



**4E** Energy Efficient End-use Equipment  
International Energy Agency

# Energy efficiency roadmap for electric motors and motor systems

**NOVEMBER 2015**

The Implementing Agreement on Energy Efficient End-Use Equipment (4E) is an International Energy Agency (IEA) Implementing Agreement established in 2008 to support governments to co-ordinate effective energy efficiency policies. Twelve countries have joined together under the 4E platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However 4E is more than a forum for sharing information – it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Participants find that is not only an efficient use of available funds, but results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions.

Current members of 4E are: Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, Sweden, UK and USA.

Further information on the 4E Implementing Agreement is available from: [www.iea-4e.org](http://www.iea-4e.org)

Motors have been a key focus for 4E due to their energy saving potential. This work is undertaken through the Electric Motor Systems Annex (EMSA), which promotes opportunities for energy efficiency in motor systems by disseminating best practice information worldwide. It supports the development of internationally harmonised test standards and policies to improve the energy performance of new and existing motor systems.

Further information on EMSA is available at: [www.motorsystems.org](http://www.motorsystems.org)



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## Contents

<b>Executive Summary</b> .....	<b>1</b>
1 Introduction .....	5
2 Adoption of test standards and MEPS .....	5
3 The transition to increased motor efficiency .....	8
4 Motor efficiency trends up to 2019 .....	9
5 Variable Frequency Drives – A step towards energy efficient motor systems .....	12
6 Energy efficiency roadmap for electric motors and motor systems .....	14
7 Observations for policy makers .....	18
8 References .....	19
<b>Attachment A: Regional methods of testing motor efficiency</b> .....	<b>20</b>
<b>Attachment B: Energy efficiency policies for motors</b> .....	<b>22</b>
<b>Attachment C: Stock and sales modelling Methodology</b> .....	<b>24</b>

## Figures

<b>Figure 1: Estimated global sales of motors by efficiency class, 1995-2015</b> .....	<b>1</b>
<b>Figure 2: Status of IEC efficiency standards for motors and motor driven units</b> .....	<b>2</b>
<b>Figure 3: Scope of policies by country/region in terms of rated power, and their indicative IE-code</b> .....	<b>7</b>
<b>Figure 4: Estimated global sales of motors by efficiency class, 1995-2015</b> .....	<b>8</b>
<b>Figure 5: Estimated global stock of motors by efficiency class, 1995-2015</b> .....	<b>8</b>
<b>Figure 6: Actual age of motors compared to expected service life</b> .....	<b>9</b>
<b>Figure 7: Estimated turnover of motor stock</b> .....	<b>10</b>
<b>Figure 8: Estimated motor market 2014 to 2019</b> .....	<b>11</b>
<b>Figure 9: Estimated global motor sales, surveys from 2009 to 2014, estimates 2015 to 2019</b> .....	<b>11</b>
<b>Figure 10: VFD use in Swiss motor systems</b> .....	<b>12</b>
<b>Figure 11: Status of IEC efficiency standards for motors and motor driven units</b> .....	<b>13</b>
<b>Figure 12: IE-code requirements for motor efficiency as a function of motor output power</b> .....	<b>15</b>
<b>Figure 13: Additional motor stray load losses</b> .....	<b>20</b>
<b>Figure 14: Motor efficiency as a function of motor output power, for motors with different speeds</b> .....	<b>24</b>
<b>Figure 15: Percent efficiency penalty between 60 Hz and 50 Hz supply</b> .....	<b>25</b>
<b>Figure 16: Theoretical relationship of efficiencies for 50 Hz and 60 Hz motors</b> .....	<b>25</b>
<b>Figure 17: Efficiency for 4-pole motors operated with 50 Hz and 60 Hz</b> .....	<b>26</b>

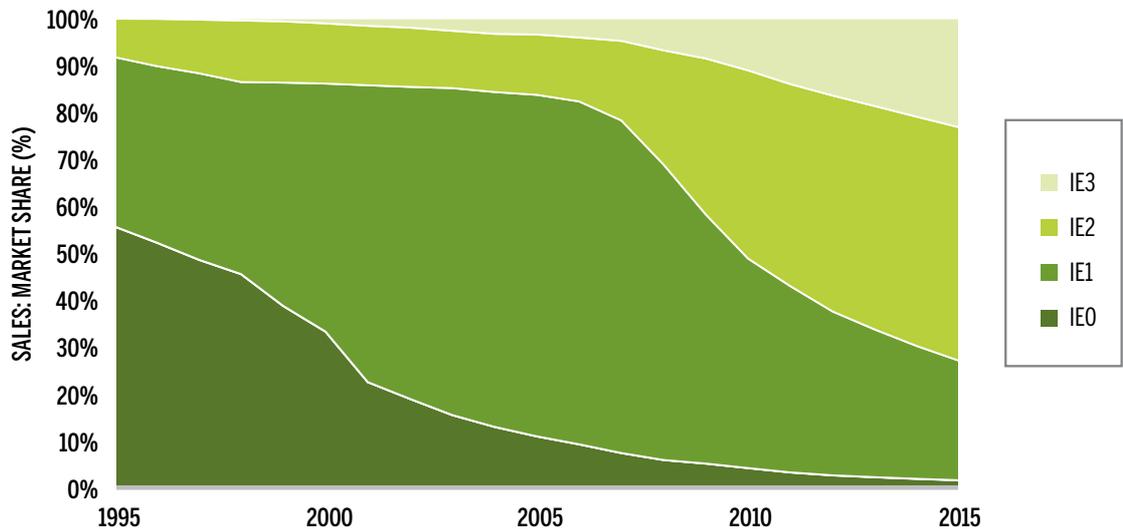
## Tables

<b>Table 1: Global survey of minimum energy performance standards for 3-phase induction motors</b> .....	<b>6</b>
<b>Table 2: SEAD Motor Awards Competition, Winners 2014</b> .....	<b>16</b>
<b>Table 3: Frame sizes and output power in Europe and Japan, 50 Hz electricity supply</b> .....	<b>16</b>
<b>Table 4: Frame sizes and output power for US and Brazil, 60 Hz electricity supply</b> .....	<b>17</b>
<b>Table 5: Overview of policies in Australia, Canada and US</b> .....	<b>22</b>
<b>Table 6: Overview of policies in EU and China</b> .....	<b>23</b>

## Executive Summary

Since 1995, efficient motors have gained an increasing share of the global market; assisted by a framework of international standards that classifies motors (IE1 to IE4) according to their energy efficiency (IE-code)<sup>1</sup>.

**Figure 1: Estimated global sales of motors by efficiency class, 1995-2015**



Note: IE0 represents all motors below the IE1 level.

Source: [7]

These standards have been widely adopted and form a common technical platform that underpins national policies aimed at increasing the uptake of more efficient motors. They form the basis for the minimum energy performance standards (MEPS) that are now in force in most advanced economies and many developing countries, and allow the comparison of product performance and benchmarking across regions.

As such, these standards provide a model for how international standardisation can encourage product policies that take account of national circumstances but are sufficiently aligned to enhance global trade.

National motor policies continue to evolve in response to new technologies, markets and economic environments that influence cost-effectiveness. In the US and China, MEPS have been extended to cover a broader range of motor sizes. The adoption of IE3 as the MEPS level in North America and the announcement that a similar policy will be adopted by the EU from 2017 onwards, is leading to increasing sales of higher efficiency motors.

The market for motors is expected to expand by 2.5% p.a. until 2019, primarily driven by growth in developing countries, and this will provide the opportunity for the introduction of higher efficient products. However, even in growing markets the impact of new motor sales on the overall efficiency is gradual, due to the long operational lifetime of motors. To speed up the increase in overall efficiency, selected economies are also considering measures that complement MEPS by encouraging the retirement of inefficient motors.

The availability of emerging motor technologies, such as permanent magnet (PM) and switched reluctance (SR) motors, offer higher levels of efficiency, but these products currently have a small market share.

However, the greatest opportunity for increasing energy savings lies in improving the efficiency of systems involving motors, called 'motor driven units'. Motor driven units include a combination of components such as motors, variable frequency drives (VFD), mechanical components (gears, belts, brakes, clutches) and applications (e.g., pumps, fans, and compressors).

Taking a systems approach adds complexity to policy making, but various examples of good practice and structured policy approaches are already included in the 4E-EMSA *Policy Guidelines for Electric Motor Systems Part 2: Toolkit for Policy Makers*, October 2014<sup>2</sup>. This report showcases best practice policy examples that have been implemented in various countries around the globe.

The development of standards and regulation is underway for VFDs, pumps, fans and compressors, however previous experience demonstrates the benefits of ongoing and coordinated efforts by governments, industry and standardisation bodies. This will not only target resources to provide the best technical and policy solutions, but will maximise opportunities for international alignment.

4E-EMSA will deliver a major new publication: *Policy Guidelines for Motor Driven Units* over the next two years to provide further advice to governments.

However, given the work already underway in developing international standards for VFDs, an initial focus for standardisation and regulation beyond motors could be on VFDs, followed by the combination of motors and VFDs (see Figure 2).

**Figure 2: Status of IEC efficiency standards for motors and motor driven units**

		SCOPE	TESTING	EFFICIENCY CLASSIFICATION
1		motor	IEC 60034-2-1 ed 2 published	IEC 60034-30-1 ed 2 published
2	 	motor, driven by a VFD	IEC/TS 60034-2-3 ed 1 published	IEC 60034-30-2 CDV October 2015
3	 	VFD	IEC 61800-9 IEC 61800-9-1 Extended Products IEC 61800-9-2 Classification CDV October 2015	
4	 	motor+VFD		

Source: Impact Energy

This roadmap for electric motors & variable frequency drives represents the first steps on the pathway to a more comprehensive approach to motor driven units.

Observations for policy makers

The following observations are based on this assessment of the current status and trends in the market, and the policy environment for motors and motor driven units:

- ▶ The development of international standards for motors, including the system of efficiency classification, has been highly effective in encouraging global trade and the alignment of national policies for motors.
- ▶ In line with changes in the cost-effectiveness of efficient motors, governments should consider progressively increasing the stringency of MEPS for motors, based on the international accepted system efficiency classification (IE-code).
  - National motor MEPS should aim to reach the IE3 level before 2020, with North America, Europe and Japan adopting IE4 levels by this time or soon after.

<sup>2</sup> Available from 4E-EMSA at <https://www.motorsystems.org/policy-publications>.

- ▶ To maximise energy savings, consideration should be given to extending the scope of regulations to incorporate motors within the range of 0.12 kW to 1,000 kW by 2020.
- ▶ Governments should take steps to remove any inconsistencies in national MEPS with respect to international standards, in order to eliminate barriers to competition and trade.
- ▶ Governments, industry and standardisation bodies should co-ordinate activities to develop relevant standards and regulations for motor driven units, with the initial focus on VFDs, followed by the combination of motors and VFDs.
- ▶ Experience from the successful development of standards for motors suggests that governments will need to play an active role in future standardisation processes relevant to motor driven units. 4E-EMSA provides a platform for member government to pool resources and be represented so that international standards better reflect the needs of regulators.

## Glossary

<b>4E</b>	Implementing Agreement Energy Efficient End-use Equipment.
<b>Asynchronous Motor</b>	An AC motor which does not run at synchronous speed. The ordinary induction motor is an asynchronous motor - single or polyphase.
<b>AC</b>	Alternating current
<b>BRICS</b>	Brazil, Russia, India, China, South Africa
<b>DC</b>	Direct current
<b>Ecodesign</b>	The Ecodesign Directive sets out minimum mandatory requirements for the energy efficiency of products in EU Member States.
<b>Efficiency</b>	The efficiency of a motor (or a motor system) is the ratio of mechanical output to electrical input. It represents the effectiveness with which the motor converts electrical energy into mechanical energy at the output shaft. The higher the efficiency, the better the conversion process, and the lower the operating costs.
<b>EMSA</b>	Electric Motor Systems Annex of IEA- 4E
<b>IEA</b>	International Energy Agency
<b>IE-code</b>	Efficiency classification based on IEC 60034-30-1, 2014
<b>IEC</b>	International Electrotechnical Commission
<b>Frame</b>	Motor mounting and shaft dimensions as standardised by IEC or NEMA, which facilitates interchangeability.
<b>Induction motor</b>	An alternating current motor in which the primary winding on one member (usually the stator) is connected to the power source. A secondary winding on the other member (usually the rotor) carries the induced current. There is no physical electrical connection to the secondary winding; its current is induced.
<b>Load</b>	The power required of a motor to drive attached equipment. This is expressed as power (kW) or torque (Newton meter, Nm) at a certain motor speed (rotations per minute, rpm).
<b>LV</b>	Low voltage motors, operate below 1000 Volt and also typically have an output power of below 1000 kW
<b>MEPS</b>	Minimum energy performance standards
<b>Motor Driven Unit (MDU)</b>	Motor driven units, a combination of VFD, motor, mechanical equipment (transmission, gear, etc.) and application (pump, fan, compressor, etc.).
<b>NEMA</b>	National Electrical Manufacturers Association, based in the United States.
<b>Permanent magnet (PM) motor</b>	Type of DC motor where the field poles and the armature poles are electromagnets. The only current used by the motor is that of the armature. It has high starting torque, good speed regulation and a definite maximum speed. It is highly efficient and valuable for constant and variable speed applications. It has to be started with a VFD or special hybrid features of the motor.
<b>Synchronous reluctance and switched reluctance (SR) motor</b>	Type of electric motor that induces non-permanent magnetic poles on the ferromagnetic rotor. Torque is generated through the phenomenon of magnetic reluctance. It is simple, very efficient and highly valuable for applications with variable speed. It has to be started with a VFD.
<b>System efficiency</b>	The ratio of the mechanical output power supplied to the load to the total electrical input power under specified operating conditions.
<b>Variable frequency drive (VFD)</b>	Electronic controller to adapt the line frequency (50 or 60 Hz) to the required rotational speed of the motor for the necessary load of the application. Also called variable speed drive or frequency converter.

## 1 Introduction

This report provides a market assessment of the energy efficiency of electric induction motors, rated between 0.12 kW and 1,000 kW. The scope includes motors designed to operate on either three or single-phases in electricity networks at frequencies of 50 Hz or 60 Hz, and are responsible for approximately 80% of all the electrical energy used by motors. The scope of this paper does not include applications such as pumps, fans and compressors.

In reviewing trends and options for the future direction of policies aimed to realize the substantial energy savings potential of electric motors, the role of electronic controllers, known as variable frequency drives (VFD) is also considered. VFDs are able to improve energy efficiency by precisely matching the rotating speed and the torque of the motor to meet any required load. Examples of good practice and structured policy approaches are included in the 4E-EMSA *Policy Guidelines for Electric Motor Systems Part 2: Toolkit for Policy Makers*, October 2014<sup>3</sup>. This report showcases best practice policy examples that have been implemented in various countries around the globe. The examples span a wide range of policies: both mandatory and voluntary, those that focus on energy management or energy audits, provide financial support, and technical information.

## 2 Adoption of test standards and MEPS

The key International Electrotechnical Commission (IEC) standards for efficiency of low voltage electric motors, as defined for this analysis, are:

- ▶ IEC 60034-1: 2010 Rating and performance.
- ▶ IEC 60034-2-1 edition 2.0, 2014, Rotating electrical machines - Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles).

These standards are the result of many years' work to harmonise approaches for the testing of electric motors globally, and few practical differences now exist between test methods (see Annex A).

In addition, IEC 60034-30-1, edition 1.0, 2014: Efficiency classes of line operated AC motors, defines a classification for motors based on their energy efficiency (IE-code). This scale accommodates very well the range of motors currently on the world market, from low efficiency (IE1) through to the best commercially available technologies (IE4). The IEC classes are pitched to require a drop in losses of around 20% between successive higher levels.

The international method of testing and the classification system are widely used, as shown in Table 1, Figure 3 and Annex B, which illustrate the performance requirements and scope of minimum energy performance standards (MEPS) by country or region.

Table 1: Global survey of minimum energy performance standards for 3-phase induction motors.

EFFICIENCY LEVELS	EFFICIENCY CLASSES	PERFORMANCE STANDARD
3-phase induction motors (Low Voltage < 1000 V)	IEC 60034-30-1, 2014 IE-Code *	Mandatory MEPS National Policy Requirement
Super Premium Efficiency	IE4	
Premium Efficiency	IE3	Canada (< 150 kW) Mexico (< 150 kW) USA (< 150 kW) South Korea Switzerland Japan (Toprunner) China ****(2016/7) EU 28** (2017)
High Efficiency	IE2	Australia*** Brazil Canada (> 150 kW) China Mexico (> 150 kW) South Korea New Zealand Turkey USA (> 150 kW)
Standard Efficiency	IE1	Costa Rica Israel Taiwan

Note: \* Output power: 0.12 kW - 1000 kW, 50 and 60 Hz, 2-, 4-, 6- and 8-poles, testing IEC 60034-2-1, 2014

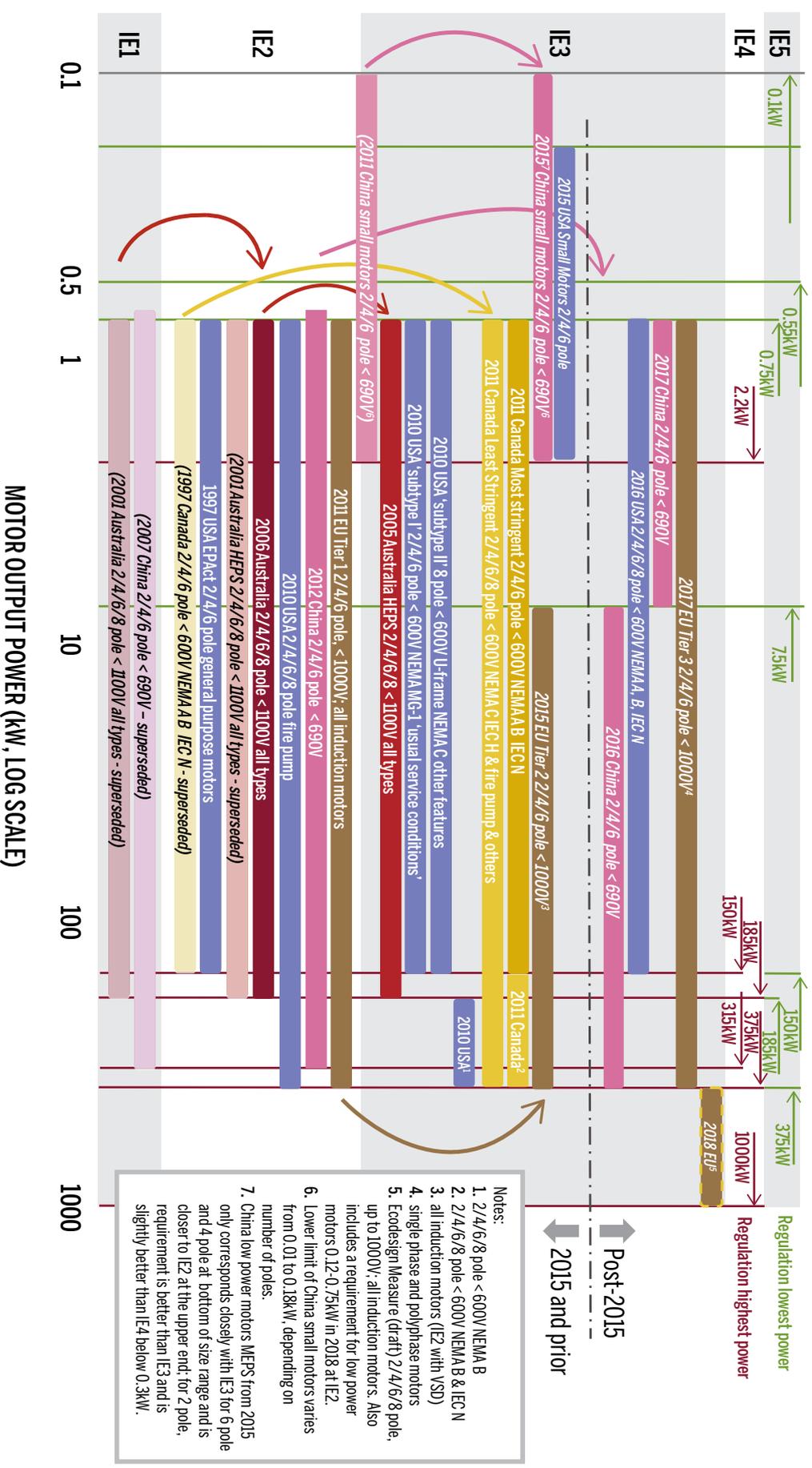
\*\* European Union: 2015: above 7.5 kW IE3 or IE2+Variable Speed Drive; 2017: above 0.75 kW

\*\*\* Australia adoption of IE Standards

\*\*\*\* China: 2016 above 7.5 kW, 2017 above 0.75 kW

Source: Impact Energy, 2015.

Figure 3: Scope of policies by country/region in terms of rated power, and their indicative IE-code



Note: In some cases the match with IEC classes is not exact, and most policies include exceptions and special inclusions for various motor types that are not shown in Figure 2. Only confirmed MEPS are shown (except for EU 2018, with yellow dashed outline).

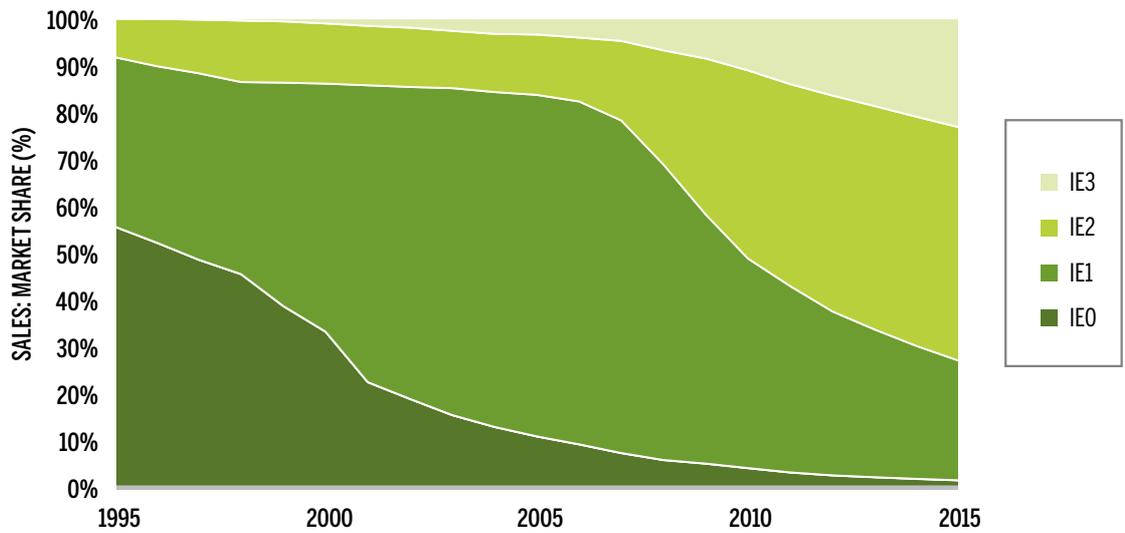
### 3 The transition to increased motor efficiency

The global sales of more efficient motors have been increasing since 1995, as shown in Figure 4<sup>4</sup>. The implementation of IE3 as the MEPS level in USA, Canada, and Mexico; and the announcement that a similar level will be adopted by the European Union from 2017 has led to a growth in sales of these higher efficiency motors.

Due to the long service life of motors, it takes many years for sales of new, more efficient, products to have a discernable impact on the overall efficiency of the installed stock, as shown in Figure 5.

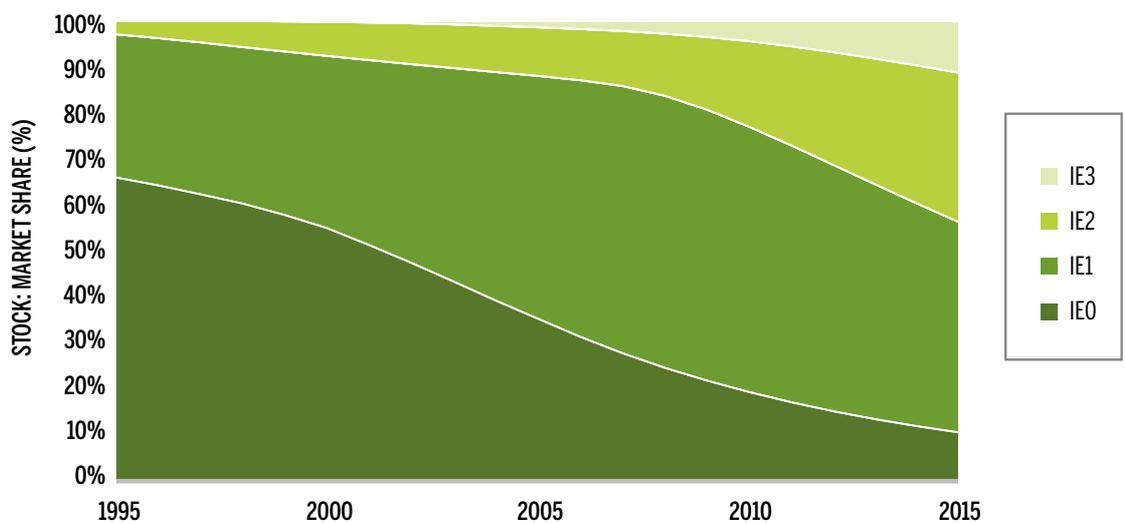
In 2013 4E-EMSA estimated that motors operated at 50 Hz contributed 65% of the global electricity motor consumption, primarily in Europe and Asia. The remaining 35% in the USA, Canada and Mexico operated at 60 Hz.

**Figure 4: Estimated global sales of motors by efficiency class, 1995-2015**



Note: IE0 represents all motors below the IE1 level.  
Source [7]

**Figure 5: Estimated global stock of motors by efficiency class, 1995-2015**



Note: IE0 represents all motors below the IE1 level.  
Source [7]

<sup>4</sup> Discussion of the methodology and inputs used in this assessment are shown in Annex C.

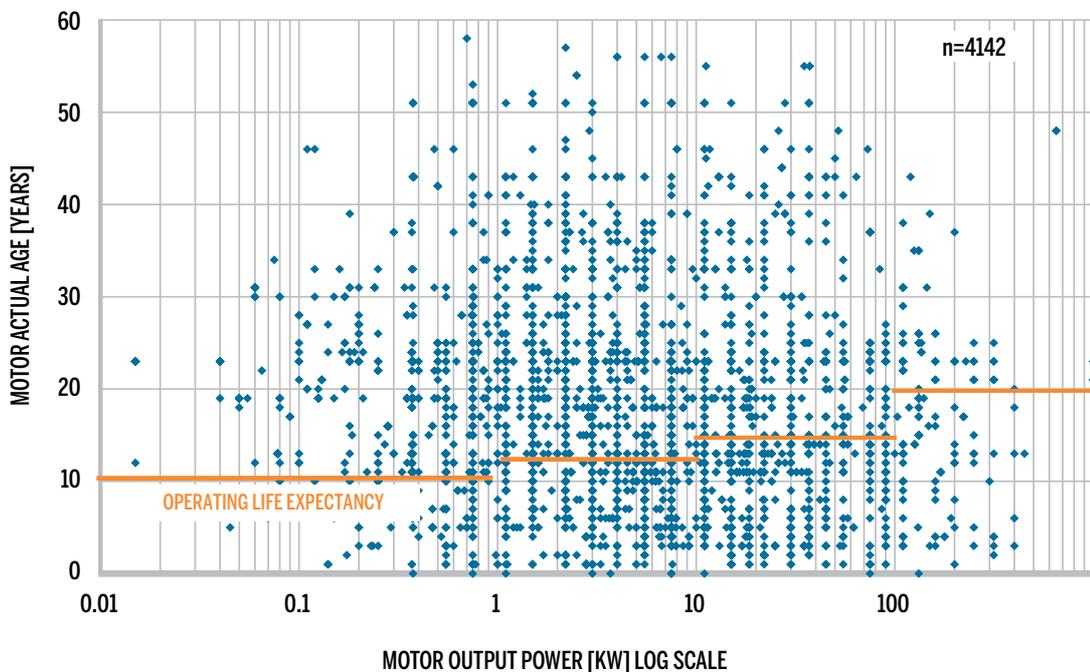
## 4 Motor efficiency trends up to 2019

Estimates of the future market are critically dependent on the rate of replacement of old motors, usually reflected in the average service life. The expansion of the motor market is also relevant, which is typically indicated by the growth in industrial production and the associated purchase of new machines as a result of economic growth. These issues are discussed below.

### 4.1 Extended operational lifetime

The service life of motors has generally been estimated at between 10-20 years, however Swiss surveys have found a large proportion of older motors still in use, with some units up to 60 years old (see Figure 6). If this finding is replicated in other markets, it suggests that the turnover of the stock will be slower than has often been predicted, and that it would take considerably longer to raise the overall efficiency of motors within a particular jurisdiction.

**Figure 6: Actual age of motors compared to expected service life**



Source: [8]

### 4.2 Impact of market growth on motor efficiency

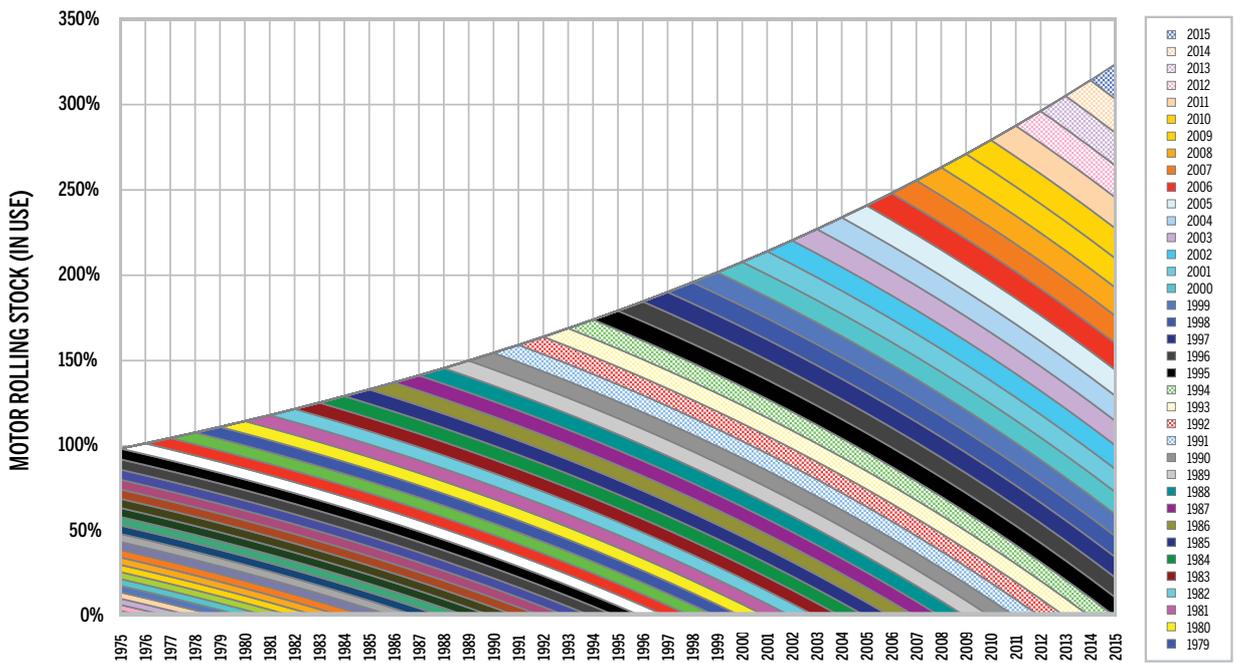
In the industrialised world (e.g. USA, Canada, Europe, Japan, Australia), 4E-EMSA estimates the average age of the motor stock to be around 20 to 30 years. The efficiency level of the stock is estimated to be around the efficiency class IE1. The average efficiency of sales is estimated to be around IE2 level in countries other than those with MEPS already at IE3.

In the high-income countries of the industrialised world the economic growth rate from 2012 to 2017 is likely to be in the region of 1% to 2% p.a.<sup>5</sup>, leading to a relatively limited expansion of industrial capacity. In these economies, the market focus is likely to be on the maintenance and replacement of machinery.

In the developing countries, the average age of motor stock is estimated to be around 10 to 15 years [13], with an average efficiency level equivalent to 15% higher losses than IE1. The efficiency level of new sales in these markets is estimated to be around IE1. However, the economic growth rate in the fast growing economies like Brazil, Russia, India, China and South Africa may be between 4% to 6% p.a. although unevenly distributed. In these economies, the market focus is on the development of new factories in expanding industries.

As shown in Figure 7, even in faster growing economies, new sales of efficient motors are slow to cause an impact on the overall efficiency of the motors stock. This indicates that policies which help raise the efficiency of motor sales, as well as encouraging the retirement and recycling of the existing motor stock before the end of its normal operational life, will be most effective.

Figure 7: Estimated turnover of motor stock



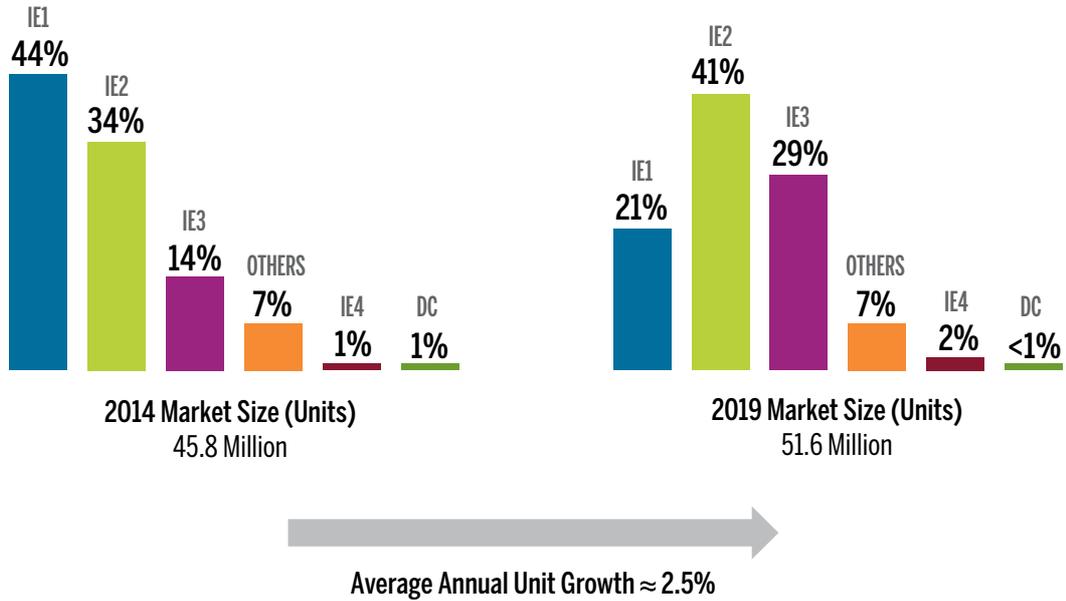
Notes: Modelling based on an average lifetime of 20 years and a 3% annual growth rate.  
 Source: Motor Model China, A+B International, EEMODS 2005.

### 4.3 Global motor market to 2019

The most recent global motor market survey and forecast assumes that the number of low voltage motors<sup>6</sup> sold between 2014 and 2019 will increase by 11%, a 2.5% p.a. This growth is mainly driven by increased sales in Asian and other BRICS countries [2]. It predicts a big shift away from Standard Efficiency IE1 to High Efficiency IE2 and to Premium Efficiency IE3. IE4 appears on the horizon with 1.5% of the global market share of motors by 2019.

<sup>6</sup> LV or low voltage motors operate below 1000 Volt and also typically have an output power of below 1000 kW.

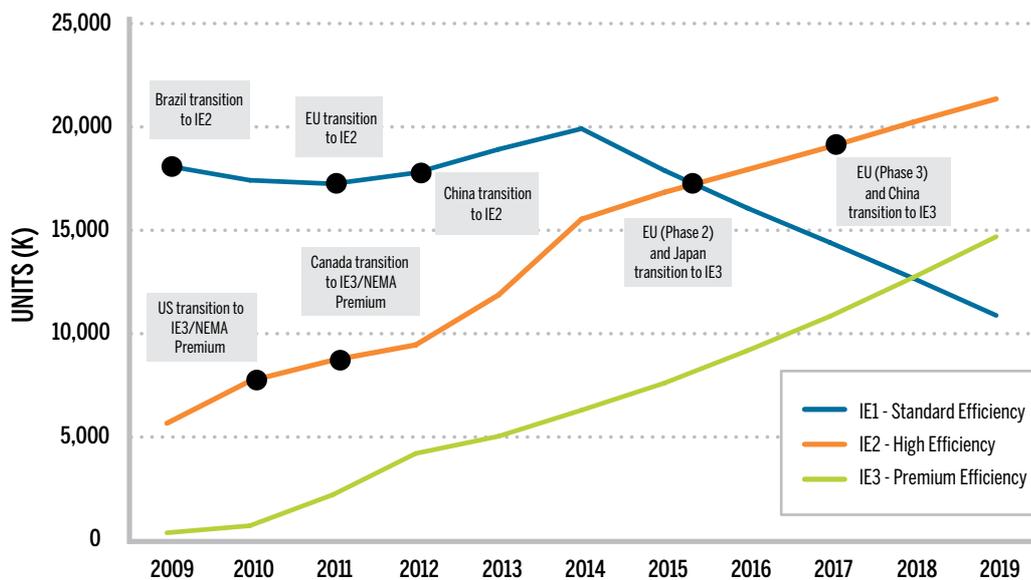
Figure 8: Estimated low voltage motor market 2014 to 2019



Source: [2]

This translates into projected sales trends of motors according to IE-code, as illustrated in Figure 9. This figure also indicates the date when new MEPS are introduced in several major economies.

Figure 9: Estimated global motor sales, surveys from 2009 to 2014, estimates 2015 to 2019



Source: IHS, Motor Summit, October 2014, updated

## 5 Variable Frequency Drives – A step towards energy efficient motor systems

Since an increasing number of motor applications are working with variable loads, 40% to 60% of all motor systems would benefit from the proper use of VFDs, and this represents a large potential to improve the energy efficiency for industrial motor systems.

Traditionally, the need to operate at part or variable load has been met by:

- ▶ Running traditional fixed speed asynchronous motors at reduced load, delivering reduced torque.
- ▶ Adding mechanical devices such as throttles, dampers, and bypasses to reduce the flow of material, gas or liquid.

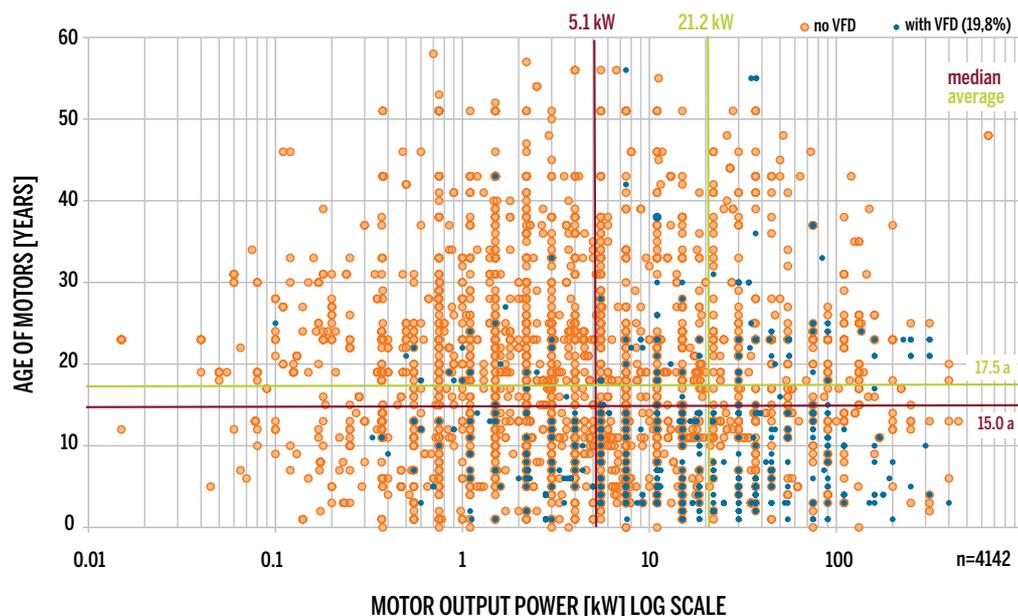
Both solutions fail to optimise the energy saving opportunities. Motors running at less than 50% load tend to have a significant reduction of their nominal efficiency, while throttles of all kinds introduce an artificial extra load, deliver less flow, and only slightly reduce the power consumption of motors at full load.

A VFD, on the other hand, electronically controls both the rotating speed and the torque of the motor to match the demand. A VFD also allows motors with heavy starting torque to start more easily. VFDs do however add cost and complexity to the design of motor systems, are responsible for additional energy losses of 2%-5% in the VFD, and 1%-3% in the motor<sup>7</sup>.

While these factors need to be taken into account, VFDs are especially effective for variable load in closed loop pumps and in fans. In linear torque applications, such as conveyor systems, the benefits of VFD during operation are less significant.

Although data on the current application of VFDs is scarce, there appears to be considerable opportunity to expand the use of VFDs in industrial applications. In China for example, an industry study shows that only 15% of motors used a VFD [14], while a Swiss study of over 4,000 motors indicates that VFDs were applied to 20% electric motors surveyed, but even then, not all VFDs were used correctly (see Figure 10) [8].

**Figure 10: VFD use in Swiss motor systems**



Source: [8]

<sup>7</sup> These extra losses of the motor are due to the harmonics coming from the pulse width modulation of the VFD.

The energy efficiency aspects of VFDs are currently under consideration by the IEC. A new publication, IEC 61800-9-2, is expected to be released by end of 2016/early 2017, and will include VFD loss measurement methods and efficiency classifications (see Figure 11). MEPS for VFDs are under consideration by the EU in the revision of the Commission Regulation (EC) No 640/2009 Implementing Directive 2005/32/EC with regard to Ecodesign requirements for electric motors expected in 2016.

**Figure 11: Status of IEC efficiency standards for motors and motor driven units**

		SCOPE	TESTING	EFFICIENCY CLASSIFICATION
1		motor	IEC 60034-2-1 ed 2 published	IEC 60034-30-1 ed 2 published
2	 	motor, driven by a VFD	IEC/TS 60034-2-3 ed 1 published	IEC 60034-30-2 CDV October 2015
3	 	VFD	IEC 61800-9 IEC 61800-9-1 Extended Products IEC 61800-9-2 Classification CDV October 2015	
4	 	motor+VFD		

Source: Impact Energy

## 6 Energy efficiency roadmap for electric motors and motor systems

The following section highlights the key policy areas for consideration in order to stimulate the transition towards a comprehensive approach to optimising energy savings from motors and motor driven systems.

### 6.1 Set IE3 Premium Efficiency level as global target for MEPS before 2020.

As shown in Table 1 and discussed in the 4E-EMSA Motor Systems Policy Guidelines 2014 [11], the IE3 Premium Efficiency level is becoming the global benchmark for motor MEPS. Many economies that have not already adopted this level are considering the transition from IE2 within the next 5 years.

### 6.2 Expand MEPS to cover VFD and motors plus VFD

While the energy savings potential in motors is significant, it is very much larger in motor systems, and therefore policy makers' attention is shifting to motor driven units (MDUs), also known as 'extended motor products'.

Motor driven units include the combination of components such as motors, VFDs, mechanical components (e.g., gears, belts, brakes, and clutches) and applications such as pumps, fans, and compressors. In this context, the assessment of energy efficiency is complex because it concerns the interactions of electrical, electro-mechanical and electronic components.

Policy makers also need to consider that the expansion into policies concerning MDUs will involve a different set of stakeholders than those involved in motors alone. For MDUs, the industry tends to be divided into the following three groups:

- ▶ Motor manufacturers (electro-mechanical specialists)
- ▶ VFD manufacturers (electronic specialists)
- ▶ System manufacturers (motor and VFD), pump, compressor, fan manufacturers.

Taking a phased approach to the capturing some of the savings available from motor driven units, an initial area for regulation could be to adopt MEPS for VFDs, and for the combination of motors and VFDs.

The IEC is currently developing international efficiency testing and classification standards (IEC 60034-30-2<sup>8</sup> and IEC 61800-9-2<sup>9</sup>), which are due to be adopted in 2016 or 2017. Once published, this will facilitate the introduction of appropriate performance requirements for VFDs, and for motors and VFDs, as national MEPS.

The policy challenges of further expanding into the area of motor driven units are evident from the divergent approaches being taken in Europe, China, and the US. 4E-EMSA has already provided technical guidance on motor system efficiency through the Motor Systems Tool<sup>10</sup>, developed by the Danish Technological Institute. The technical assistance provided by 4E EMSA will be augmented by the development of a major publication over the next two years: '*Policy Guidelines for Motor Driven Units*'.

### 6.3 Expand the coverage of existing regulations

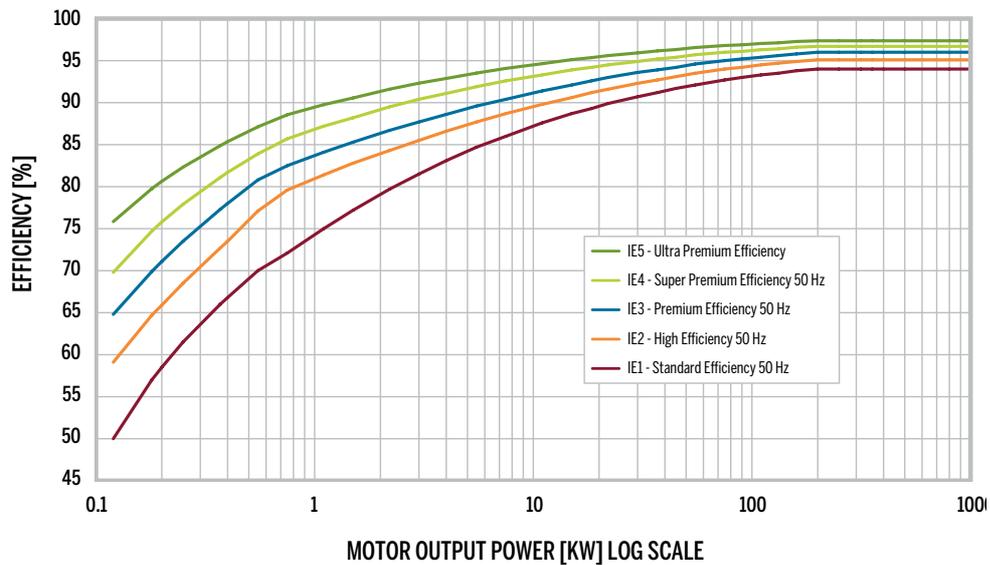
The scope of motor classifications (IE-code) in IEC 60034-30-1 was expanded in 2014 to include motors with an output from 0.12 kW to 1,000 kW in 2, 4, 6 and 8 poles for 50 Hz and 60 Hz (see Figure 12), compared to 0.75 kW-375 kW previously. This added a very large number of smaller motors (low voltage up to 1,000 volts), including those built into appliances and equipment such as exhaust fans and washing machines.

<sup>8</sup> IEC 60034-30-2: Efficiency classification for motors fed by VFD

<sup>9</sup> IEC 61800-9-2: Testing and efficiency classes for VFD and motor plus VFD combinations

<sup>10</sup> [www.motorsystems.org/motor-systems-tool](http://www.motorsystems.org/motor-systems-tool)

Figure 12: IE-code requirements for motor efficiency as a function of motor output power, 4 pole 50 Hz



Source: IEC 60034-30-1, 2014

The US has adopted MEPS (from 15 March 2015) for small open motors rated from ¼ to 3 horsepower (0.18 kW up to 2.2 kW) and 60 Hz with 2, 4 and 6 poles<sup>11</sup>. These US regulations cover a variety of different technologies: poly-phase; capacitor-start capacitor-run and capacitor-start induction-run including single phase and poly-phase motors; built in a two-digit NEMA frame.

In Europe, consideration is being given to upgrading the Ecodesign requirements for motors, to include a broader scope from 0.12 kW to 1000 kW. This may come into force after 2016<sup>12</sup>.

In 2014 China introduced MEPS (in GB 30254-2013) to cover medium and high voltage motors (6 kV up to 25 MV), with output power from 220 kW to 24'000 kW, with 2, 4, 6, 8, 10 and 12 poles. This standard includes three efficiency tiers, from the lowest tier 3, to the most stringent tier 1.

However, as of today no country has increased the coverage of their MEPS to reflect the full range of motors now covered by the IEC standard, which represents a substantial opportunity to increase energy savings.

## 6.4 Adopt IE4 level as MEPS in major industrial economies after 2020

One of the next challenges is to increase the minimum efficiency of new motors to the IE4 level in the major economies of North America, Europe and Japan. This will reflect improvements in the cost of performance, opportunities for increasing the energy efficiency of asynchronous induction motors, and the introduction of new motor technologies (PM, SR, etc.), which provide a variety of possibilities for more efficient motors.

An examination of the motors registered as available in Australia, Canada and the US by 4E shows that many models already meet the IE4 Super Premium efficiency level, and a few isolated models meet IE5 levels.

A further indication of the efficiency of best performing models can be taken from the SEAD Motor Awards Competition, finalised in October 2014<sup>13</sup>. The SEAD Awards focused on mid-sized electric motors (0.75– 375 kW) and winners were selected at the international level, as well as for North America, Australia and India, as shown in Table 2.

<sup>11</sup> Federal Register, Energy Conservation Standards: § 431.446 Small electric motors energy conservation standards and their effective dates. Washington DSC, US, 2014

<sup>12</sup> See Lot 30: [10]

<sup>13</sup> See <http://www.superefficient.org/About-Us/News/Motor%20Awards%20Winners%20Press%20Release>

**Table 2: SEAD Motor Awards Competition, Winners 2014**

REGION	RATED POWER	MOTOR SUPPLIER AND MODEL	FULL LOAD EFFICIENCY (%)	MOTOR IE-CODE
International	4 kW	Nanyang* YZTE4-112M	91.2	IE4
	11 kW	Nanyang YZTE4-160M	93.5	IE4
North America	3.7 kW (5 hp)	Nanyang NSPE184T	91.1	IE4
	41 kW (15 hp)	Nanyang NSPE254T	93.6	IE4
Australia	4 kW	Nanyang YZTE4-112M	91.2	IE4
	11 kW	Nanyang YZTE4-160M	93.5	IE4
India	3.7 kW	Siemens (India) 1LA21134NA80	88.4	IE3
	11 kW	Siemens (India) 1LA21134NA80	91.4	IE3

\*Nanyang Explosion Protection Group Company Limited.

### 6.5 Improve international alignment

The following inconsistencies occur between the international IEC and the regional NEMA standards for motors. These should be addressed to improve harmonization of the global market:

- ▶ IEC describes efficiency using a smooth curve for 50 Hz, while NEMA defines efficiency requirements for 60 Hz using a stepped function based on frame sizes. This leads to some incomparable efficiency requirements for the same motors.
- ▶ Frame sizes identified by IEC<sup>14</sup> and NEMA<sup>15</sup> will need to be reappraised once new technologies enter the market. This is because new technologies (PM, and SR,) can deliver more power in a smaller frame, compared to equivalent asynchronous induction motors.

As a result, frame sizes can potentially be downsized for new technology motors, providing an opportunity to remove inconsistencies between the IEC and NEMA<sup>16</sup> standards (see Table 3 and Table 4).

**Table 3: Frame sizes and output power in Europe and Japan, 50 Hz electricity supply**

IEC FRAME (MM)	MAX. OUTPUT POWER (kW) PER FRAME SIZE					
	2-POLE JAPAN	2-POLE EN	4-POLE JAPAN	4-POLE EN	6-POLE JAPAN	6-POLE EN
80	0.75	1.1	0.75	0.75	0.4	0.55
90	2.2	2.2	1.5	1.5	0.75	1.1
100		3	2.2	3	1.5	1.5
112	3.7	4	3.7	4	2.2	2.2
132	7.5	7.5	7.5	7.5	5.5	5.5
160	18.5	18.5	15	15	11	11
180	30	22	30	22	22	15
200	45	37	45	30	37	22
225	55	45	55	45	45	30
250	90	55	90	55	75	37
280	132	90	132	90	110	55
315	160	132	160	132	132	90

Source: Martin Doppelbauer, 2013

<sup>14</sup> IEC 60072-1 edition 6.0: Dimensions and output series for rotating electrical machines - Part 1: Frame numbers 56 to 400 and flange numbers 55 to 1080, 1991; and IEC 60072-2: Dimensions and output series for rotating electrical machines - Part 2: Frame numbers 355 to 1000 and flange numbers 1180 to 2360, Geneva, Switzerland, 1990.

<sup>15</sup> American National Standards Institute (NSI)/NEMA MG 1-2011: American National Standard Motors and Generators, Washington DC, US, 2011.

<sup>16</sup> It should be noted that the change of frame sizes due to downsizing, technology development and potential international harmonization will have an impact on the replacement of motors in existing machines.

**Table 4: Frame sizes and output power for US and Brazil, 60 Hz electricity supply**

US FRAME (INCH)	BRAZIL FRAME (MM)	MAX. OUTPUT POWER (kW) PER FRAME SIZE					
		2-POLE BRAZIL	2-POLE US	4-POLE BRAZIL	4-POLE US	6-POLE BRAZIL	6-POLE US
-	71	0.75	-	0.55	-	0.25	-
-	80	1.5	-	1.1	-	0.55	-
14x	90	3	1.5	2.2	1.5	1.1	0.75
-	100	3.7	-	3.7	-	2.2	-
18x	112	5.5	3.7	5.5	3.7	3	1.5
21x	132	11	7.5	11	7.5	7.5	3.7
25x	160	22	15	18.5	15	15	7.5
28x	180	-	22	22	22	18.5	15
32x	200	37	37	37	37	30	22
36x	225	55	55	55	55	37	37
40x	250	75	75	75	75	55	55
44x	280	110	185	110	185	90	150
-	315	185	-	185	-	150	-

Source: Martin Doppelbauer, 2013

### 6.6 Promote technologically neutral policies

Governments should avoid policies that differentiate between competing technologies, as these can cause unfair competition in the market and hinder technological progress. This means that MEPS and classification standards for motors, fans, pumps and compressors should be technologically neutral, so that there is a level playing field for all equivalent products.

One example is the adoption of MEPS levels that differentiate between equivalent motors based on technology in the recently published US small motor regulation. This sets different performance requirements for motors that are single/poly-phase, Open (OPD<sup>17</sup>)/Closed (TEFC<sup>18</sup>) and by the use of capacitors. Also, in China, the high voltage motors regulation specifies different performance requirements for 1000 kW motors depending on their rated voltage.

### 6.7 Reinforce policy-makers' involvement in standardization

As governments seek to maximize energy savings in motor driven units in the future, it is increasingly important that they work with international standards bodies to develop appropriate test methods, performance metrics and efficiency classifications, keeping pace with government objectives. This will not only provide the necessary robust platform for governments to implement national policies, but will also maximize global harmonization.

To date 4E-EMSA has provided representation for policy makers in relevant standardisation groups, and has been instrumental in developing standards that are sufficiently reliable, robust, and fit for policy implementation. This has been achieved by bringing evidence from independent testing into the standards development process, and providing updates on the development of standards to a wide range of stakeholders, through the Motor Summits and newsletters.

<sup>17</sup> OPD = Open Motors, Drip Proof

<sup>18</sup> TEFC = Totally enclosed motors, fan cooled

## 7 Observations for policy makers

The following observations are based on this assessment of the current status and trends in the market, and the policy environment for motors and motor driven units:

- ▶ The development of international standards for motors, including the system of efficiency classification, has been highly effective in encouraging global trade and the alignment of national policies for motors.
- ▶ In line with changes in the cost-effectiveness of efficient motors, governments should consider progressively increasing the stringency of MEPS for motors, based on the international accepted system efficiency classification (IE-code).
  - National motor MEPS should aim to reach the IE3 level before 2020, with North America, Europe and Japan adopting IE4 levels by this time or soon after.
- ▶ To maximise energy savings, consideration should be given to extending the scope of regulations to incorporate motors within the range of 0.12 kW to 1,000 kW by 2020.
- ▶ Governments should take steps to remove any inconsistencies in national MEPS with respect to international standards, in order to eliminate barriers to competition and trade.
- ▶ Governments, industry and standardisation bodies should co-ordinate activities to develop relevant standards and regulations for motor driven units, with the initial focus on VFDs, followed by the combination of motors and VFDs.
- ▶ Experience from the successful development of standards for motors suggests that governments will need to play an active role in future standardisation processes relevant to motor driven units. 4E-EMSA provides a platform for member government to pool resources and be represented so that international standards better reflect the needs of regulators.

## 8 References

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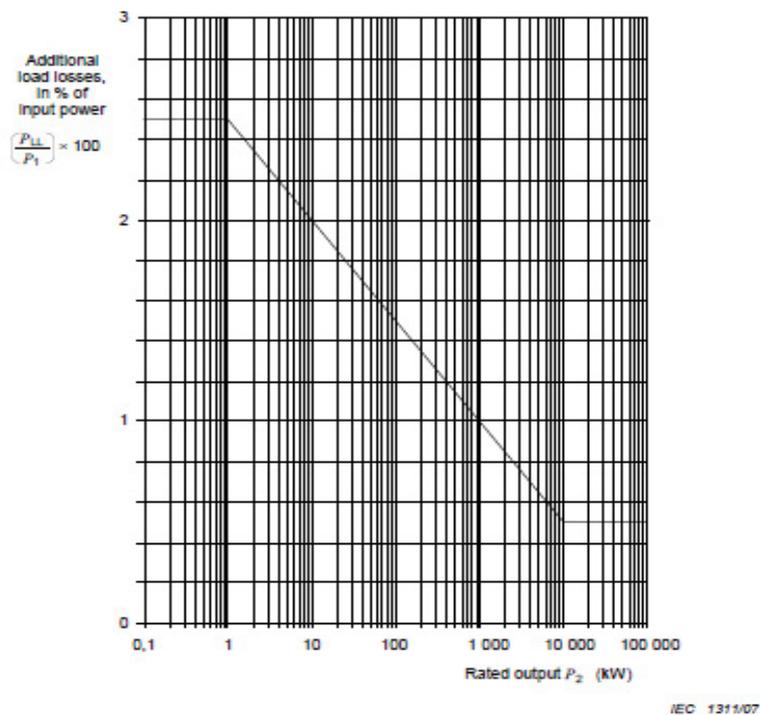
## Annex A: Regional methods of testing motor efficiency

Motor testing methodologies in most regions are now closely based upon the IEC 60034 series of standards and are highly comparable with the US IEEE 112B and Canadian CSA C390. Historically, one significant source of differences has been how stray losses<sup>19</sup> are accounted for in motor testing, and the calculation of efficiency. Older test methods assigned these losses as a flat rate of 0.5% of input power, but more accuracy was introduced in IEC 60034-2-1: 2007 by assigning losses as a relationship to the input power. As shown in Figure 13, stray losses can total over 2% of input power in smaller size motors.

The internationally accepted approach in IEC 60034-2-1, 2014 indicates that the losses are to be measured through specific test procedures, and this gives the most accurate results.

**Figure 13: Additional motor stray load losses**

The value of additional load losses  $P_{LL}$  at rated load shall be determined as a percentage of input power  $P_1$  using the following curve.



The values of the curve may be described by the following formulas:

$$\text{for } P_2 \leq 1 \text{ kW}$$

$$P_{LL} = P_1 \times 0,025$$

Source: IEC 60034-2-1, 2014

<sup>19</sup> 'Stray losses' is the name given to a group of miscellaneous load dependent losses that are not associated with primary copper and secondary losses, iron losses and mechanical losses.

## Test methodologies in Australia

The 2012 GEMS determination for Australia refers to AS/NZS 1359.5:2004 and allows either of two approaches to be used, referred to as Method A (indirect based on sum of losses) and Method B (direct measurement based on output torque). Currently work is being done to simplify energy efficiency requirements by aligning with the International Electrotechnical Commission's internationally accepted test standard, IEC 60034-2-1, 2014. The main proposal is mandating the 'preferred method', Method 2-1-1B, Summation of separate losses - Additional load loss determined by the method of residual loss. This 'preferred method' is equivalent to the Method A in the current Australian and New Zealand performance standard AS/NZS 1359.5:2004. The proposal includes removal of the current option to test to 'Method B' as per AS/NZS 1359.5:2004 and removal of the MEPS levels specified for using Method B.

Further details of the test methods in use in Australia are given on the EnergyRating website<sup>20</sup>. Data can be registered under any of the following test methods in Australia:

- ▶ AS/NZS 1359.102.3:2000
- ▶ IEEE 112-B
- ▶ IEC 60034-2-1
- ▶ AS 1359.102.1:1997
- ▶ IEC 61972

## Test methodologies in Canada

The relevant test methodology for Canada is C390-10<sup>21</sup> *Test methods, marking requirements, and energy efficiency levels for three-phase induction motors* (2010). This establishes minimum efficiency levels for both NEMA and IEC motor designations that are covered by legislated requirements, and includes requirements for both 50 Hz and 60 Hz motors.

CSA C390-10 provides test results that are highly comparable with those from the North American IEEE 112B and with IEC 60034-2-1. Both, the 1998 and 2010 versions of CSA C390, require stray losses to be measured.

## Test methodologies in the United States

The test procedure in the US since 2012 is the Final Rule *Test Procedures for Electric Motors and Small Electric Motors*, Federal Register, 77 FR 26608 (May 4, 2012). An amendment to the Final Rule was published in 2013<sup>22</sup> that clarified the scope of coverage.

To reduce the testing burden the US Department of Energy (DOE) also permits manufacturers to use an alternative efficiency determination method (AEDM). The AEDM can be used to certify to DOE that other motors (which do not need to be physically tested) are compliant.

<sup>20</sup> See <http://www.energyrating.gov.au/for-industry/regulation-information-for-industry/product-standards/overview/asnzs1359/>, Overview and Test Procedures – AS/NZS 1359 Three Phase Electric Motors, accessed 14 October 2014.

<sup>21</sup> See <http://shop.csa.ca/en/canada/energy-efficiency/c390-10/invt/27016222010>.

<sup>22</sup> Final Rule: Test Procedures for Electric Motors, Federal Register, 78 FR 75962 (December 13, 2013).

## Annex B: Energy efficiency policies for motors

Table 5: Overview of policies in Australia, Canada and US

ECONOMY	POLICY	YEAR(S) INTO FORCE	BROAD TYPES AFFECTED*	SCOPE IN RATED POWER	NOMINAL EQUIVALENT IE LIMIT
Australia	MEPS	2001, updated 2006	2/4/6/8 pole; 3-phase; up to 1100 V; all but certain exceptions	0.73-185 kW	2001: IE1 2006: IE2
	High Efficiency (HEPS, voluntary)	2001, updated 2005	2/4/6/8 pole; 3-phase; up to 1100 V; all but certain exceptions	0.73-185 kW	2001: IE2 2005: IE3
Canada	MEPS - initial MEPS – Most stringent	1997-2011 2011	2/4/6 pole; 3-phase; up to 600 V; NEMA A, B and IEC N	0.75-150 kW	1997 IE2 2011: IE3
	MEPS – Least stringent	2011	2/4/6/8 pole; 3-phase; up to 600 V; NEMA C & IEC H, fire pump & others	0.75-375 kW	IE2
	MEPS – Least stringent	2011	2/4/6/8 pole; 3-phase; up to 600 V; NEMA B & IEC N	150-375 kW	IE2
US	MEPS EPAAct	1997	2/4/6 pole; general purpose motors	0.75-149 kW	(IE2)
	MEPS 'subtype I'	2010	2/4/6 pole; up to 600 V; NEMA MG-1 'usual service conditions'	0.75-149 kW	IE3
	MEPS 'subtype II'	2010	8 pole; up to 600 V; U-frame; NEMA C; other features	0.75-149 kW	IE3
	MEPS fire pump	2010	2/4/6/8 pole	0.75-375 kW	IE2
	MEPS NEMA B	2010	2/4/6/8 pole	187-375 kW	IE3
	<i>Amended MEPS</i>	<i>2016</i>	<i>2/4/6/8 pole; 3-phase; up to 600 V; NEMA A, B, IEC N</i>	<i>0.75-375 kW</i>	<i>IE3</i>
	<i>Small motors MEPS</i>	<i>2015</i>	<i>2/4/6 pole open, single phase and poly-phase motors</i>	<i>0.18-2.2 kW</i>	<i>IE3</i>
US/Canada	NEMA Energy Efficient (voluntary)	(Not known)	(Not known)	(Not known)	IE2
	NEMA Premium (voluntary)	2001	NEMA A, B, special and definite purpose	0.75-375 kW	IE3
	<i>NEMA Super-Premium**</i>	<i>(Not known)</i>	<i>(Not known)</i>	<i>(Not known)</i>	<i>IE4</i>

Requirements in italics are not in force as of 2015

IE levels in grey are superseded.

\*Exclusions apply in each case.

\*\* NEMA super-premium appears to be an informal level equivalent to IE4, no formal reference or definition has been identified although it is referred to in various promotional brochures.

Table 6: Overview of policies in EU and China

ECONOMY	POLICY	YEAR(S) INTO FORCE	BROAD TYPES AFFECTED*	SCOPE IN RATED POWER	EQUIVALENT IE LEVEL (APPROX.)
EU	CEMEP voluntary label	1998-2010	Not known)	1.1-90 kW	2001: IE1 2006: IE2
	Ecodesign regulation – Tier 1	2011	2/4/6 pole, up to 1000 V; all squirrel cage induction motors	0.75-375 kW	IE2
	Ecodesign regulation – Tier 2	2015		7.5-375 kW	IE3 (IE2 with VSD)
	<i>Ecodesign regulation – Tier 3</i>	2017		0.75-375 kW	IE3 (IE2 with VSD)
	<i>Ecodesign measure (draft)</i>	2015	2/4/6/8 pole, up to 1000 V; all squirrel cage induction motors	0.75-7.5 kW	IE2
		2015		7.5-375 kW	IE3
		2017		0.75-375 kW	IE3 (IE2 with VSD)
		2018		0.12-0.75 kW	IE2
		2018		375-1000 kW	IE3
		2018		Brake motors	0.75-375 kW
2020		All motors		0.75-1000 kW	IE3
China <sup>1</sup>	MEPS Tier 1	2007	2/4/6 pole; 3-phase; up to 690 V	0.55-315 kW	IE1
	MEPS Tier 2	2012		0.55-315 kW	IE2
	MEPS for small motors <sup>2</sup> – Tier 1	2011	3-phase; up to 690 V; asynchronous	0.01-2.2 kW	Similar to IE2
	MEPS for small motors <sup>2</sup> – Tier 2	2015	3-phase; up to 690 V; asynchronous	0.01-2.2 kW	Similar to IE3 for some of size range
	<i>MEPS Tier 3</i>	2016	2/4/6 pole; 3-phase; up to 690 V	7.5-375 kW	IE3
	<i>MEPS Tier 4</i>	2017	2/4/6 pole; 3-phase; up to 690 V	0.75-7.5 kW	IE3
	<i>'Reach target' (aspirational target)</i>	2015	(Not known)	(not known)	IE4
	<i>Energy labels and incentives for large motors</i>	(Not known)	3-phase; up to 6000 V and up to 10000 V	355-25000 kW	(Not known)

Requirements in italics are not yet in force.

IE levels in grey are superseded.

\*Exclusions apply in each case.

<sup>1</sup> Source: EuP Lot 30: Electric Motors and Drives, Task 1: Product Definition, Standards and Legislation, ENER/C3/413-2010, Final April 2014, p25. Also English translations of Chinese standards.

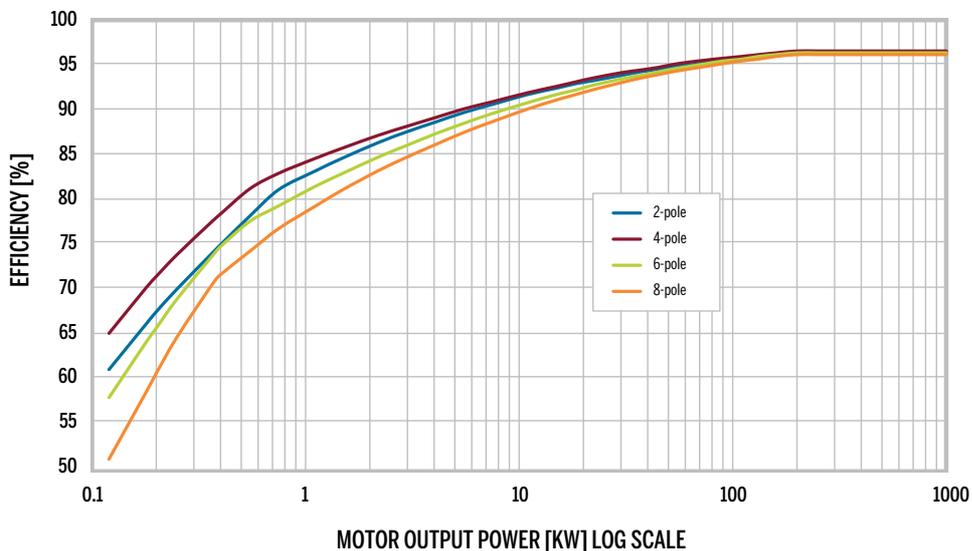
<sup>2</sup> China also has MEPS for other specific types of small motor: capacitor run asynchronous, capacitor start asynchronous and motors for fans in room air conditioners but the equivalence of these to IE classes has not been determined.

## Annex C: Stock and sales modelling Methodology

The assessment of the market presented in this report has been undertaken by tracking the change in motors by IE-code, as defined by IEC 60034-30-1, for induction motors [1]. This approach takes advantage of the relatively robust data available by efficiency classes. By comparison, comparing datasets of individual motor efficiencies are hampered by the following problems and inaccuracies:

- ▶ Tracking sales by motor size (e.g., measured by output power in kW) may not adequately account for variations in efficiency and losses of similar sized motors (see Figure 12).
- ▶ Similarly, motor efficiency varies significantly with rotational speed (derived from various numbers of poles: 2-, 4-, 6-, 8-poles), especially in smaller sizes (see Figure 14). Therefore, to provide an accurate picture, data on motor speed or the number of poles needs to be included.

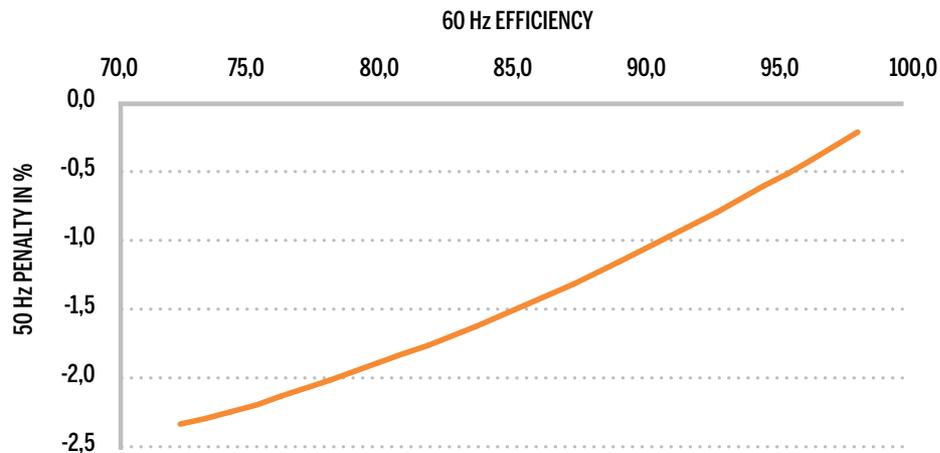
**Figure 14: Motor efficiency (IE3) as a function of motor output power, for motors with different speeds, 2-, 4-, 6- and 8-poles**



Source: IEC 60034-30-1, 2014

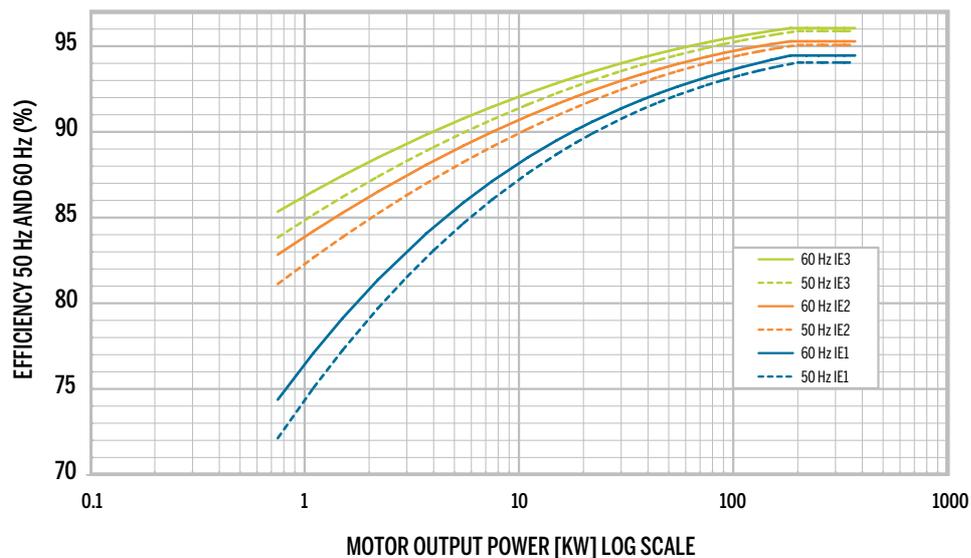
- ▶ The efficiency of motors designed and operated for 60Hz electricity supply are not directly comparable with those designed for 50Hz supply, since the former have approximately 7% to 9% lower losses, as shown in Figure 13. Using data based on IE-codes effectively allows comparison as IEC 60034-30-1 sets the thresholds higher for 60 Hz motors than for those operated at 50Hz (see Figure 15).

Figure 15: Percent efficiency penalty between 60 Hz and 50 Hz supply.



Source: Martin Doppelbauer, 2003

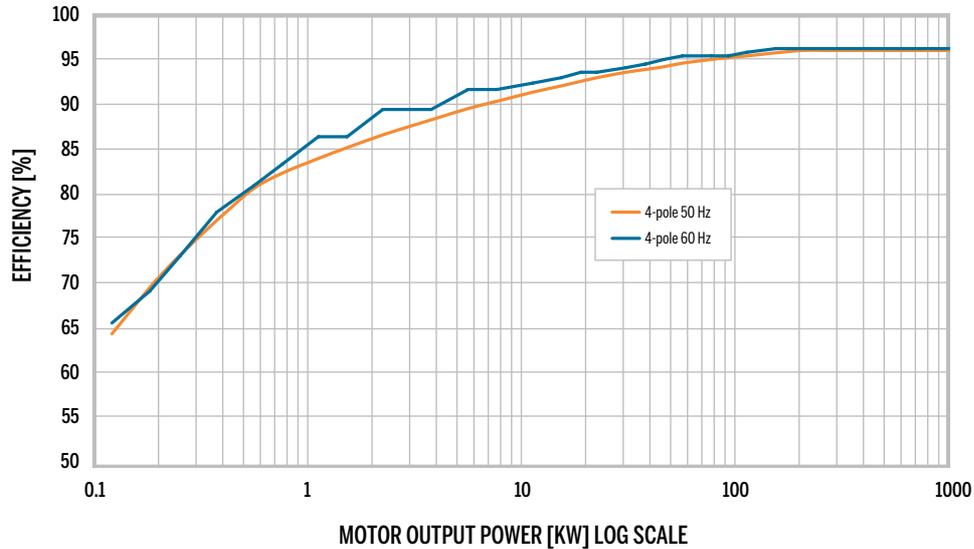
Figure 16: Theoretical relationship of efficiencies for 50 Hz and 60 Hz 4-pole motors



Source: Martin Doppelbauer, 2006

- ▶ Before 2007, motor efficiencies were tested using different measurement standards. Only since the publication of the global testing standard in 2007, IEC 60034-2-1<sup>23</sup>, and its recent revision published in 2014, has it been possible to undertake a repeatable comparison of efficiencies in different testing labs with high accuracy and low uncertainty. (See Annex A)
- ▶ Different methods are used for setting efficiencies depending on motor output power: the IEC uses a smooth geometrical curve with continuous output power, while NEMA in North America defines a staggered curve depending on frame sizes (see Figure 17).

Figure 17: Efficiency (IE3) for 4-pole motors operated with 50 Hz and 60 Hz



Source: IEC 60034-30-1, 2014

Motor efficiencies also depend on frame sizes that are defined differently in different parts of the world (see Table 3). Larger frames allow for more active material and therefore higher efficiencies.

It should also be noted that any tracking of the market for motors with a VFD or VFDs themselves is currently hindered by the fact that:

- ▶ Although IEC standards for measurement of losses of motors with a VFD (IEC TS 60034-2-3; 2013<sup>24</sup>) have been published; IE-codes for motors driven with a VFD (IEC 60034-30-2<sup>25</sup>, CD in 2015) and IE-codes and testing methods for VFDs (IEC 61800-9-2<sup>26</sup>, CDV in 2015) are still in the process of being developed<sup>27</sup>.

## Data sources

The following surveys, and research reports have been used to inform this analysis of the market for electric motor efficiency.

### International surveys:

- ▶ 4E-EMSA survey table of Minimum Energy Performance Standards (MEPS), updated and published annually at the international conference Energy Efficiency in Motor Driven Systems (EEMODS) and Motor Summit between 2007 and 2014.
- ▶ IHS/IMS Motor Market Survey provides extracts of data of motor sales 2009-2013 and market estimates up to 2018: published in conference papers at EEMODS 2013 and Motor Summit 2014 [1].

<sup>24</sup> IEC TS 60034-2-3: Rotating electrical machines - Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors, Geneva, Switzerland, 2013

<sup>25</sup> IEC 60034-30-2: Rotating Electrical Machines – Part 30-2: Efficiency classes of variable speed AC motors (IE-code), not published.

<sup>26</sup> IEC 61800-9-2: Adjustable Speed Electrical Power Drive Systems –Part 9-2: Ecodesign for power drive systems, motor starters, power electronics & their driven applications - Energy efficiency indicators for power drive systems and motor starters, not published.

<sup>27</sup> Motors with VFDs and powered by new technologies (Permanent Magnet and Synchronous Reluctance motors) which are currently entering the market are not yet included in MEPS

**National and regional surveys:**

The following national or regional surveys have been used:

- ▶ Copper Association survey for China 2015 [4].
- ▶ European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) annual survey data of eff1/eff2 and eff3 market sales; from ca. 2010 with IE1, IE2, IE3 sales.
- ▶ National Electrical Manufacturers Association (NEMA) confidential annual survey of sales of EPAct and NEMA Premium motors [5].
- ▶ Japan Electrical Manufacturers Association (JEMA) annual statistics (data contain subcategories that cannot be clearly identified).
- ▶ China National Institute for Standardization (CNIS) series of research reports on motor sales, efficiencies and policies, 2003 and onwards.
- ▶ Australia's Department of Industry and Science annual review of registration data.

**Research papers**

The following published research papers that include market analysis have been used:

- ▶ Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems, IEA Energy Efficiency Series [3] and [7].
- ▶ Martin Jakob: Global motor market study [6] (see annex Figures 14 -16).
- ▶ European Commission, Ecodesign Lot 11 [9].
- ▶ European Commission, Ecodesign Lot 30 [10].
- ▶ US Department of Energy Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Electric Motors [12].

**Survey quality and quantity**

The above provides relatively robust market data, however the following issues should be noted:

- ▶ Quantitative comparisons are complicated by the inconsistent or lack of clear definition of the scope of surveys [3]. This can be partially resolved by combining a top down approach, based on electric energy use in industry, with a bottom up approach, based on national surveys.
- ▶ National sales data may also be difficult to unravel since it often combined imports and exports of individual motors and the trade in machinery that incorporates some of these motors.
- ▶ Where data is sourced from national surveys of members of the respective industry associations (e.g. NEMA, CEMEP, JEMA) the sample often excludes imported products and national non-members.