APEC-CAST MOTOR REPAIRS PROJECT

ON BEHALF OF THE APEC EXPERT GROUP ON ENERGY EFFICIENCY AND CONSERVATION

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Task 2: Market Overview

Final Report

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ECONOLER

ABBREVIATIONS

AC	Alternating current
ACEEE	American Council for an Energy-Efficient Economy
ADC	Aluminium die cast
APEC	Asia-Pacific Economic Cooperation
CuDC	Copper die cast
DOE	U.S. Department of Energy
EE	Energy Efficiency
EIA	U.S. Energy Information Administration
EuP	Energy using product
Hp	Horsepower
ICA	International Copper Association
IEA	International Energy Agency
kW	Kilowatt
NZ	New Zealand
ODP	Open drip-proof
TEFC	Totally enclosed fan-cooled
TWh	Terawatt-hour
US	United States of America

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EXECUTIVE SUMMARY

This report establishes the market characteristics of three-phase AC induction motor failure and repair in five economies: China, Japan, New Zealand (NZ), the United States of America (US) and Vietnam. The term "three-phase AC induction motors" is hereinafter referred to as "motors".

Country-specific Data Collection

Mostly for New Zealand and the US, two national studies on electric motors were identified to collect data on the number, types and sizes of motors installed, their applications and purposes, or their number of operating hours per year. Other data provided by the studies include the number of motor failure cases each year or the number of failed motors that were repaired and put back in service. The first study was conducted in 1998 in the US and the second, in 2006 in NZ. For China, Japan and Vietnam, no information was available.[1]

To collect recent country-specific market data on motor sales, use, failure and repair, email and telephone interviews were conducted as a primary research strategy with stakeholder countries. Their feedback confirmed that not only there is no field data on motor failure and repair in China, Japan and Vietnam, but also the studies identified in New Zealand and the US were the most recent in their respective economies.

Due to the difficulty of obtaining recent market data, in-person interviews at repair shops were conducted in each country to collect data on motor failure and repair market characteristics, such as the percentage of failed motors that are repaired and put back in service, type of failure, motor rewind intervals, the distribution of failed motors among power classes, enclosure types, and number of poles. Because shops did not keep specific records in the format needed in the survey form, some questions were answered based on respondents' practical experience in the field of motor repair.

Findings

For the purpose of this study, motors were divided into four categories according to their rated power: up to 50 kW (67 hp); 51 to 200 kW (68 to 268 hp); 202 to 375 kW (269 to 502 hp); and 375 kW and above (502 hp and above). Based on data collected from a literature review and the survey conducted at the repair shops, the market characteristics of motor failure and repair in the five economies is presented as follows.

› Motors up to 50 kW in rated power accounted for approximately 94% of the total stock of motors in operation in these economies. Motors with a rated power between 51 kW – 200 kW, between 202 kW – 375 kW and above 375 kW respectively accounted for 6.2%, 0.3% and 0.2% of the total stock of motors in operation in each economy.

[1] This does not mean that reports or statistics do not exist in these three countries; it only means that they were not public or available to us.

- The majority of motors were sent to repair shops because of winding failure (despite being more common, repair of failed bearings was excluded from this study as rewinding techniques were more the focus of this study than mechanical failure repair). The general trend was that the proportion of rewound motors increased with power rating. As for winding failure with or without lamination damage, the situation was slightly different across the economies. In China, the prevalence of lamination damage was slightly higher than in the other economies. However, in Japan, the prevalence of lamination damage was lower than in the other economies. Possible causes of this phenomenon in this country could be better condition-monitoring practices, preventive maintenance practices, motor design and winding quality.
- Very few motors with rotor failure were sent to repair shops. All US respondents made it clear that rotor-related failure accounted for 1% to 3% at the most. The average was approximately 5% for the other economies surveyed except China, where the prevalence of rotor failure was higher (approximately 30%). This finding could be explained with the hypothesis that none of the shops surveyed in China reported using repair standards, guidelines, procedures or specifications. This could lead to poor rotor handling during repair. Poor rotor quality could also be the cause of this problem.
- Rotor replacement measure is beneficial to constant load unlike variable load, for which the speed increase must be determined and, therefore, the amount of power drawn versus motor efficiency improvement.
- Motors below 200 kW (268 hp) in rated power accounted for 79% to 90% of all failed motors sent to repair shops across the countries. This finding could be explained by the fact that these motors accounted for the largest part of the stock of installed motors in operation.
- Fewer than one in three shops surveyed was ISO 9001 certified. None of the shops surveyed in the US had ISO certification. ISO 9001 is a quality management standard that applies to daily management operations within certified shops. Moreover, some shops surveyed made it clear that ISO certification has virtually nothing to do with the AC motor repair/rewind business. For these shops, test certificate from some of their larger customers and motor manufacturers mean much more.
- Several US interviewees raised a general issue about the long-term viability of the rewind industry, given the changing job market and interests of a different generation. Few people are being trained because of the lack of personnel committed to fully learning the trade of motor rewinding and making it a career. The fact that there are no training programs in community colleges or short courses specific to this trade is another reason for the lack of experienced rewinders. Nonetheless, motor rewinding is absolutely critical in motor reworking.

INTRODUCTION

The efficiency of electric motor is generally affected by repair practices in repair shops around the world. At the beginning of 2000, there was a common belief that rewinding or repairing three-phase AC induction motors could systematically result in a reduction of its original energy efficiency (EE) by up to 2 percent after repair, depending on motor size.[2] However, advanced practices in motor rewinding and repair exist, and unlike traditional poor practices, they have the potential to partly or totally eliminate motor efficiency degradation. Even though technical solutions for improving repair or rewinding practices exist, most motor repair shops in developing economies still apply poor practices. Obviously, this situation can result in substantial electrical energy waste since motors are by far the largest end-use for electricity. Indeed, according to the International Energy Agency (IEA), electric motors account for between 43 and 46 percent of global electricity consumption.[3] This level of electricity consumption is not surprising since electric motors are used not only in a wide range of industrial systems, but also in many types of applications such as pumping, ventilation and compressors, in the commercial, residential and agricultural sectors.

In many developing countries, a significant portion of the installed electric motor stock fails each year, and most of the failed motors are repaired and put back into service. For example, in China it is estimated that 10 percent of all electric motors in industrial applications fail during operation each year. Out of these, 87 percent are repaired and put back into service. The potential for energy savings from improved motor repair practices in countries, especially in developing ones, is enormous.

The primary aim of this study is to estimate the EE improvement potential related to available technical solutions through the adoption of best practices, which may later be included in related standards. More specifically, the study seeks to: 1) document and analyze current best practices in selected APEC countries; 2) establish the market characteristics concerning motor repair in each country; and 3) estimate the potential for EE improvement through repair and refurbishment by using available technical solutions and following best practices in the industry. The study will benefit policy-makers and bodies in charge of setting standards because it will help raise their awareness of the potential for energy savings associated with repair and preventive maintenance of installed motors.

This second report (in a series of three) describes the market characteristics concerning motor failure and repair in five economies: China, Japan, New Zealand (NZ), the United States of America (US) and Vietnam. The report analyzes the installed stock of three-phase squirrel cage AC induction motors in operation in each country and the number of motors that fail per year. It also presents a description of key market characteristics concerning electric motor failure and repair in these five economies. In this report, three-phase AC induction motors are simply referred to as motors.

[2] Motor Challenge Fact Sheet at http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/mc-0382.pdf
[3] International Energy Agency at http://www.iea.org/newsroomandevents/news/2011/may/name,19833,en.html

1 COUNTRY-SPECIFIC DATA COLLECTION

To collect information on motors, the research team combined three approaches: literature research; telephone interviews and emailing, and in-person interviews at repair shops.

Literature Research With regards to the five countries under study, the team identified studies on electric motors conducted in New Zealand and the US.

In New Zealand, the study[4] was conducted in 2006on motor replacement in the industrial sector, as part of the Electricity Commission pilot project on motor system operation efficiency improvement. The field data of this study provided information on the number of motors that failed each year and the number of failed motors that were repaired and returned to service. It also provides information on the rewind intervals on motors based on results obtained from the survey conducted as part of this study and a Canadian study[5] conducted in 2001.

In 1998, the US Department of Energy (DOE) commissioned a major market assessment study[6] on the US electric motor population and its use as part of its Motor Challenge Program.[7] Upon completion, the study provided a detailed profile of the stock of motor-driven equipment in US industrial facilities, including an estimate of the number of motors that fail each year, the percentage of failed motors repaired and put back in service and operation parameters of motors in use, such as the average load factor, annual operating hours and service lifetime. The study contains little information on motor failure or repair. In addition, the only information provided seems more a rule of thumb than factual information. Since then, no other study of this kind has been conducted in the US.[8] But other study reports refer to the 1998 DOE study to make projections of current motor stock in the US, confirming that the DOE study is the most recent comprehensive assessment of motors in the US.

Another important source of information on motors in the US is the report[9] on motor shipment analysis issued by the DOE. The report presents data on the share of motors by horsepower rating based on the distribution available in the database of the Washington State University Extension Energy Program (WSU), which collected data from extensive field measurements.

The study team also identified a handbook on energy efficient motor systems published by the American Council for an Energy-Efficient Economy (ACEEE) in 2002. The handbook provides a profile of the motor population and use in the US based on past field motor surveys conducted in commercial and industrial facilities in the 1980s and 1990s. The profile contains data on motor population, distribution, as well as use by size and type. It also contains motor distribution by speed, enclosure, duty and load factors, and motor life.

[4] Electricity Commission, *Industrial Motors Efficiency: Motor Replacement*. 2006.
[5] Ibid, p 37
[6] USDOE, *United States Industrial Electric Motor Systems: Market Opportunities Assessment*.1998.
[7] Motor Challenge is an industry/government partnership designed to help industrial businesses capture significant energy and cost savings by increasing motor system efficiency.
[8] Interview with the Office of Energy Efficiency & Renewable Energy within the USDOE on March 4, 2013.
[9] DOE, 2012, “Shipments Analysis”

For China, Japan and Vietnam, no information was available[10] with regards to the number of electric motors installed, their types and sizes, their applications and purposes, or the numbers of their operating hours per year. Neither was there much data on the numbers of motor failure cases each year or the numbers of failed motors that were repaired and put back in service.

The team also identified the preparatory studies on motors conducted under "The Energy Using Product (EuP)" Directive (2005/32/EC) in Europe.[11] Even though countries are not covered by this study, the information in these preparatory studies was considered as a benchmark to cross-check other information collected in the stakeholder countries.

Email and Telephone Interviews

To collect recent country-specific market data on motor sales, use, failure and repair, email and telephone interviews were conducted with stakeholders (motor manufacturers' associations, motor experts in public agencies in charge of electric motors standards and labeling programs, non-profit organizations engaged in energy-efficient motor promotion, etc.). Stakeholder feedback confirmed that no field data on motor failure and repair exists in China, Japan or Vietnam. Also, the feedback confirmed that the 1998 and 2006 studies carried out in the US and NZ, respectively, were the most recent.

In-person Interviews

Due to the difficulty of obtaining recent market data with the activity above, in person interviews and shop visits were organized with a limited number of repair shops in each target country. These visits allowed the research team to collect data on motor failure and repair market characteristics, such as the percentage of failed motors that are repaired and put back to service, the frequency of each type of failure, motor rewind intervals and the distribution of failed motors among power classes, enclosure types as well as number of poles. Because shops did not keep specific records in the format needed for this survey, some questions were answered based on the respondent's practical experience in the field of motor repair.

[10] This does not mean that there were no reports or statistic available in the countries surveyed, but they were not public or available to us.
[11] See the preparatory studies under "The Energy Using Product (EuP)" Directive (2005/32/EC) by Anibal T. de Almeida et al, 2008

2 MOTOR USE IN THE SURVEYED COUNTRIES

This section analyzes motor electricity consumption in the surveyed countries and estimates the stock of installed motors in use in each economy.

2.1 ELECTRICITY USE IN THE SURVEYED COUNTRIES

U.S. Energy Information Agency[12] (EIA) statistics show that electricity consumption increased over the 2006–2010 period in all the five surveyed economies, as shown in Table 1 below. The 2011 and 2012 figures are derived from consumption data from 2006 to 2010 based on the average annual growth rate.

Table 1: Annual Electricity Consumption in TWh

Year	China	US	Japan	Vietnam	New Zealand (NZ)
2006	2,525	3,817	985	52	39
2007	2,874	3,890	1 011	59	40
2008	3,054	3,865	966	66	39
2009	3,271	3,724	938	75	39
2010	3,634	3,886	1 002	86	41
2011	3,980	3,904	1 006	97	41
2012	4,359	3,922	1 011	110	41
Average Annual Growth Rate (2006-2010)	**9.5%**	**0.5%**	**0.4%**	**13.3%**	**0.9%**
Average Gross Domestic Product (GDP) Growth Rate (2006-2010)[13]	**11.2%**	**0.7%**	**0.4%**	**7.0%**	**0.9%**

Source: EIA Statistics.

As shown in the table above, electricity consumption grew faster in China and Vietnam than in Japan, NZ and the US. In fact, while the average annual electricity consumption growth rate from 2006 to 2010 in China and Vietnam was respectively 9.5% and 13.3%, the rate in the other countries was less than 1% over the same period. This observation is coherent with the state of development of those countries, as China and Vietnam are emerging economies with fast-growing GDP and electricity demand. In the industrialized economies of Japan, NZ and the US, the low average annual growth rate in electricity consumption could be the result of long-term aggressive EE initiatives across major end-use sectors, such as industry, commerce and residences.

[12] http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=2 (October 4, 2013)
[13] World Bank Statistics http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/countries (October 4, 2013)

2.2 ELECTRICITY USE OF THREE-PHASE AC INDUCTION MOTORS

All electric motors, DC and AC combined, account for approximately 40% to 55% of electricity consumption across the five economies.[14] At the world level, electric motors contribute to 46% of total electricity consumption.

Due to limited data available, as discussed in Section 1, a methodology had to be developed to estimate the electricity consumption of three-phase squirrel cage AC induction motors for each country. To be in line with the scope of this study, the estimate focuses on motors with a power rating of more than 1 hp (0.75 kW).

The methodology for estimating electricity use of motors was based on a top-down approach which involved deriving the electricity use of these motors from the national electricity consumption figures based on the share of electricity use accounted for by these motors in the total electricity consumption of all types of motors. Details about the methodology are presented in Appendix 1.

Based on this top-down approach, the estimated electricity consumption of motors for 2012 is presented in Figure 1 below.

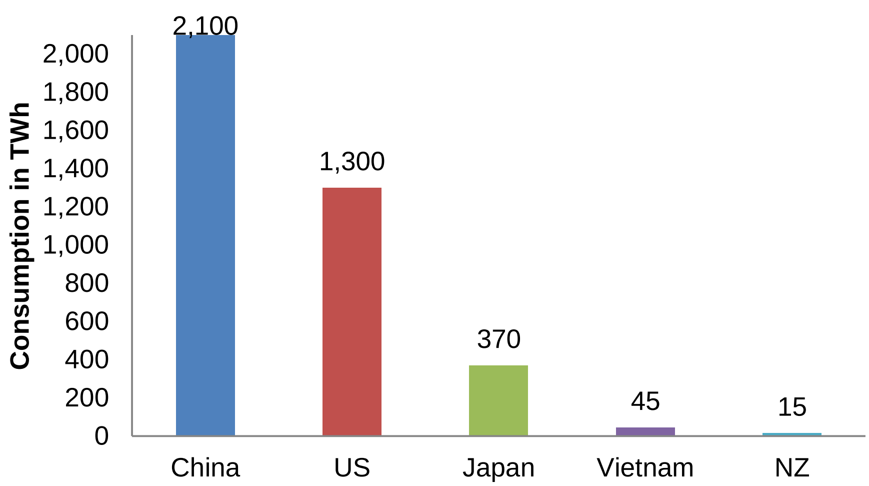

Figure 1: Electricity Use of Motors by Country

Electricity use by motors varies from one country to another. China and the US have the highest motors electricity consumption, 2,077 TWh and 1,300 TWh respectively. The two economies with the lowest motor electricity consumption are Vietnam and NZ, with approximately 45 TWh and 16 TWh, respectively. Motors in the five economies collectively consume 3,805 TWh of electricity, representing approximately 53% of the global electricity consumption by all electric motors, which was estimated at 7,200 TWh.[15]

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14 IEA, 2011, p. 37.
15 IEA, 2011, p. 39.

2.3 MOTOR POPULATION AND DISTRIBUTION BY POWER RANGE

As with motor electricity consumption, it was also necessary to estimate the population of motors in use for each economy. The methodology used was also based on a top-down approach, which involved estimating energy consumption by motors according to the power range and thus deriving their numbers. The methodology is described in detail in Appendix II.

Based on the electricity use by motors in 2012 and other assumptions discussed in Appendix II, the number of motors in use in each economy has been estimated and is presented in Table 2 below.

Table 2: Three-Phase AC Induction Motors in Operation (Million Pieces)

Power Class	China	US	Japan	Vietnam	NZ
Under 50 kW (67 hp)	40	31	7	1	0.300
51 - 200 kW (68 - 268 hp)	3	2	0.49	0.06	0.020
202 - 375 kW (269 - 502 hp)	0.11	0.08	0.02	0.003	0.001
Above 375 kW (Above 502 hp)	0.08	0.06	0.01	0.002	0.001
Total	**43**	**33**	**8**	**1.0**	**0.32**

As can be seen from Table 2, the majority of motors have a rated power up to 50 kW. In fact, motors under 50 kW account for approximately 94% of the total stock of motors in operation in the economies. AC motors with a rated power between 51 kW – 200 kW, 202 kW – 375 kW and above 375 kW respectively account for 6.2%, 0.3% and 0.2% of the total stock installed in each economy.

This distribution trend shown in the table above is more or less in line with the breakdown reported in published reports of previous field surveys conducted on the industrial and commercial sectors.

Table 3: AC Motor Population Distribution by Literature Review

Power Class	Current Study	Washington State University Database[16]	EuP Lot 11 Study in 2008[17]	DOE Motor Market Study[18]
Under 50 kW (67 hp)	93.3%	96.8%	96%	94.3%
51 - 200 kW (68 - 268 hp)	6.2%	3.1%	3.54%	4.7%
202 - 375 kW (269 - 502 hp)	0.3%	0.3%	0.15%	0.70%
Above 375 kW (Above 502 hp)	0.2%	-	0.2%	0.21%
Total	**100.0%**	**100%**	**100%**	**-**

[16] The Washington State University (WSU) conducted an extensive field measurement under its Extension Energy Program. See T. de Almeida et al, 2002,
[17] Anibal T. de Almeida *et al*, 2008, p. 15.
[18] DOE, 1997, p. 51.

3 FAILURE MODES IN MOTOR REPAIR MARKET

This section summarizes key data on failures associated with electric motors that workshops receive in the five economies surveyed. The data analyzed in this section resulted from in-person interviews with repair shops in the five economies. Information from the NZ study on motor failure was also used as a coherence check of the results obtained in this particular country.

3.1 WINDING FAILURE

The study has covered repair practices associated with stator and rotor failures. For each country, the survey looked at the percentage of the failed motor population affected by either winding failure with/without lamination damage or rotor failure.

Winding failures are mainly caused by electrical factors, as well as excessive temperature and overload conditions. As for lamination damage, there are several potential causes, including an unreliable winding, inadequate external protection systems, stator damage while dismantling a failed bearing and poor condition-monitoring practices.

Table 4 presents the survey results with respect to winding and rotor failure at the shops surveyed in the economies. For a given country in the table, each block of three values can exceed 100%, because it was reported that rotor failure could occur together with stator winding failure.

Table 4: Winding and Rotor Failure Modes by Power Rating

Power Rating and Failure Modes	Percentage				
	China	Japan	NZ	US	Vietnam
Under 50 kW - Winding failure with lamination damage	25%	7%	23%	98%	28%
Under 50 kW - Winding failure without lamination damage	46%	88%	76%		72%
Under 50 kW - Rotor failure	29%	7%	5%	1-3%	9%
51 to 200 kW - Winding failure with lamination damage	24%	8%	25%	98%	28%
51 to 200 kW - Winding failure without lamination damage	45%	87%	77%		72%
51 to 200 kW - Rotor failure	31%	6%	5%	1-3%	11%
201 to 375 kW - Winding failure with lamination damage	34%	9%	25%	98%	35%
201 to 375 kW - Winding failure without lamination damage	41%	87%	73%		66%
201 to 375 kW - Rotor failure	29%	4%	7%	1-3%	11%
Above 375 kW - Winding failure with lamination damage	33%	9%	22%	98%	30%
Above 375 kW - Winding failure without lamination damage	41%	87%	78%		70%
Above 375 kW - Rotor failure	30%	3%	8%	1-3%	4%

As shown by the survey results, the majority of electric motors were sent to repair shops due to winding failure. As for winding failure with or without lamination damage, the situation was slightly different across the surveyed economies. Among all the failed motors received at the shops surveyed in NZ and Vietnam, approximately 75% simply had failed due to winding failure without lamination damage and 25% had failed due to winding failure with lamination damage. In the US, most shops surveyed indicated that approximately 98% of failed motors were due to winding failure with and without lamination damage. These shops did not distinguish between cases with and without lamination damage.

In China, the prevalence of lamination damage was slightly higher than in the abovementioned economies. However, in Japan, the prevalence of lamination damage was lower (less than 10%). Better condition-monitoring practices, preventive maintenance practices, machine design and winding quality were possible causes of this trend observed in Japan.

Rotor failure prevalence in the economies under study is analyzed in the following section.

3.2 ROTOR FAILURE

This section first analyzes motor rotor failure modes and then examines the rotor market from the replacement perspective. The information on motor rotor failures presented below was collected from interviews with the repair shops surveyed.

3.2.1 Prevalence of Rotor Failure in the Repair Market

According to an expert from a leading motor industry who was interviewed as part of the present study, rotor failure accounted for approximately 5% to 7% of all the motor failures, as the power rating of motors increases. In other words, for powerful machines (above 375 kW), rotor failures typically accounts for 7% of all failures; as for smaller motors (less than 375 kW), motor failures account for 5%. This general trend is more or less in line with the one revealed by the shop survey results for most economies covered by the study.

In fact, the survey results (See Table 4) revealed that a very low number of motors with simply rotor failure were sent to repair shops. All the respondents in the US made it clear that failure strictly due to rotors were in the range of 1% to 3% at most. The average was approximately 5% for the other economies surveyed except China, where the prevalence of rotor failure was higher (approximately 30%). A hypothesis to explain this phenomenon could be that none of the shops surveyed in China reported using repair standards, guidelines, procedures or specifications. This could result in poor handling of rotors during repair. Also, this could be due to poor rotor quality.

3.2.2 Rotor Replacement

Two main points need to be mentioned with regards to the EE aspect of replacing aluminium rotor with copper rotor.

First, for quadratic type loads where torque is proportional to the square of the speed of the motor and the motor operates at a slightly higher speed, the power drawn is increased by the cube of the ratio of the two speeds. That is to say: if the speed is increased by 1% (quite possible with the more efficient copper rotor), the power drawn will increase by 3%. In fact, there is a risk of increasing motor power consumption after replacing aluminium rotor with a copper rotor if the motor drives a quadratic load, such as a fan, a pump or a compressor. Even though replacing an aluminum rotor with a copper one in a motor improves EE, the motor speed can increase by 1% to 5% depending on the changes made. In short, rotor replacement in a motor driving a quadratic load could make motor electricity consumption greater than energy savings in the motor as a result of rotor loss reduction and should be considered only by including this potential effect in the analysis, as the energy increase can eliminate any gain on motor efficiency by the more efficient motor.

Second, for constant torque load such as reciprocating compressors, actual flow fans, conveyor belt and crushers, a reduction in rotor loss resulting from replacing the aluminum rotor with a copper one improves motor efficiency with a similar increase in rotor speed. However, the negative effect is much less since this load is linear instead of quadratic, especially if the equipment is driven by a mass or volume signal (a higher speed means that a higher volume or mass will be moved in less time).

It is worth noting that rotor replacement is required when either fixing a failure or problem with an existing rotor or implementing loss-reduction measures on motor rotors already in use. In the first case, a common best practice is to replace rotor bars with bars made from the same materials and in the same dimensions used in the original design. When bars are replaced to reduce overall loss in motors, a recommended best practice is to replace an aluminum rotor with a copper rotor during repair. According to motor industry experts, at least 80% of all motors in installation of manufactured in all the five economies or globally use only aluminium.

In summary, the rotor replacement measure is beneficial most of the time to constant load while it will be less or not beneficial to variable load, for which the speed increase and associated power drawn must be determined compared to the load reduction resulting from increased motor efficiency.

3.2.3 Market Potential for Rotor Replacement

There are four types of rotor construction: 1) aluminium die cast (ADC); 2) copper die cast (CuDC); 3) the fabricated aluminium bar; and 4) the fabricated copper bar. In general, only the ADC, fabricated aluminium bar and copper bar rotors are in common usage today. CuDC rotor is a new technology.

A few repair shops replaced ADC rotors with copper bars by fabricating the copper bars and inserting them in the slots. But this process is not common, as it is difficult to acquire bars to fit the slots and the core would be challenging to reassemble since it is normally held together by the rotor cage. In terms of execution quality and insofar as a typical well-equipped repair shop is concerned, rotor repair/replacement is not done on a regular basis because such work involves using some amount of design knowledge. For example, in the case of a recent ICA study,[19] rotor replacement work was done by Chinese motor manufacturers and not by repair shops.

Replacing ADC rotors with CuDC rotors requires technology changes to be made by the manufacturer. This could take some time and the manufacturing cost could be higher. Hence, the CuDC rotor is typically not available in the market and can only be supplied by the manufacturer. Custom orders to the manufacturer are likely to be for large motors. It could be for small ones, but repair shops prefer making rotor bars themselves. Shops mainly replaced rotors themselves with new units to shorten downtime since it may take quite some time to get a new rotor.

To summarize, this measure has market potential if repairs are viewed as opportunities to reduce rotor losses and spare copper rotors are available during the repair period. The availability of volume-produced copper rotors is one of the challenges for large-scale implementation of this type of EE measure. The estimated energy savings potential for this technology, assuming availability of the technology, will be presented in the Task 3 report.

4 MARKET CHARACTERISTICS OF ELECTRIC MOTOR FAILURE AND REPAIR

This section summarizes key market data on AC motor failure and repair in the five economies. The data has been collected from a literature review for NZ and in-person interviews with repair shops in the economies. Three major points are covered: 1) the percentages of failed motors repaired versus those replaced; 2) the characteristics (power rating, enclosure type, number of poles, and rewind interval) of failed motors that the shops received; and 3) the characteristics of repair shops.

The in-person interviews were conducted using the survey form described and presented in Appendix III of the Task 1 report.

4.1 FAILED MOTORS REPAIRED VERSUS REPLACED

Estimating the energy savings potential resulting from the adoption of best practices in motor repair involved analyzing the number of failed motors that were repaired upon receipt at repair shops. As shown by the survey results (see Figure 2), a large proportion of motors received by the surveyed shops were repaired instead of being replaced. However, in the lower power rating category, the percentages of failed motors replaced vary across economies by horsepower category. While more than 60% of failed motors up to 50 kW were repaired in China and Japan, less than 50% were repaired in NZ and the US.

Overall average results suggest that 54% of failed motors under 50 kW (67 hp) were repaired, 69% for 51 - 200 kW (68 - 268 hp), 87% for 202 - 375 kW (269 - 502 hp) and 89% for motors above 375 kW (502 hp). Unlike small motors (less than 50 kW (67 hp), the majority of failed motors of 50 kW (67 hp)

[19] The study looked into the EE improvement of motors by changing ADC rotors for CuDC rotors, described in Task 1 report.

and above tend to be repaired. Past study results found in the literature review also suggest this tendency in motor repair or replacement. The US survey in the manufacturing sector quoted in de Almeida *et al* (2002: p. 243) is an example of a past study. A juxtaposition of data from this survey and the current study is presented in the figure below.

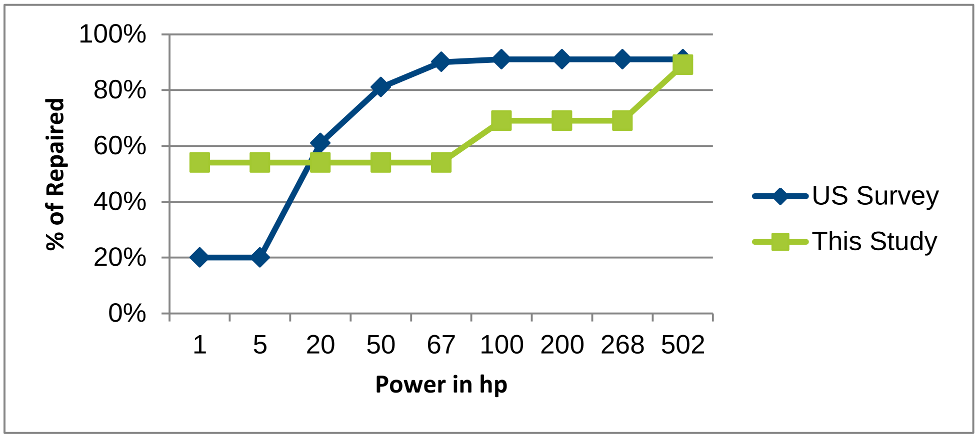

Figure 2: Percentage of Failed Motors Repaired

As shown in Figure 2 based on the US survey, the majority of failed motors above 50 hp (37 kW) were usually repaired rather than replaced. By contrast, a large portion (80%) of failed motors under 5 hp (4 kW) were usually replaced instead of being repaired; so were quite a percentage (40%) of failed motors between 6 hp – 20 hp (5 kW – 15 kW).

Data from studies on electric motors undertaken in the EU[20] suggested that rewinding was less competitive and less cost effective on smaller machines while more competitive one larger ones, which explains the trend described above.

In conclusion, the proportion of failed motors repaired instead of being replaced increased across the economies as the rated power increased.

4.2 CHARACTERISTICS OF FAILED MOTORS SENT FOR REPAIR

This section looks into the distribution of the failed motor population by power rating category by focusing on power rating, enclosure type and number of poles. It also describes other characteristics, such as rewind interval and motor lifetime.

4.2.1 Distribution of Failed Motors by Power Category

According to the survey results (see Figure 3), the proportion of failed motors below 50 kW (67 hp) from all those sent to repair shops varied between 56% and 67% depending on the economy surveyed

[20] See the preparatory studies under "The Energy Using Product (EuP)" Directive (2005/32/EC) by Anibal T. de Almeida *et al*, 2008, p. 87.

except in the US, where the proportion was approximately 43%. Motors with a power rating from 51 to 200 kW (68 to 268 hp) accounted for an average of 25% of failed motors in China, Japan, NZ and Vietnam and for 44% in the US. Larger motors accounted for a very low share across the five economies.

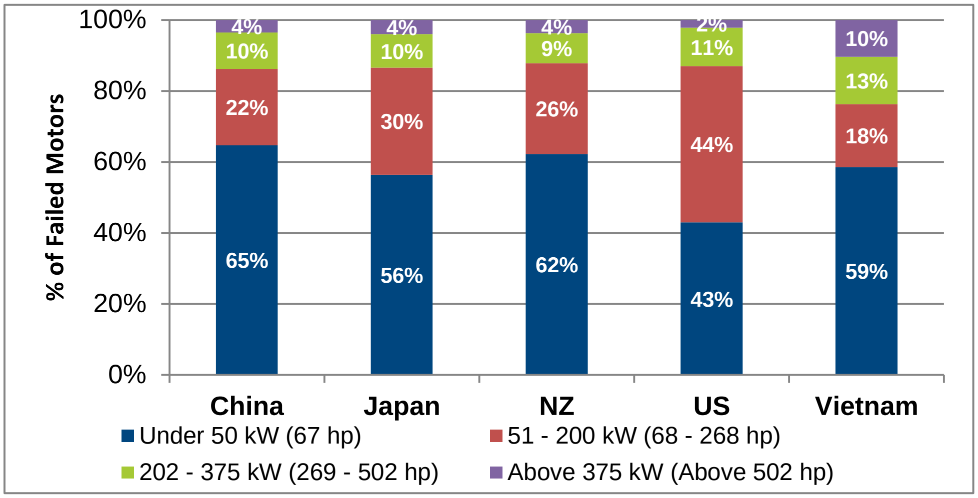

Figure 3: Distribution of Failed Motors by Power Category

Interestingly enough, motors in the first two power rating categories - i.e., motors below 50 kW (67 hp) and those from 51 kW to 200 kW (68 to 268 hp) – together accounted for 79% to 90% of all failed motors sent to repair shops across the economies. In the US, the first two categories of motors evenly accounted for 43% and 44% of failed motors respectively.

The observed trend regarding the distribution of motors in operation was that motors below 50 kW (67 hp) accounted for the largest part of the installed motor stock, as shown in Table 3 in Section 2.3 above.

4.2.2 Distribution of Failed Motors by Enclosure Type

Motors are widely used and exist in two main enclosure types: totally enclosed fan-cooled (TEFC) and open drip-proof (ODP). Motor efficiency varies among these types. The survey mainly focused on the TEFC enclosure type. The survey results (see Table 5) show significant variations across the economies.

Table 5: Distribution of Failed Motors with TEFC Enclosure

Power Rating	Percentage (TEFC)				
	China	Japan	NZ	US	Vietnam
Under 50 kW (67 hp)	84%	69%	94%	49%	73%
51 - 200 kW (68 - 268 hp)	83%	63%	86%	51%	49%
202 - 375 kW (269 - 502 hp)	76%	46%	83%	51%	31%
Above 375 kW (Above 502 hp)	74%	47%	83%	56%	30%

In China and NZ, TEFC motors accounted for more than three quarters of motors received by repair shops.

US shops received a smaller percentage of TEFC motors under 50 kW (67 hp) than shops in the other countries. Also, regardless of the size class, TEFC motors accounted for approximately half of failed motors sent to repair shops surveyed in the US. This pattern was not consistent with the distribution of installed motors by enclosure type as shown by data on the US. In fact, past studies in the US indicated that 21% to 30% of installed motors were models with TEFC housings while 56% to 73% were with ODP enclosures.[21] Based on this data, it was expected that TEFC motors accounted for fewer than 50% of all motors received by shops in the US.

The smallest percentage of TEFC motors among the higher rating categories (202 - 375 kW or 269 - 502 hp) and above 375 kW (502 hp) was observed in Vietnamese shops, among which it was also observed that independent shops received a lower percentage of TEFC motors as compared to shops affiliated to a manufacturer. In Japan, for motors below 200 kW (269 hp) and those above 200 kW (269 hp), TEFC motors accounted respectively for 66% and 46% of motors received by shops.

4.2.3 Distribution of Failed Motors by the Number of Poles

AC motors exist in different pole configurations, ranging from 2, 4, and 6 to 8 and 12 poles. For the purpose of the present study, motors have been divided into 2 categories: 1) with 4 or fewer poles and 2) with more than 4 poles. This choice was made because there is a clear difference in EE between these two categories of motors. Motors with more than 4 poles generally have a much lower efficiency level than those with 4 or fewer poles. However, the reliability of motors having more than 4 poles is higher than those with 4 or fewer poles. The survey results are presented in

Table 6.

Table 6: Distribution of Failed Motors with 4 Poles or Fewer

Power Rating	Percentage

[21] T de Almeida, 2002, 201

	China	Japan	NZ	US	Vietnam
Under 50 kW (67 hp)	82%	77%	89%	73%	72%
51 - 200 kW (68 - 268 hp)	76%	70%	88%	73%	45%
202 - 375 kW (269 - 502 hp)	75%	68%	87%	65%	39%
Above 375 kW (Above 502 hp)	73%	73%	84%	65%	39%

The survey results suggest that the majority (approximately 70%) of motors, regardless of the power rating category, received by repair shops had 4 or fewer poles in all the surveyed economies except Vietnam, where approximately 40% of motors above 50 kW (67 hp) had 4 or fewer poles.

The trend observed in the economies (except Vietnam) was consistent with results of past US surveys,[22] which indicated that 70% to 97% of installed motors had 4 or fewer poles. This would explain why motors with 4 or fewer poles accounted for a large majority of motors received by repair shops.

4.2.4 Motor Lifetime and Rewind Interval

Motor lifetime depends largely on how the motor is properly selected and maintained. More specifically, factors such as the number of operating hours, load factor, the number of start/stop cycles, power quality and environmental conditions (temperature, vibrations, humidity, chemical pollutions) influence motor life. Consequently, there is variation in motor lifetime, as shown by data available from two studies[23] and presented in the table below.

[22] Ibid, 201

[23] The first was a survey of motor repair shops conducted in 1995 in the US and the results are quoted in Anibal T. de Almeida *et al*, 2002, "*Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities*", Second Edition. The second source is the final report of the preparatory studies on electric motors undertaken under "The Energy Using Product (EuP)" Directive (2005/32/EC). For the second study, see Anibal T. de Almeida *et al*, 2008, "*EuP Lot 11 Motors*", Final Report, ISR – University of Coimbra.

Table 7: Motor Lifetime (including Repair) Revealed by Two Sources

Power Range	Average Life (Years)[24] (EuP Lot 11 Study in 2008)	Average Life (Years)[25] (Repair Shop Survey in 1995 in the US)	Life Range (Years)[26] (Repair Shop Survey in 1995 in the US)
0.75 – 3.75 kW (1 – 5 hp)	12	17.1	13 - 19
3.75 – 7.5 kW (5 – 10 hp)	12	19.4	16 - 20
7.5 – 15 kW (10 – 20 hp)	15	19.4	16 - 20
15 – 37.5 kW (20 – 50 hp)	15	21.8	18 - 26
37.5 – 75 kW (50 – 101 hp)	15	28.5	24 - 33
75 – 93 kW (101 – 125 hp)	20	28.5	24 - 33
93 – 250 kW (125 – 335 hp)	20	29.3	25 - 38
Above 250 kW (Above 335 hp)	-	29.3	25 - 38

Data on US motor life span is available, though not recent. By contrast, this data is not available from the literature of the other countries (China, Japan, NZ and Vietnam) covered by the study.

The rewinding interval or average time between rewinding is another key factor that influences motor lifetime. The survey results show a significant variation across the five economies. The rewind interval varies from 3 to 21 years across the economies and is not consistent with existing survey results reported in the literature.

Data from a Canadian study quoted in the New Zealand study suggests that rewinding occurs between 3.8 and 7.3 years, with the interval between rewinds decreasing with the motor size.[27] According to a study by the International Energy Agency (IEA), large motors are repaired one, two or even three times during their lifetime.[28] A survey of 12 New Zealand repair shops showed a variation of motor life between rewinds. The survey results suggest a time between rewinds of 12 to 16 years.[29] These figures, collected from available literature, showed a significant variation of the number of times a motor is repaired during its lifetime.

Specific data from surveys in China, Japan, the US and Vietnam is not available from the literature. As a result, assumptions based on motor lifetime and rewind interval information mentioned in the previous paragraph will be used as a proxy for the economies when estimating the EE potential resulting from the adoption of best practices in motor repair.

[24] Anibal T. de Almeida *et al*, 2008, p. 63.
[25] Anibal T. de Almeida *et al*, 2002, p. 206.
[26] Ibid.
[27] Electricity Commission, 2006, p. 16.
[28] IEA, 2011, p. 75
[29] Electricity Commission, 2006, p. 16.

4.3 CHARACTERISTICS OF REPAIR SHOPS

To collect country-specific market data, 45 repair shops were interviewed in the five economies. More specifically, 10 shops were interviewed in China, 10 in Japan, 10 in NZ, 7 in the US and 8 in Vietnam. In each economy, understanding the characteristics of the motor repair market requires an analysis of motor repair workshops. The main findings from the analysis of those surveys are presented as follows.

Shops in China and the US displayed have similar motors received/employee metric across different shop sizes. A high motor received/employee number in Japan and NZ could suggest that subcontracting was carried out by some of these shops. Shops affiliated to a manufacturer averaged a higher motor/employee level as compared to independent shops and this difference was most pronounced in small shops. It was likely that many of these shops catered to the replacement motor market.

In addition, less than one in three shops surveyed was ISO 9001 certified. None of the shops in the US had ISO certification. In Japan and Vietnam, the average age of shops that were ISO certified differed significantly from that of shops that were not ISO certified. While the ISO certified shops were 20 years older on average than those that were not ISO certified in Vietnam, Japanese shops that were ISO certified were 30 years younger than shops that were not ISO certified.

It is worth mentioning that ISO 9001 is a quality standard that applies to daily management operations within certified shops. A repair shop implementing the ISO 9001 does not necessarily employ good practices when repairing or rewinding motors. All US respondents made it clear that the ISO certification had virtually nothing to do with the AC motor repair/rewind business. Therefore, test certificate from some of their larger customers and motor manufacturers mean much more to these shops.

Furthermore, several interviewees in the US voiced a general problem about the long-term viability of the rewind industry, given the changing job market and interest of a different generation. According to the interviewees, who were mostly in their 60s, as time goes by, every year key rewind people become one year older and few people are being trained to take their place because of the lack of personnel who wants to learn motor rewind as a career path and is committed to learning the trade fully. Another reason which explains the lack of experienced rewinders is that there are no training programs in community colleges or short courses specifically geared to the topic. And yet, rewind is absolutely critical in reworking a motor. Only very experienced focused and dedicated personnel can properly perform such work. The rewind business requires good mechanical skills, but the combination of mechanical, electrical and rewind experts is very hard to find for the motor rewind shop business.

FINDINGS

Based on data collected through the literature review and the survey of repair shops, this report established the main market characteristics concerning motor failure and repair in five economies: China, Japan, NZ, the US and Vietnam. The main findings are presented as follows.

- Three-phase squirrel cage induction motors in the five economies collectively contributed approximately 53% of the global electricity consumption for all electric motors, according to the report estimate.
- The stock of installed motors in operation in each economy surveyed showed the same trend as that of motor electricity consumption. Regarding the distribution of the motor population by power range, motors up to 50 kW accounted for approximately 94% of the total stock of three-phase AC motors in operation in each economy. Motors with rated power between 51 kW – 200 kW, 202 kW – 375 kW and above 375 kW accounted for 6.2%, 0.3% and 0.2%, respectively, of the total stock in operation in each economy.
- The majority of electric motors were sent to repair shops because of winding failure. The general trend was that the proportion of rewound motors increased with increases in motor power rating. As for winding failure with or without lamination damage, the situation was slightly different across the economies. In China, the prevalence of lamination damage was slightly higher than in the other economies. However, in Japan, the prevalence of lamination damage was lower than in the other economies. Possible causes of this phenomenon in this country could be better condition-monitoring practices, preventive maintenance practices, motor design and winding quality.
- Very few motors with rotor failure were sent to repair shops. All US respondents made it clear that rotor-related failure accounted for 1% to 3% at the most. The average was approximately 5% for the other economies surveyed except China, where the prevalence of rotor failure was higher (approximately 30%). This finding could be explained with the hypothesis that none of the shops surveyed in China reported using repair standards, guidelines, procedures or specifications.. This could lead to poor rotor handling during repair.
- Rotor replacement measure is beneficial to constant load unlike variable load, for which the speed increase must be determined and, therefore, the amount of power drawn versus motor efficiency improvement.
- Motors below 200 kW (268 hp) accounted for 79% to 90% of all failed motors sent to repair shops across the countries. This finding could be explained by the fact that these motors accounted for the largest part of the stock of installed motors in operation.
- Fewer than one in three shops surveyed was ISO 9001 certified. None of the shops surveyed in the US had ISO certification. ISO 9001 is a quality standard that applies to daily management operations within certified shops. Moreover, some shops surveyed made it clear that ISO certification has virtually nothing to do with the AC motor repair/rewind business. For these shops, test certificate from some of their larger customers and motor manufacturers mean much more.
- Several US interviewees raised a general issue about the long-term viability of the rewind industry, given the changing job market and interests of a different generation. Few people are being trained because of the lack of personnel committed to fully learning the trade of motor

rewinding and making it a career. The fact that there are no training programs in community colleges or short courses specific to this trade is another reason for the lack of experienced rewinders, Nonetheless, motor rewinding is absolutely critical in motor reworking.

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APPENDIX I
ELECTRICITY USE BY THREE-PHASE AC INDUCTION MOTORS

METHODOLOGY

The methodology used to estimate electricity use by three phase AC induction motors was based on a top-down approach. This approach involved using the data available from the literature (study reports, the internet, journals, etc.) to deduct the electricity use of three phase AC motors from the national electricity consumption figures by comparing the share of electricity that these motors use to the total electricity consumption level of all types of motors. The calculation process consists of four steps, as described in the following sections.

Step 1: Estimating Electricity Consumption by Sector

The International Energy Agency (IEA) has established a database providing information on national electricity consumption by major sectors. However, it does not provide the information by application category, such as lighting, electric motors and HVAC. Therefore, the share of electricity consumption by sector had to be estimated for each of the five countries under study. The percentages by end-use sector are presented in the table below.

Table 8: Shares of Electricity Consumption by End-use Sector in 2009[30]

	China	Japan	NZ	US	Vietnam
Industry	66.4%	28.9%	35.4%	21.9%	51.9%
Transport	1.1%	2.1%	0.3%	0.2%	0.8%
Residential	15.9%	30.6%	34.0%	37.4%	37.8%
Commercial and Public Services	5.5%	38.0%	24.5%	36.3%	8.6%
Agriculture and Forestry	3.1%	0.1%	4.3%	0.0%	0.9%
Fishing	0.0%	0.0%	0.3%	0.0%	0.0%
Others Non-specified	8.0%	0.3%	1.3%	4.1%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: IEA Statistics.

By applying the percentages in the table above to the 2012 national electricity consumption figures presented in section 2.1, results on estimated annual electricity consumption by end-use sectors were obtained and are presented in the table below.

[30] The percentages were calculated from the 2009 statistics.

Table 9: Electricity Consumption (TWh) by End-use Sector in 2012[31]

Sector	China	Japan	NZ	US	Vietnam
Industry	2,896	292	15	860	57
Transport	46	21	0	8	1
Residential	693	310	14	1,467	42
Commercial and Public Services	240	384	10	1,425	9
Agriculture and Forestry	134	1	2	0	1
Fishing	0	0	0	0	0
Others Non-specified	350	3	1	161	0
Total[32]	**4,359**	**1,011**	**41**	**3,922**	**110**

The figures in Table 9 were then used to calculate the electricity consumption levels of all types of motor by end-use sector.

Step 2: Estimating the Electricity Consumption for all Types of Motor by End-use Sector

For each end-use sector, figures related to the average share of electricity use by all types of motor were available from the literature.[33] The figures were taken from research results based on surveys and were used to estimate electric energy use by motors in specific sectors.

Table 10: Shares of Electricity by all Types of Motor by End-use Sector

Sector	Percentage	Observation
Industry	68.9%	Motors are mostly used in industrial handling and processing.
Transport	60.0%	Motors are mostly used in electric locomotives.
Residential	21.0%	Motors are mostly used in refrigerators, freezers and HVAC.
Commercial and Public Services	38.3%	Motors are mostly used in HVAC.
Agriculture and Forestry	25.0%	Motors are mostly used in pumps and fans.
Fishing	25.0%	Motors are mostly used in pumps and fans.
Others Non-specified	31.0%	Motors used at amusement parks, for example-

Source: IEA, 2011.

The figures in Table 10 are not based on any country covered by the study. In fact, typical shares of electricity use by motors by sector were not available from the literature for any of the five countries surveyed. Therefore, due to this data limitation, the same sector-specific percentages were applied to

[31] The percentages were calculated from the 2009 statistics.
[32] Values calculated using country totals for 2012 and sector splits for 2009, assuming the splits are constant over 2009-2012
[33] IEA, 2011, "Energy-Efficiency Policy and Opportunities for Electric Motor-Driven System".

each of the five economies. Multiplying the percentage of a given sector, as shown in Table 10, by the electricity use figure of the sector, as shown in Table 9, produced results about electric motor consumption by sector in 2012, as presented in the table below.

Table 11: Estimates of Motor Electricity Consumption (TWh) by End-use Sector in 2012

Sector	China	Japan	NZ	US	Vietnam
Industry	1,995	201	10	593	39
Transport	28	13	0	5	1
Residential	146	65	3	308	9
Commercial and Public Services	92	147	4	546	4
Agriculture and Forestry	33	0	0	0	0
Fishing	0	0	0	0	0
Others Non-Specified	109	1	0	50	0
Total	**2,403**	**427**	**18**	**1,502**	**52**
Share of National Total Electricity Consumption	**55.1%**	**42.3%**	**42.6%**	**38.3%**	**47.7%**

The estimates in the table above do not distinguish between motor types and their use because the estimated figures include all types of AC and DC motors. The next step was to single out three-phase AC induction motors since this study focuses on medium- and large-sized AC induction motors.

Step 3: Estimating Electricity Consumption of Three-phase AC Induction Motors

Regardless of the type of motor, small motors with power rating up to 1 hp (0.75 kW) accounted for approximately 90% of all the installed electric motor stock and accounted for 9% of the total electricity used by electric motors. As for integral horsepower electric motors with power rating above 1 hp, they accounted for approximately 91% of the total electricity used, though they accounted for only 10% of all the installed electric motor stock.[34] Also, of all integral horsepower electric motors, DC and universal motors accounted for 5% of integral power motor electricity consumption while AC induction motors accounted for the remaining 95%.[35] Applying this percentage to the total electricity consumption calculated in the previous step produced the result for the electricity consumption of three-phase AC induction motors. The estimate for each country is presented in the table below. It is important to note that the values in this table are rough estimates because of the lack of country-specific data. Therefore, the results are presented with only two significant digits.

[34] IEA, 2011, p. 30.
[35] T. de Almeida, 2002, p. 196.

Table 12: Three-phase AC Induction Motor Electricity Consumption (TWh)

Sector	China	Japan	NZ	US	Vietnam
Electricity Consumption Three Phase AC induction Motors	2,100	370	15	1,300	45
Share of National Total Electricity Consumption	**48.2%**	**36.6%**	**36.8%**	**33.1%**	**41.2%**

APPENDIX II
MOTOR POPULATION ESTIMATE

METHODOLOGY

The methodology applied to estimate the AC motor population in use in each country was based on a top-down approach, which involved estimating the AC motor energy consumption level by power class and deriving the number of AC motors. The calculation process consisted of two steps, as discussed in the following sections.

Step 1: Estimating AC Motor Electricity Consumption by Power Class

Except for the US, data on electricity consumption for installed electric motors by horsepower class were not available from the literature for China, Japan, NZ or Vietnam. For the US, the American Council for EE Economy (ACEEE)[36] calculated motor stock[37] by motor type and horsepower class, based on sales data and other data from many different studies. This estimate of electricity use of the motor stock provides a good basis for determining electricity use by AC motors as presented in the table below.

Table 13: Estimates of AC Motor Stock and Energy Use by Power Class (U.S. – 1997)

Power Class	Stock (1,000 Motors)	Power Average	Annual Electricity Use (TWh)	Percentage of Total Electricity Use (%)
0.75 - 3.75 kW (1 - 5 hp)	16,774	1.5 kW (2.07 hp)	44.0	3.4%
3.75 - 15 kW (5 -20 hp)	9,367	8.7 kW (11.9 hp)	163.0	12.5%
15 - 37 kW (20 - 50 hp)	3,208	23.9 kW (32.50 hp)	175.0	13.4%
37 - 75 kW (50 -100 hp)	1,646	47.8 kW (65 hp)	230.0	17.7%
75 - 149 kW (100 - 200 hp)	1,059	99.2 kW (135 hp)	294.0	22.6%
149 - 373 kW (200-500 hp)	251	220.5 kW (300 hp)	181.0	13.9%
Above 373 kW (Above 500 hp)	76	882.0 kW (1,200 hp)	215.0	16.5%
Total for Three Phase AC induction Motors	**32,381**		**1,302.00**	**100.0%**

Source: T. de Almeida, 2002, p. 197

Because country-specific data was not available, the same percentages of total electricity use were applied to all the five countries. Therefore, applying these percentages to the total electricity use for

[36] The American Council for an Energy-Efficient Economy (ACEEE) is a non-profit organization, which acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors (See http://aceee.org/).
[37] See ACEEE estimate as quoted in T. de Almeida, 2002.

AC motors, as shown in Table 12, has produced the estimates of motor electricity consumption by power class for each country, as presented in the table below.

Table 14: Electricity Use (TWh) by Power Class

Power Class	China	Japan	NZ	US	Vietnam
0.75 - 3.75 kW (1 - 5 hp)	71	13	1	44	2
3.75 - 15 kW (5 -20 hp)	263	46	2	163	6
15 - 37 kW (20 - 50 hp)	282	50	2	175	6
37 - 75 kW (50 -100 hp)	371	65	3	230	8
75 - 149 kW (100 - 200 hp)	474	84	3	294	10
149 - 373 kW (200-500 hp)	292	51	2	181	6
Above 373 kW (Above 500 hp)	347	61	3	215	7
Total for AC induction Motors	**2,100**	**370**	**15**	**1,300**	**45**

The figures in the table above were used to estimate the total number of AC motors by power class in the second step.

Step 2: Estimating the Number of AC Motors by Power Class

The number of AC motors by power class is estimated by using the following formula:

$$\mathbf{N_c = \frac{\eta * E_c}{LF_{ac} * H_{ac} * 0.735 * P_{ac}}} \qquad \textbf{Equation 1}$$

Where:

N_c	Number of Three-phase AC induction motors
η	Average EE of AC motors
LF_{ac}	Average operating load factor of AC motors
H_{ac}	Average operating hours
P_{ac}	Average power of AC motors in hp (See values in Table 13)
E_c	Electricity consumed by the number (N_{ac}) of AC motors (See values in Table 14)
a	Letter standing for average
c	Motor rating class for which the number (N) of AC motors is determined
0.735	Conversion factor from hp to kW

For the surveyed countries, the values for η, LF_{ac} and H_{ac} were assumed after reviewing data from different studies. If a country-specific value pertaining to a given parameter was not available, the value collected through the literature review was used as a proxy for the country. The values that were used to estimate the number of AC motors by horsepower range are presented in the table below.

Table 15: Assumed Values for Key Parameters

Power Class	China	Japan	NZ	US	Vietnam	Source
Average efficiency of AC motors						T. de Almeida et al, 2002. The average efficiency by horsepower category is the figure for the US and is used as a proxy for the other countries.
0.75 – 3.75 kW (1 - 5 hp)	80.5%	80.5%	80.5%	80.5%	80.5%	
3.75 - 15 kW (5 -20 hp)	87.8%	87.8%	87.8%	87.8%	87.8%	
15 - 37 kW (20 - 50 hp)	90.0%	90.0%	90.0%	90.0%	90.0%	
37 - 75 kW (50 -100 hp)	91.9%	91.9%	91.9%	91.9%	91.9%	
75 - 149 kW (100 - 200 hp)	92.8%	92.8%	92.8%	92.8%	92.8%	
149 - 373 kW (200-500 hp)	93.0%	93.0%	93.0%	93.0%	93.0%	
Above 373 kW (Above 500 hp)	93.0%	93.0%	93.0%	93.0%	93.0%	
Average annual operating hours						DOE, 1997, as cited in T. de Almeida et al, 2002, p. 197. The average annual operating hours figures are from the US DOE motor market study conducted in 1997. These values are used as a proxy for the other countries.
0.75 – 3.75 kW (1 - 5 hp)	2,745	2,745	2,745	2,745	2,745	
3.75 - 15 kW (5 -20 hp)	3,391	3,391	3,391	3,391	3,391	
15 - 37 kW (20 - 50 hp)	4,067	4,067	4,067	4,067	4,067	
37 - 75 kW (50 -100 hp)	5,329	5,329	5,329	5,329	5,329	
75 - 149 kW (100 - 200 hp)	5,200	5,200	5,200	5,200	5,200	
149 - 373 kW (200-500 hp)	6,132	6,132	6,132	6,132	6,132	
Over 373 kW (Over 500 hp)	7,186	7,186	7,186	7,186	7,186	
Average power rate (hp)						T. de Almeida et al, 2002, 197. The average horsepower figures by category are figures for the US and are used as a proxy for the other countries.
0.75 – 3.75 kW (1 - 5 hp)	2.07	2.07	2.07	2.07	2.07	
3.75 - 15 kW (5 -20 hp)	11.9	11.9	11.9	11.9	11.9	
15 - 37 kW (20 - 50 hp)	32.50	32.50	32.50	32.50	32.50	
37 - 75 kW (50 -100 hp)	65	65	65	65	65	

Power Class	China	Japan	NZ	US	Vietnam	Source
75 - 149 kW (100 - 200 hp)	135	135	135	135	135	
149 - 373 kW (200-500 hp)	300	300	300	300	300	
Above 373 kW (Above 500 hp)	1,200	1,200	1,200	1,200	1,200	
Average load factor (LF)						› China: IEA Motor Study, 2011, p. 43. › Japan: Ibid. › US: T. de Almeida et al, 2002, p. 197. › Vietnam: Ibid. (Mexico's LF in the source used as a proxy) › New Zealand: Industrial Motors Efficiency Project, 2006, p. 8.
	62%	60%	60%	50%	56%	
Total Electricity Consumption of AC motors						See Table 14 above
	2,100	370	15	1,300	45	

Based on the values indicated in Table 15 above and $\mathbf{N_c} = \frac{\eta * E_c}{LF_{ac} * H_{ac} * 0.735 * P_{ac}}$ Equation 1, the number of three-phase AC induction motors by country is presented as follows.

Table 16: Number of Three-phase AC Motors (Million Pieces)

Power Class	China	Japan	NZ	US	Vietnam
0.75 – 3.75 kW (1 - 5 hp)	22	4	0.17	17	1
3.75 - 15 kW (5 -20 hp)	13	2	0.09	10	0.30
15 - 37 kW (20 - 50 hp)	4	1	0.03	3	0.10
37 - 75 kW (50 -100 hp)	2	0.39	0.02	2	0.05
75 - 149 kW (100 - 200 hp)	1	0.25	0.01	1	0.03
149 - 373 kW (200-500 hp)	0.32	0.06	0.002	0.25	0.01
Above 373 kW (Above 500 hp)	0.08	0.01	0.001	0.06	0.002
Total	**43**	**8**	**0.32**	**33**	**1.0**

The numbers of motors in the classes covered by the study are presented as follows.

Table 17: Number of Motors (Million Pieces) Covered by the Study

Power Class	China	Japan	NZ	US	Vietnam
Under 50 kW (67 hp)	40	7	0.300	31	1
51 - 200 kW (68 - 268 hp)	3	0.49	0.020	2	0.06
202 - 375 kW (269 - 502 hp)	0.11	0.02	0.001	0.08	0.003
Above 375 kW (Above 502 hp)	0.08	0.01	0.001	0.06	0.002
Total	**43**	**8**	**0.32**	**33**	**1.0**

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