From laggard to world leader – the role of policies in the EU motors and drives market transformation

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Abstract

The importance of motors as a major consumer of electricity in industry and service buildings has been recognised for a long time. Several studies showed the very large energy saving potential for these products. However, in the year 2000 the EU motor market was dominated by low efficiency motors (IE0 represented about 70 % of the sales). The paper addresses the evolution and impact of motor policies in the EU.

After a period of Voluntary Agreement with limited impact, the Commission Regulation 640/2009 was adopted, which specifies requirements regarding Ecodesign of electrical motors and the use of Variable Speed Drives (VSD), following the first EuP study on motors (Lot 11) which highlighted the importance of introducing Minimum Efficiency Performance Standards (MEPS) relating to these products in Europe.

A new study (Lot 30) has since then been carried out to evaluate the possibility of extending the scope of the Regulation to motors outside the current power range and to technologies other than three-phase induction motors. Electronic controllers, such as VSDs and soft-starters were also subject of the study.

Lot 30 identified a series of policy options that will lead to the reduction of environmental impacts taking into consideration the Life Cycle Cost and the best available technologies in the market. Scenario analysis projected the energy and economic savings for the period of 2013–2030 from each of these options. Six policy options were identified, as well as their possible implementation timelines. Innovative policies, such as Super-Premium and VSD MEPS were proposed for the first time making Europe the leading region in Motor systems regulation.

The policy options proposed, while reducing the environmental impact of motor systems, will begin to prepare the path for the introduction of system oriented policy options, based on the Extended Product Approach and the standardisation work being carried out by CENELEC with the EN50598 series of standards. The main results of the Lot 30 study are presented in this paper.

Introduction

Motors are a major electricity consumer – about 70 % of the industrial electricity consumption and about 35 % in the non-residential buildings sector (Waide, et al., 2011) – and almost all the major economies have some kind of voluntary or mandatory regulatory scheme regarding motor efficiency. Most of these economies have mandatory minimum efficiency levels for motors sold in the respective countries and labelling schemes for the promotion of higher efficiency motors.

In Europe, the recognition of motors as a major electricity consumer has led to a series of successful SAVE[1] studies (de Almeida, 1996) (de Almeida, 2000) (de Almeida, 2001) showing the energy saving potential for these products.

Following this recognition, and with the aim of capturing the identified potential savings, a voluntary agreement supported by the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) and the European

1. The EU SAVE programme (Specific Actions for Vigorous Energy Efficiency) was the union-wide programme dedicated to promoting energy efficiency in industry, commerce and the domestic sector.

Commission was established in 1998 and signed by 36 motor manufacturers, representing 80 % of the European production of standard motors (Bertoldi, et al., 2000). In this agreement three motor efficiency levels were defined as:

1. EFF1 (similar to IE2).
2. EFF2 (similar to IE1).
3. EFF3 (below standard).

Based on this classification scheme there was a voluntary undertaking by motor manufacturers to reduce the sale of motors with EFF3 efficiency levels (standard efficiency).

The CEMEP/EU agreement was a very important first step to promote motor efficiency classification and labeling, achieving a significant market transformation. Low efficiency motors were essentially removed from the EU motor market which was a positive development. However, the penetration of high and premium efficiency motors in 2009 was still very modest.

The 2008 Lot 11 EuP study on motors (de Almeida, et al., 2008) highlighted the importance of introducing Minimum Efficiency Performance Standards (MEPS) relating to these products in Europe.

Following the study, on July 2009, Commission Regulation 640/2009 (EC, 2009) was adopted, which specifies requirements regarding ecodesign of electrical motors and the use of electronic speed control (VSD). More recently the 640/2009 regulation was amended by Commission regulation 4/2014 (EC, 2014), to avoid loopholes created by the definition of operating conditions.

Minimum efficiency requirements for electric motors were set, in three tiers starting in June 2011, as shown in Figure 2.

The efficiency levels were taken from the international standard IEC 60034-30:2008 (IEC, 2008).

The requirements set, apply to 2-, 4- and 6-pole, single speed, three-phase, induction motors in power range 0,75 kW to 375 kW, rated up to 1,000 V and on the basis of continuous duty operation. The following types of motor are excluded:

- Motors designed to operate wholly immersed in a liquid;
- Motors completely integrated into a product (e.g. pump or fan) where the motor's energy performance cannot be tested independently from the product;
- Motors specifically designed to operate:
  - At altitudes exceeding 4,000 meters.
  - Where ambient air temperatures exceed 60 °C.
  - In maximum operating temperatures above 400 °C.
- Where ambient air temperatures are less than -30 °C for any motor or less than 0 °C for a motor with water cooling;
- Where the water coolant temperature at the inlet to a product is less than 0 °C or exceeds 32 °C;
- In potentially explosive atmospheres as defined in Directive 94/9/EC;
- Brake motors.

The requirements set out in the regulation also apply when these devices are integrated into other products (e.g. machines).

Nevertheless, the scope of the existing Regulation only covers part of the electric motors placed on the market. In order to evaluate the adequacy of covering motors not currently covered by legislation (e.g. in different power ranges or using different technologies) a new preparatory study – Lot 30: Special motors, 2014 – was launched in 2012. Electronic controllers, such as VSDs and soft-starters were also subject of the study.

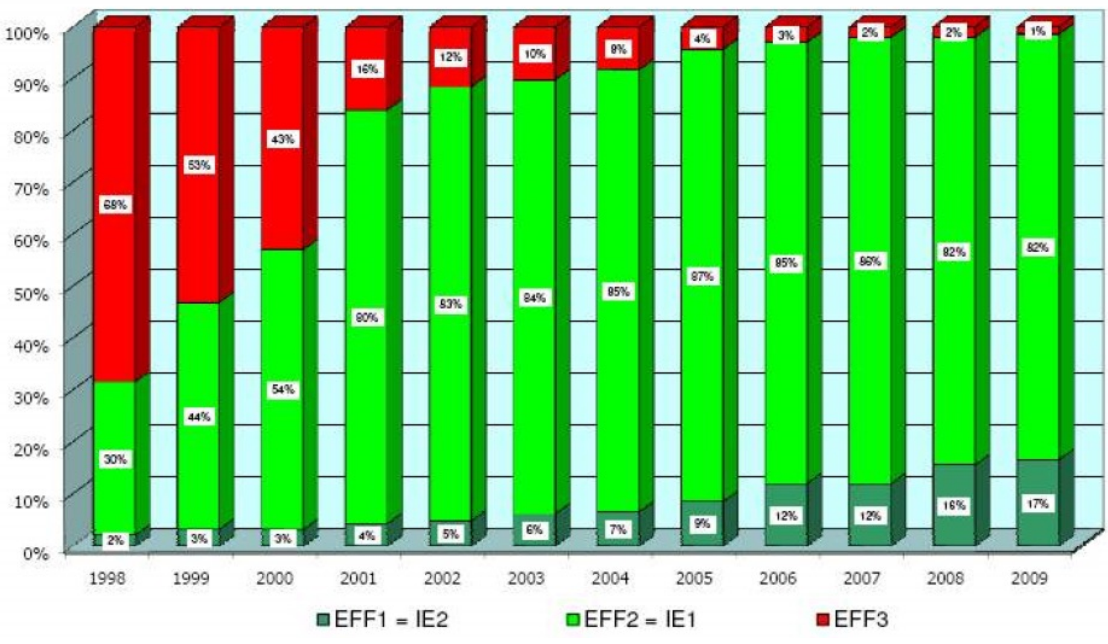

Figure 1. Total motor-sales in the scope of the CEMEP/EU Voluntary Agreement in the period 1998–2009 (CEMEP).

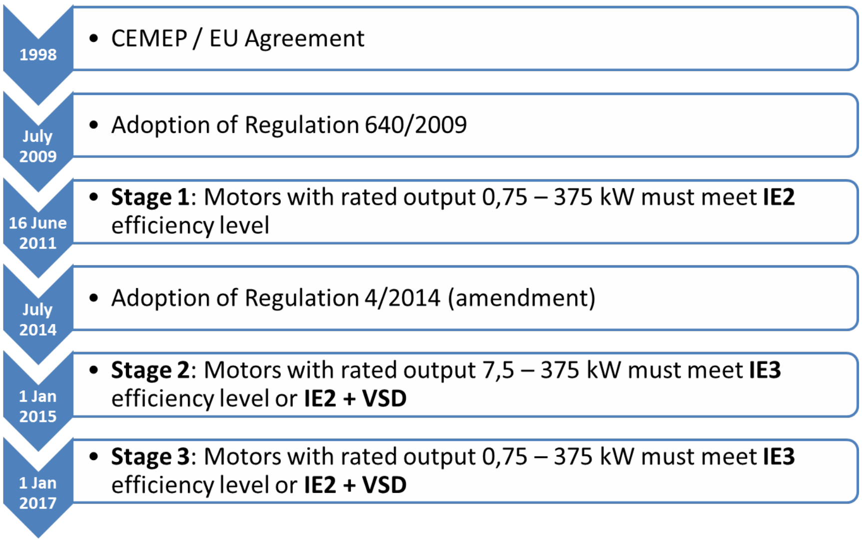

Figure 2. Timeline of EU motor policies.

The study is based on a methodology for the Ecodesign of Energy-using Products (MEEuP) (VhK, 2005) developed for the European Commission, which is common to all the EuP preparatory studies and identified: a) Existing relevant standards and legislation b) Market characteristics for the products under consideration; c) Relevant environmental aspects of the products and their technical/economical potential for improvement; d) Technical analysis of the Best Available Technologies (BAT) and of the Best Not Available Technologies (BNAT); e) LCC assessment; f) Scenario, policy, impact and sensitivity analysis.

The study proposes a list of policy options to remove inefficient motors and VSDs from the market but is unlikely to lead to big technological changes, therefore not overstressing the capabilities of manufacturers, particularly, of small and medium enterprises. This happens mainly because the improvement options identified in Lot 30 already exist in the market. The proposed MEPS can, in this way, be seen as an opportunity to drive the market towards more efficient products as well as an incentive for manufacturers to continue to search for innovative and efficient technological solutions.

The proposed policy options for improving the environmental impact of motors and drives, which resulted from the analysis carried out during the Lot 30 preparatory study, are presented in this paper, as well as the improvement potential associated with each of them. A brief overview of current international practice is also given for the sake of comparison.

International Legislation

Most major economies have set or are in the process of setting minimum energy performance requirements for electric motors. Motor efficiency regulations around the world are to date limited to AC induction motors. In principle other types might be included, but given the much smaller amount of energy used by these other types, the potential energy saving will be much smaller.

An overview of the AC three-phase, integral horsepower, induction motor efficiency voluntary agreements and regulation around the world is presented in Figure 3 and Table 1.

Until recently, efficiency regulations were limited to motors over 0,75 kW and under 150 or 180 kW which is the power range where most of the electricity consumption was found (Waide, et al., 2011). The power range was later broadened to 375 kW in most countries. This is the power range covered by IEC 60034-30:2008.

Lately, following the success of regulations for 3 phase motors, and the high costs of mandatory MEPS for motors beyond the current IE3 "rallying point", attention has turned to smaller fractional horsepower motors. So far, only China and the US have regulations approved covering motors under 0,75 kW.

USA

The USA has recently issued a regulation, Energy Conservation Standards for Small Electric Motors, regarding the efficiency of "small induction motors", either single-phase or polyphase, ranging from ¼ to 3 horsepower (0,18 to 2,2 kW), to be enforced in 2015. The Energy Policy and Conservation Act (EPCA) defines small electric motors as a NEMA (National Electrical Manufacturers Association) general purpose alternating current single-speed induction motor, built in a two-digit frame number series in accordance with NEMA Standards Publication MG1–1987.

The standards apply to three types of electric motors:

- Polyphase Small Electric Motor.
- Single-phase Capacitor-Start Induction-Run.
- Single-phase Capacitor-Start Capacitor-Run.

Minimum efficiency levels are set at IE3 levels according to the new IEC60034-30-1 (IEC, 2014) for poly-phase motors. Minimum efficiency levels set for single-phase motors have no standard IE equivalent. For comparison purposes the levels for 4 pole motors are shown against standardised IE2 and IE3 IEC levels in Figure 4.

The standards do not apply to motors integrated in already regulated equipment (e.g. refrigerators, washing machines, clothes dryers).

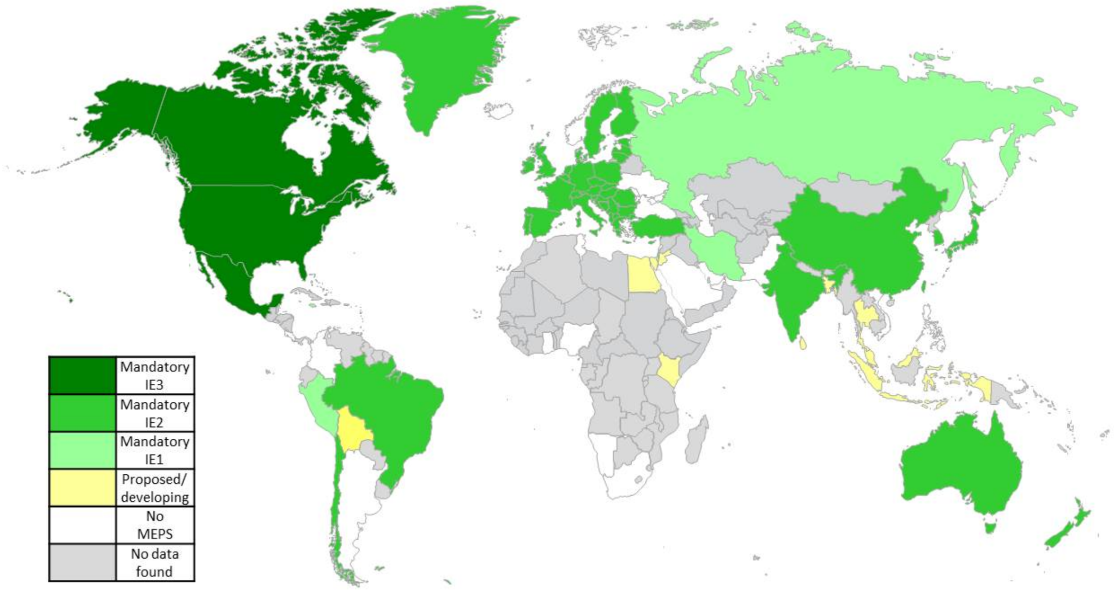

Figure 3. Overview of Minimum Energy Performance Standards (MEPS) Worldwide (Integral Polyphase Induction Motors).

Table 1. Overview of Minimum Energy Performance Standards (MEPS) Worldwide (Integral Polyphase Motors) (source: EMSA).

Efficiency Levels	Efficiency Classes (IEC 60034-30)	Testing Standard	Country	MEPS Regulation
Premium Efficiency	IE3	IEC 60034-2-1 IEEE 112B CSA C390 Low Uncertainty	USA (< 150 kW) Canada Europe 2015* (> 7,5 kW), 2017 Korea 2015 Mexico	EISA 2007/US DOE 10 CFR Part 431 Canadian EEA, CSA C390 ED Directive, Regulation 640/2009 MOCIE/KEMCO NOM 016-ENER-2010
High Efficiency	IE2		USA (> 150 kW) Canada (> 150 kW) Australia New Zealand Brazil Korea China Europe Switzerland	EISA 2007/US DOE 10 CFR Part 431 Canadian EEA, CSA C390 AS/NZS 1359:2004 AS/NZS 1359:2004 NBR 17094-1 MOCIE/KEMCO GB 18613-2010 ED Directive, Regulation 640/2009
Standard Efficiency	IE1	Medium Uncertainty	China Brazil Costa Rica Israel Taiwan Switzerland	

China

MEPS for small motors were recently enforced in China through the standard GB 25958-2011 – Minimum allowable values of energy efficiency and efficiency grade for small-power motors (GB, 2011).

This standard applies to:

- small three – phase asynchronous motors (10 W–2.2 kW),
- capacitor – run asynchronous motors (10 W–2.2 kW),
- capacitor – start induction motors (120 W–3.7 kW),
- double – value capacitor induction motors (250 W–3 kW) for general purpose with the voltage ≤ 690 V, 50 Hz AC power,
- fan motors for room air conditioner (6 W–550 W).

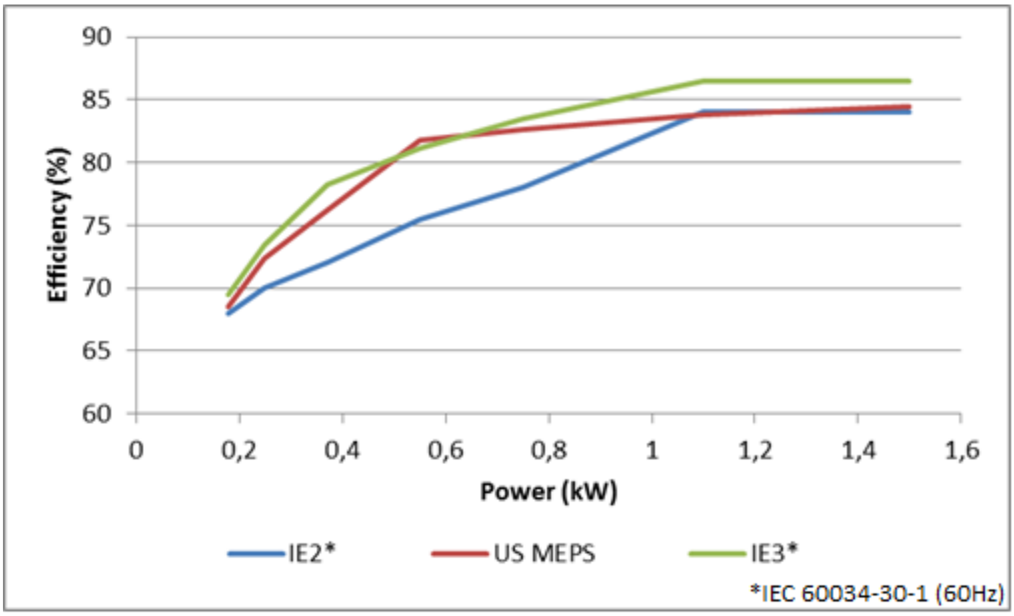

Figure 4. US single-phase MEPS and IEC 60034-30-1 standard levels.

Market

Motor market data, relating to Europe, was primarily sourced from official EU statistics so that it is coherent with official data used in EU industry and trade policy. ProdCom (which stands for Production Communautaire) is the official Eurostat source of statistics on the production of manufactured goods. Where ProdCom data was found to be incomplete or inaccurate it was complemented with data provided by CEMEP[2].

In 2010 over 250 million motors were sold in Europe (Eurostat), 91 % of which were in the small power range, that is, under 750 W, which are currently unregulated in Europe. The share of large motors is very small (only 0.01 %) and the remaining 9 % of motors sold are in the medium power range. These values are consistent with the available estimates of global sales of motors.

In the small power range (< 750 W), DC motors account for 56 % of the number of units sold but more than 37 % of this motors are used in automotive applications which are outside the scope of this study. There are two main reasons for this: automotive applications are outside the scope of the Ecodesign Directive and motors for off-grid applications were not included in the study due to their specificities.

The decreasing price of electronic controllers is expected to lead to the further decline in AC single-phase motor sales, and the increase in AC multi-phase motors and in DC brushless motors.

In the medium power range (0.750 to 375 kW), AC multi-phase motors are responsible for 50 % of sold units (72 % in value). The conventional Brushed DC motor market in this power range is expected to continue to decline as this technology is being replaced by three-phase induction motors. Very high efficient technologies (e.g. PM motors, LSPM motors), which until recently were considered customized products, are becoming available in the market in standard dimensions, as commodity products (De Almeida, et al., 2014).

Table 2 shows the VSD market data for the power ranges considered in the study.

Latest market trends show that the number of VSD units sold with power handling capabilities below 7.5 kVA has risen considerably in the last decade driven by developments in power electronics and by a decrease in prices. The market for VSDs sold integrated into small pumps and fans, particularly in HVAC high-efficiency applications, has also been increasing significantly.

Environmental Impact

For the evaluation of the environmental impact of motors and VSDs, the study collected data considered relevant for the evaluation of the environmental impact and of the LCC both for individual products and for the EU stock. Besides the market data presented above, the data collected included other relevant parameters, such as: Efficiency; Bill-of-Materials; typical number of hours of use; typical load factors/profiles; maintenance practices.

A total of 22 BaseCases were modelled to ensure that the key characteristics of each group of products are adequately captured and are representative of the whole spectrum of products for each category. The results are shown for 12 BaseCases representative of motors and VSD as standalone products (not combined). The BaseCases are the reference point for further improvements, and therefore ideally represent the average new EU product. To evaluate the BaseCase environmental impacts, a reporting software tool named EuP EcoReport is used.

It was found that for all types of motor, the energy consumption (in use phase) dominates in almost all types of environmental impact. This indicates that reducing the energy consumption should be the priority option for reducing the environmental impact of motors. Therefore, the environmental impact in other phases (production, distribution, end-of-life) was not further analysed.

2. European Committee of Manufacturers of Electrical Machines and Power Electronics.

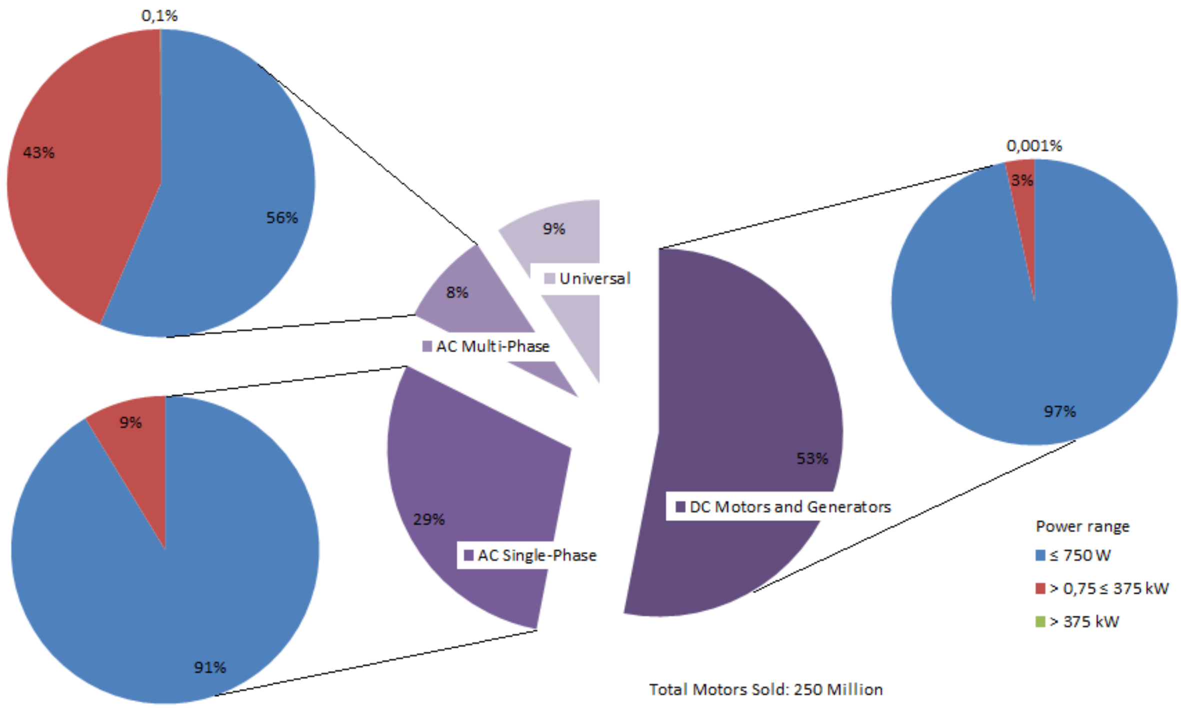

Figure 5. European Motor Market by technology and power range, 2010.

Table 2. European VSD Market, 2012 (source: CEMEP).

	Power range					
	> 120 W ≤ 750 W		> 0,75 kW ≤ 375 kW		> 375 kW ≤ 1000 kW	
	n. units	Mio €	n. units	Mio €	n. units	Mio €
VSDs	1.13 Mio	200	2.89 Mio	2,500	7,000	260

The total environmental impact of VSDs is considerably less than that of motors, partly because they are inherently efficient at mid to high load, and because they are only used in some motor systems. However, particular attention should be given to this subject in order to identify any cost effective technologies that might be capable of reducing their losses, especially as the total stock is anticipated to keep increasing. It must be noted that the energy benefits from using a VSD always come from decreasing the losses of the system on the load side and that if this benefits can be achieved they largely surpass the losses in the drive itself.

Because of the gradually more stringent MEPS being introduced worldwide combined with the raised awareness towards the economic and environmental benefits of using high efficiency motors, in recent years manufacturers have been introducing in the market increasingly better solutions in terms of energy efficiency.

Advances in motor design, tighter tolerances, the use of superior magnetic materials, larger copper/aluminium cross-section in the stator and rotor to reduce resistance are just some of the techniques that contribute to lowering the losses in induction motors and allowing them to reach very high (IE4) efficiency levels (de Almeida, et al., 2011).

Other technologies, such as permanent magnet synchronous motors and synchronous reluctance motors, have been developed that also reach these high efficiency levels and are actually candidates to IE5 class (De Almeida, et al., 2014).

Similarly, developments in power semiconductor technology and materials, such as GaN (Gallium Nitride) and SiC (Silicon Carbide) IGBTs and MOSFETs, allow for a significant reduction in the losses (both switching and conduction) in VSDs. Improved control algorithms also contribute to the increase in efficiency of these devices.

Table 3 shows the energy savings potential of introducing MEPS at higher efficiency levels.

It should be noted that:

- Not all measures in Table 3 are necessarily economic and so the most ambitious energy saving opportunities may not in practice be realizable. The reason behind this is that life-cycle cost analysis has shown that in some cases the life-cycle cost of the improved technological option is greater than that of the BaseCase.
- Energy savings are in addition to those claimed for existing regulation.

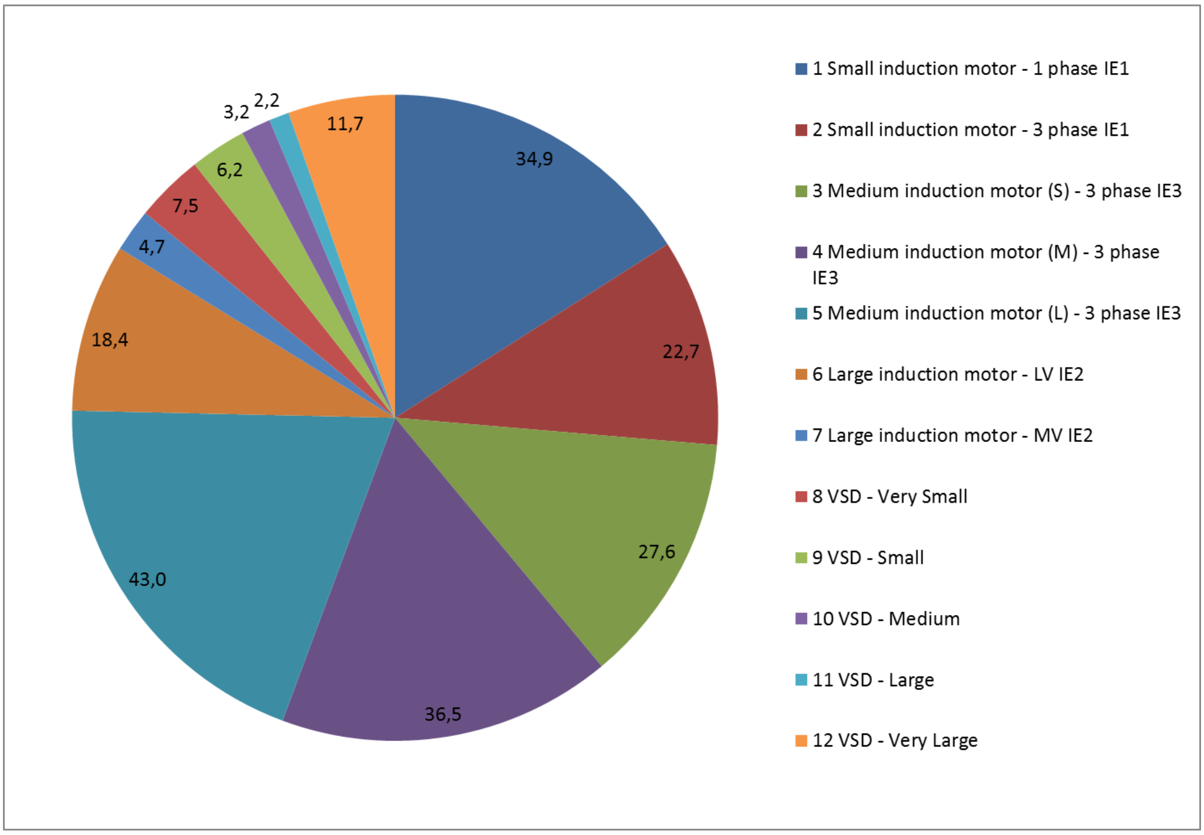

Figure 6. Breakdown of energy losses, by product.

Table 3. Energy Savings from the introduction of different improved technology options, relative to each BaseCase.

Ref	Description	Size (kW)	BAT 1		BAT2		BAT3	
			Efficiency Level	Energy Savings (TWhPa)	Efficiency Level	Energy Savings (TWhPa)	Efficiency Level	Energy Savings (TWhPa)
1	Small induction motor 1 phase IE1	0,37	IE2	4.6				
2	Small induction motor 3 phase IE1	0,37	IE2	9.9	IE3	12.15	IE4	14.59
3	Medium induction motor (S) 3 phase IE2	1,1	IE3	0.87	IE4	4.73	IE5	6.80
4	Medium induction motor (M) 3 phase IE2	11	IE3	0.93	IE4	6.84	IE5	10.14
5	Medium induction motor (L) 3 phase IE2	110	IE3	1.07	IE4	6.96		
6	Large induction motor – LV IE2	550	IE3	3.12	IE4	4.19		
7	Large induction motor – MV IE2	550	IE3	1.14	IE4	1.53		
8	VSD – Very Small	0.37	IE2 VSD	0.75				
9	VSD – Small	1.1	IE2 VSD	0.62				
10	VSD – Medium	11	IE2 VSD	0.32				
11	VSD – Large	110	IE2 VSD	0.22				
12	VSD – Very Large	550	IE2 VSD	1.17				

Table 4. Projected energy savings by Policy Option.

Policy Options	Energy Saving [TWhpa]		Proposed date of coming into force
	2030	Total	
PO1a. Small single phase motors (120 W–750 W) – IE2	4.6		01/01/2018
PO1b. Small three phase motors (120 W–750 W) – IE2	9.9		01/01/2018
PO1c. Large LV and MV motors (375 kW–1,000kW) – IE3	2.9	4.2	01/01/2018
PO2. Removal of option to use an IE2 motor where a VSD is used	2.7		01/01/2020 Subject to review
PO3. Explosion proof and brake motors in the scope of the Regulation	0.9	0.95	01/01/2018
PO4a. Medium motors (750 W–375 kW) – IE4	5.6	7.9	
PO4b. Large motors (375 kW–1,000 kW) – IE4		1.4	To be re-evaluated in the future
PO5. VSD MEPS at IE1			01/01/2018
PO6. Mandatory information requirements	Not Applicable		01/01/2018

- The energy savings presented in the table represent the potential gain of replacing the BaseCase technology with the BAT. The Basecase modelling underlying strategy is similar to that carried out for the environmental impact analysis.

Policy Options

Based on the estimated potential savings a number of policy options are suggested in order to achieve the desired reduction of the environmental impacts of electric motors. These options and respective projected savings are summarised in Table 4.

Conclusions

Several of the proposed Policy Options are in line with current international practice:

- PO 1: Expansion of scope of existing regulation to include MEPS at IE3 for large three phase induction motors and at IE2 for small three-phase and single phase motors. Saving 28.8 TWhpa.
- PO 2: Removal of the current option to use an IE2 motor + VSD instead of an IE3 motor. Saving 2.4 TWhpa.
- PO 3: Removal of the exemption given to explosion proof and brake motors under Regulation 640/2009. Saving 0.26 TWhpa.

In addition, the analysis has identified two further additional options, which are pioneer at World level, that yield appreciable energy savings:

- PO 5: Set a MEPS at IE1 for VSDs so as to remove the poorest efficiency models from the market. Energy savings attributed to this measure are small (< 1 TWhPa). The use of MEPS at higher level (e.g. IE2) is being investigated, since a significant percentage of VSDs on the market already meet this performance level and the potential savings are much larger.
- PO 6: Raising of MEPS for medium and large motors (0.75 to 1,000 kW) to IE4. The savings potential of applying these Super Premium motors reaches 9.4 TWhpa.

Option PO4, regarding information requirements, has no directly attributable energy savings but is necessary to increase the scope of the information requirements to support the expanded scope of proposed motor regulation.

Global harmonization of motor and drive regulations is an advantage to both producers and users of motors, with the important USA and Chinese markets having regulations that can be considered equivalent to PO1a (small motors only), PO2 and PO3.

IE4 Super Premium motors are at an early stage of development, and currently most appropriate for applications with long running hours. However, the economics might change in the future, with price reduction through high volume production, and so it is suggested that PO6 is not adopted now but should be reconsidered at the time of first review.

The introduction of the proposed policy options would achieve environmental and economic improvements at EU level with potential cost-effective savings of up to **31.2 TWh/year** of which **26 TWh/year** is achievable by 2030.

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