	6.1%	1129	8.6%	1596
Cement	4,777	88.5%	15.0%	634.2	11.4%	545	10.1%	482
Chemicals	22,109	66.3%	15.8%	2312.5	7.5%	1660	8.7%	1925
Pulp and paper	17,764	85.3%	21.0%	3176.7	10.1%	1794	12.7%	2256
Sum	**142,046**			**10297**		**8404**		**14301**
Sum minus 1000hp+	**131,888**			**9887**		**6654**		**10886**

Country-Specific Data : United States	Year 2008	Unit
Average **Unit** Price of Electricity for Industry	70.1	US$/MWh
Emission Factor for Grid Electricity in 2008	0.60	(kgCO2/KWh)
Average Transmission and Distribution Losses of the Electricity Grid in the Country in 2008	6.5%	%
Weighted Average Net Generation Efficiency of Fossil Fuel-Fired Power Plants in the Country in 2008	35.1%	%
Weighted Average Net Generation Efficiency Including T&D losses (%)	32.8%	%
Conversion Rate from Final to Primary Electricity	3.05	

Country-Specific Data : Canada	Year 2008	Unit
Average **Unit** Price of Electricity for Industry	57.5	US$/MWh
Emission Factor for Grid Electricity in 2008	0.50	(kgCO2/KWh)
Average Transmission and Distribution Losses of the Electricity Grid in the Country in 2008	6.6%	%
Weighted Average Net Generation Efficiency of Fossil Fuel-Fired Power Plants in the Country in 2008	30.94%	%
Weighted Average Net Generation Efficiency Including T&D Losses (%)	28.9%	%
Conversion Rate from Final to Primary Electricity	3.46	

Country-Specific Data : European Union	Year 2007	Unit
Average **Uunit** Price of Electricity for Industry	107.8	US$/MWh
Emission Factor for Grid Electricity in 2007	0.44	(kgCO2/KWh)
Average Transmission and Distribution Losses of the Electricity Grid in the Country in 2007	6.4%	%
Weighted Average Net Generation Efficiency of Fossil Fuel-Fired Power Plants in the Country in 2007	40.9%	%
Weighted Average Net Generation Efficiency Including T&D Losses (%)	38.3%	%
Conversion Rate from Final to Primary Electricity	2.61	

Country-Specific Data : Thailand	Year 2008	Unit
Average **Unit** Price of Electricity for Industry	74.6	US$/MWh
Emission Factor for Grid Electricity in 2008	0.52	($kgCO_2/KWh$)
Average Transmission and Distribution Losses of the Electricity Grid in the Country in 2008	6.1%	%
Weighted Average Net Generation Efficiency of Fossil Fuel-Fired Power Plants in the Country in 2008	38.1%	%
Weighted Average Net Generation Efficiency Including T&D Losses (%)	35.8%	%
Conversion Rate from Final to Primary Electricity	2.80	

Country-Specific Data : Vietnam	Year 2008	unit
Average **Unit** Price of Electricity for Industry	53.4	US$/MWh
Emission factor for Grid Electricity in 2008	0.49	($kgCO_2/KWh$)
Average Transmission and Distribution Losses of the Electricity Grid in the Country in 2008	9.4%	%
Weighted Average Net Generation Efficiency of Fossil Fuel-Fired Power Plants in the Country in 2008	27.8%	%
Weighted Average Net Generation Efficiency Including T&D Losses (%)	25.2%	%
Conversion Rate from Final to Primary Electricity	3.97	

Country-Specific Data : Brazil	Year 2008	Unit
Average **Unit** Price of Electricity for Industry	115.3	US$/MWh
Emission Factor for Grid Electricity in 2008	0.146	($kgCO_2/KWh$)
Average Transmission and Distribution Losses of the Electricity Grid in the Country in 2008	16.6%	%
Weighted Average Net Generation Efficiency of Fossil Fuel-Fired Power Plants in the Country in 2008 *	38.7%	%
Weighted Average Net Generation efficiency including T&D Losses (%)	32.3%	%
Conversion Rate from Final to Primary Electricity	3.10	

* It should be noted that in Brazil electricity generation mix is 87% hydropower, 3% nuclear, and 10% fossil fuel. In this study, the net generation efficiency of fossil fuel-fired power plants is used for converting electricity consumption from final to primary energy in all countries.

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