Policy Guidelines for Motor Driven Units

Part 2: Recommendations for aligning standards and regulations for pumps, fans and compressors

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Electric Motor Systems
EMSA

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This report was commissioned by the 4E Executive Committee.

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4E Electric Motor Systems Annex (EMSA)

Electric motor systems in industrial plants, infrastructure applications and buildings that drive pumps, fans, compressors and other equipment, are responsible for 53% of the world's total electricity consumption. New and existing technologies offer the potential to reduce the energy demand of motor systems across the global economy by 20% to 30%. The know-how to realise energy savings exists but is not widely applied.

The 4E Electric Motor Systems Annex (EMSA) promotes the opportunities for energy efficiency in motor systems by disseminating best practice information worldwide. It supports the development of internationally aligned test standards and regulations to improve the energy performance of new and existing motor systems.

Between 2008 and 2017, EMSA has:

- Contributed to the development of internationally aligned, globally applicable technical standards for motor systems. EMSA participates in relevant International Electrotechnical Commission (IEC) standards committees and contributes independent research results.
- Established a global network of testing laboratories.
- Contributed to the SEAD Global Efficiency Medal Competition for Electric Motors.
- Helped to disseminate the messages of the IECEE (Worldwide System for Conformity Testing and Certification of Electrotechnical Equipment and Components) Global Motor Energy Efficiency Program.
- Expanded the Global Motor Systems Network 5500 contacts from 85 countries. Members include representatives of governmental bodies, international organisations, standards developers, researchers, motor systems efficiency experts, utilities, industrial end-users and manufacturers. Members receive the EMSA Newsletter in English, Chinese, Japanese, Spanish or German, with updates on national and regional policy initiatives and EMSA's activities.
- Developed the Motor Systems Tool for engineers. The Motor Systems Tool helps to optimise the energy efficiency of a complete motor system.

The following reports related to motor systems have been published:

- EMSA Motor MEPS Guide (2009)
- EMSA Motor Policy Guide – Part 1 (2011)
- EMSA Policy Guidelines for Electric Motor Systems – Part 2 (2014)
- 4E Energy efficiency roadmap for electric motors and motor systems (2015)
- 4E EMSA Policy Guidelines for Motor Driven Units – Part 1 (2016).

Further information on EMSA is available at: www.motorsystems.org

4E Electric Motor Systems EMSA

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Glossary

Advanced metric: A metric that is available and in use for regulatory purposes, one that covers the complete MDU, addresses differences in constant and variable loads and – if possible – leads to a technology neutral way of expression of efficiency. An advanced MEPS applies such a metric.

Alignment (or international alignment): Establishing globally applicable technical (IEC/ISO) standards covering product definitions, test procedures, metrics, efficiency classifications and information requirements for MDUs as a suitable basis to be referenced in national regulations for minimum energy performance standards.

Ecodesign: The European Ecodesign Directive provides a procedure for setting mandatory requirements and labels on relevant environmental characteristics, e.g. energy efficiency, of energy related products placed on the market in the European Union.

Efficiency: The efficiency of a motor (or a motor driven unit) is the ratio of mechanical output to electrical input. It represents the effectiveness with which the motor or MDU converts electrical power into mechanical power at the output end under specified operating conditions.

Energy performance: The characteristics of a product in respect to the energy or power it uses under certain conditions.

Extended Product Approach: In the EU, the term 'Extended Product' was introduced in 2012, during the revision of the European Ecodesign regulation for water pumps No 547/2012. As the Ecodesign framework regulation allows only MEPS for single products, Europump (the European association of pump manufacturers) proposed the term 'Extended Product' in order to recognise that pumps are composed of at least two components (e.g. motor and pump). The idea for this proposal is that this combination (motor and pump) can have one testing method and one efficiency requirement. In a more recent European CENELEC standard (EN 50598-2: 2013 and EN 50598-1: 2014), MDUs have subsequently been referred to as 'Extended Products' and an 'Extended Product Approach' was defined. The 'Extended Product Approach' integrates individual losses of different components to calculate the total loss of the system and thereby define the system efficiency.

Additional note: the European definition of the 'Extended Product' prioritises the driving (motor) over the driven equipment (pump) and does not include the mechanical equipment. EMSA prefers the term 'Motor Driven Unit'.

Frame: Motor mounting and shaft dimensions as standardised by IEC or NEMA, which facilitates comparability and interchangeability.

IE-code: Efficiency classification for motors based on IEC 60034-30-1, 2014, e.g. IE1, IE2, IE3, IE4 (operating on fixed speed) and IEC 60034-30-2, 2016 (operating on variable speed).

International standard: A globally recognised technical standard developed by IEC/ISO. International standards are typically developed through a multi-annual consensus finding process by the members of relevant international IEC/ISO technical committees and their working groups, largely made up of industry representatives (i.e. manufacturers of the product concerned).

Isentropic Efficiency: The ratio of the required isentropic power to package input power. The isentropic efficiency makes it possible to easily identify the losses of the compressor when compared to an ideal isentropic process. The higher the efficiency, the fewer losses occur. The isentropic efficiency is unaffected by differences in outlet pressure levels, and cannot be misunderstood as no conversion of units (from imperial to SI, etc.) is required.

Load: The power required of a motor to drive the attached equipment. This is expressed as power (kW or horsepower) or torque (Newton meter, Nm) at a certain motor speed (rotations per minute, rpm).

Electric motor: A machine that converts electrical power into rotational mechanical power.

Minimum Energy Performance Standard: Minimum Energy Performance Standard means a mandatory minimum efficiency requirement for a product or system within one country as stipulated in the relevant national regulation. Several tiers (minimum efficiency levels) can be defined for introducing an increased stringency over time.

Motor Driven Unit: A Motor Driven Unit converts electric power into mechanical power to provide the motion of a machine or the flow of material (gas/fluid/solid) and consists of the following individual components: variable frequency drive (if available), electric motor, mechanical equipment (gear, belt, clutch, brake if necessary) and a driven application (pump, fan, compressor, transport or other).

Motor system: The motor system has a wide system border than the Motor Driven Unit and includes several elements between the front end (e.g. electric supply grid, mains, transformers, power factor controls, uninterruptable power supply) and the use end (e.g. ducts, pipes, throttles, heat exchanger) with its specific process operating conditions.

Power: The rate of doing work per time. It is the amount of energy used per unit of time. In the SI system, the unit of power is the joule per second (J/s), known as watt (W).

Regulation: Regulation is a legal measure for requirements of performance and/or declaration for products in a single or a group of countries.

Synchronous rotating speed: The rotating speed defined by the grid frequency and the number of poles in a synchronous electric motor.

Technical standard: An established norm or requirement for technical products or systems. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices e.g. for definition, testing, efficiency determination and/or classification for electric motors and MDUs.
Test: A laboratory procedure to determine one or more performance characteristics of a given product or system, according to a specified methodology and procedure.
Transmission: Transmission is the transfer and/or adjustment of speed and torque at constant power with a gear or belt, etc.
Variable frequency drive (VFD): Electronic controller to adjust the line frequency (50 or 60 Hz) to the required rotational speed of the motor for the necessary load of the driven application. Also called variable speed drive (VSD) or frequency converter.

Acronyms

4E	IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
BEP	Best Efficiency Point
CAGI	Compressed Air and Gas Institute
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CPS	Current Policy Scenario
DOE	US Department of Energy
EEMODS	Energy Efficiency in Motor Driven Systems
EMSA	Electric Motor Systems Annex
EU	European Union
EPA	Extended Product Approach
FEI	Fan Electrical Index
FEP	Fan Electrical Power
FMEG	Fan Motor Efficiency Grade
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
MDU	Motor Driven Unit
MEPS	Minimum Energy Performance Standard(s)
NEMA	National Electrical Manufacturers Association
NGO	Non-governmental organisation
NPS	New Policy Scenario
OEM	Original Equipment Manufacturer
PEI	Pump Efficiency Index
TBT	Technical barriers to trade
USA	United States of America
VFD	Variable Frequency Drive
WEO	World Energy Outlook
WTO	World Trade Organization

Executive summary

This Policy Guideline proposes policy options for the international alignment of technical standards and minimum energy performance standards (MEPS) for pump, fan and compressor Motor Driven Units (MDUs). The results are presented in two parts. Part 1, published in October 2016, describes existing standards and regulations for these products. This report, Part 2, provides recommendations for advancing standards and regulations and their international alignment.

Motor Driven Units, energy demand and markets

A Motor Driven Unit converts electric power into mechanical power to provide the motion of a machine or the flow of material (gas/fluid/solid) and consists of the following individual components: variable frequency drive, electric motor, transmission (e.g. gear, belt, clutch, brake) and the driven application (e.g. pump, fan, compressor, transport) as shown in Figure 1.
All motor systems consume annually about 10 700 TWh and are responsible for 53% of the global electric energy consumption. This corresponds approximately to the combined electricity consumption of China, the European Union (28 countries) and the USA. About 70% of this is used by pumps, fans and compressors, which are the focus of this study [1].
The IEA's 'World Energy Outlook 2016' (WEO) predicts that the electricity consumption of motor systems will have more than doubled by 2040. Implementing coordinated national policies for efficient motor systems with Minimum Energy Performance Standards (MEPS) could deliver estimated savings in the range of 1 400 TWh/a to 3 100 TWh/a by 2040. This report focuses on the three major economic regions China, the European Union and the USA, as these regions represent around 58% of the total 10 700 TWh/a (2015) global electricity consumption of motor systems [4].
According to recent market analysis by IHS Markit, the global MDU market amounted to a total of USD 97.6 billion in 2015 and these three regions represent about two-thirds of the world market of pumps, fans and compressors, equal to USD 66 billion [8].

Benefits

The benefits of setting MEPS for MDUs and better aligned standards and MEPS for MDUs are threefold:

1. Reaping larger energy savings

Larger energy savings stem from:

- Moving from regulating components (i.e. driven application) to regulating systems (MDUs),
- A wider coverage of the number of products under the scope of the regulations,
- Stimulating the use of the most efficient MDU for specific applications,
- Introducing stepwise more stringent requirements through setting ambitious goals (efficiency class and minimum efficiency for all components), taking into account national market conditions.

Two examples from the EU illustrate the order of magnitude of the savings that can be reached. In the case of fans, by extending the scope of regulated products and increasing the stringency of MEPS levels, 70% to 100% more savings (14-24 TWh/a) can be reached. In the case of pumps, at least 11 times higher savings (3.6-39 TWh/a) can be obtained by moving from MEPS covering individual components to cover the entire MDU, differentiating between constant and variable load and extending the prod-

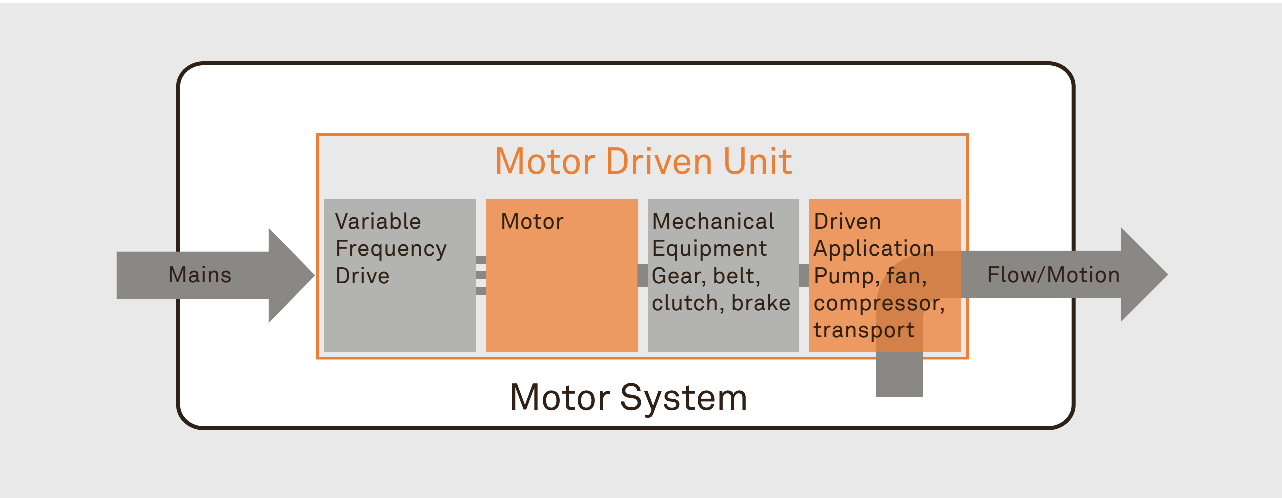


Figure 1: Motor Driven Unit. The orange boxes indicate the components that are always part of a Motor Driven Unit, the grey boxes show additional MDU components.

uct coverage. These data demonstrate the possible additional energy savings due to aligning or/and upgrading the MEPS based on international standards.

2. Lower costs

Better-aligned standards and MEPS for MDUs globally mean less cost for all stakeholders, including manufacturers, end-users, regulators and market surveillance authorities. Manufacturers can profit from avoiding multiple product performance testing to meet various different national certification requirements, which lowers transaction costs. This in turn reduces product costs for the benefit of end-users. Policy makers face lower administrative and transaction costs through a more straightforward regulatory process. New countries can introduce MEPS and more effective compliance programmes at lower cost. Market surveillance authorities profit from multinational collaboration: mutually accepting and exchanging check test results, reducing the burden on individual countries.

3. Faster market transformation

Referencing robust international IEC/ISO standards as a basis for regulations leads to a shorter time before highly efficient MDUs are available in multiple markets. The development, implementation and enforcement of MEPS can be easier and faster as a few key manufacturers cover a significant part of the global market. Compliance and verification is enhanced through manufacturers moving from producing components to integrated products. MEPS are adopted earlier at lower cost in more countries and higher compliance levels are reached faster through:

- Increased market transparency,
- International product performance benchmarking and technology tracking,
- Encouragement for manufacturers to invest into research,
- Development and marketing of more efficient products,
- Increased understanding of requirements by global suppliers,
- Higher competitiveness of markets,
- Lower global barriers to trade [23] [24].

Status of MEPS

MEPS for all three MDUs, pumps, fans, compressors, are in place, under revision and/or under development within these three regions. This brings opportunities for evolution towards a next generation of regulation, based on new and updated standards with clear definitions, metrics, efficiency classification and information requirements. Table 1 shows which region has the most advanced MEPS, i.e. MEPS with a metric covering the complete MDU, taking into account the efficiencies of MDU components.
Setting MEPS for MDUs requires consideration of product definition, the categories of products within scope, the method of determining the efficiency of the MDU (testing), the metric used for expressing efficiency, tier levels, and information and performance requirements. The 'alignment of tier level' for example proposes the tier level that supports the most advanced technology that is economically viable (in a given country). The 'alignment of metric' proposes the most advanced metric available and in use, i.e. one that covers the complete MDU, addresses differences in constant and variable loads and – if possible – leads to a technology neutral way of expression of efficiency.

Pump MDU characteristics per region (darker colour = more advanced MEPS)

MDU	Product type	China	EU	USA
Pump	Clean water	**Pump only**	**Pump only**	**MDU**
	MEPS status	In effect	In effect (under revision)	Published, in effect per 2020
Fan	Industrial fans	**Fan only**	**MDU**	**MDU**
	MEPS status	In effect	In effect (under revision)	Under development
Compressor	Standard air	**Compressor package**	**Compressor package**	**Compressor package**
	MEPS status	In effect	Under development	Pre-published

Notes: darker colour = more advanced MEPS with a metric at MDU level. The evaluation of the status of MEPS in the different regions is based on the regulations that are currently (2017) in effect. The regulation for compressors in the EU is in draft stage, whilst in the USA there are currently no regulations for fans and compressors, therefore not marked with colour in the table.

Table 1: Status of MEPS for MDU in China, EU and USA

Recommendations

The recommendations focus first on international standards and their development process, so that national regulations can be implemented and enforced more easily and quicker. Additional recommendations for policy makers are proposed to expedite the international alignment of standards and regulations.

Contributing to the development of international standards

The two key standards developing organizations in the field of MDUs, the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO), offer globally applicable international standards for MDUs which are strategically important for setting aligned national MEPS. Based on the 10 years of experience in the development of international standards for electric motors, Figure 2 shows the nine steps necessary to integrate the key elements for MDUs within the respective IEC/ISO standards. (The four most important recommendations are marked orange.)

General recommendations for policy makers

Policy makers should ensure that regulatory needs are accommodated in the international standards development process. The experience with electric motors has shown that for this it is essential to involve independent experts as national representatives in the relevant technical committees and working groups of IEC and ISO. This will also assist with the alignment of terminology and definitions between technical standards and regulations.
All general recommendations for policy makers are shown in Table 2 (next page).

1. **• Ensure that regulatory objectives are reflected in the standards development process.**
   • Involve more (industry-) independent members in the standards developing working groups.
   • Ensure adoption of international standards into regional and national standards as per IEC/ISO statutes.
2. • Align technical and regulatory terminology and definitions so that technical standards are a suitable basis for regulation in different regions.
3. • Establish specific criteria for information requirements concerning MDU efficiency and energy performance.
4. **• Define one preferred method for efficiency testing (MDU-level vs. component-level).**
   • Standardise load profile/operating points for efficiency determination.
5. **• Define a common metric for efficiency determination reflecting the general operating conditions of MDUs in use.**
6. **• Define an energy efficiency classification scheme for MDUs as basis for regulators to set MEPS.**
7. • Provide expanatory user guides alongside testing and classification standards.
8. • Define requirements for Alternative Efficiency Determination Methods (AEDM) for MDUs.
9. • Define certification procedures for MDUs applicable in all countries in the future.

Figure 2: Recommendations for the process and steps of MDUs to be included in IEC/ISO standards. The four most important recommendations are marked orange.

Detailed recommendations for each MDU

Pumps

- Define the 'complete MDU' for clean water pumps. China and EU can move towards applying this definition in their MEPS, like the US definition in their MEPS (In the Working Document for revision of the EU MEPS this newer definition is used as well).
- The scope should be wide, i.e. include clean water pumps and a selection of pumps for 'unclean' water e.g. wastewater, as well as circulators. The stipulated range for power, flow rate and pressure needs to be defined by impact analysis within regional markets. All three regions have opportunities for applying a broader scope to their MEPS. Circulators can be covered in MEPS like in the EU.
- Use the Pump Energy Efficiency Index (PEI or EEI) that includes the three main components. As in the USA, this metric can be used with differentiation for constant and variable load. China and EU could follow.
- When establishing MEPS for MDUs the specification of information requirements should be based on IEC/ISO standards when possible. The MEPS should avoid setting additional efficiency requirements on already regulated components of the MDU while maintaining any existing component requirements[1]. All regions can implement (China) or keep (EU and USA) this approach in their regulations.
- Use international testing standards as the basis to develop regional standards, without adding restrictions or deviations, and maintain alignment to the extent possible. Apply wire-to-water testing or the use of calibrated components. When default values for motors and VFDs are allowed to be used in the MDU efficiency calculation, use default values based on international standards.

1 When defining minimum efficiency requirements for a MDU e.g. a pump, the motor used in the pump MDU should be required to meet any existing MEPS for motors however, the pump MEPS should not put any additional requirements on the motor. This approach still provides manufacturers with the flexibility to either select motor improvements as a way to improve the wire-to-water efficiency of the pump, or to select a baseline motor (meeting the motor MEPS) and make improvements to the hydraulic efficiency of the pump, or a combination of the two.
This approach is applicable only for those MDUs whose components can be separated and tested individually. For integrated MDUs like circulators this is not the case.

General recommendations for policy makers (To be addressed at national level)		To be addressed at IEC/ISO level	Additional energy savings
Internation-al standards	Bring the policy perspective into the standards development process by involving more (industry-)independent members.	X	high
	Align terminology and definitions used in technical standards and in regulations.	X	low
Product definition	Include the main components of the MDU in the product definition, i.e. the motor, the driven application and if applicable a VFD and a transmission.		high
Scope	Include in the scope the most commonly used MDUs.		high
	Include other categories in the regulation as suited to regional markets.		medium
Test procedure	Ensure that the international test standards are adopted into local regulations without adding restrictions and/or deviations.		low
Metric	Use one common metric for the MDU efficiency that includes all components of the MDU and is suitable for a classification scheme.	X	high
Setting MEPS	Establish mandatory information requirements for manufacturers to declare the efficiency and performance parameters of the product/MDU.	X	medium
	Apply minimum requirements for the MDU when it is included in another product.		medium
	Establish MEPS tiers based on the international efficiency classification standard.	X	medium

Notes:
- Darker orange colour means higher importance: high, medium, low
Colour scheme: savings estimates based on identified benefits, see section 4.1
- All recommendations are to be addressed at national level. Recommendations to be addressed also on IEC/ISO level are marked with 'x'

Table 2: General recommendations for policy makers for further alignment of standards and regulations for pump, fan and compressor MDUs

Fans

- Include all MDU components into the product definition for standard fans. The EU has done so, China and USA can follow.
- The three regions all cover the most widely and commonly used fans, i.e. axial, centrifugal and mixed flow fans. The risk of diverging scopes between regions is present, but the different time paths for regulating markets give opportunities for alignment. Attention is needed to maintain alignment.
- Apply a metric that includes all three main components of the MDU. The EU metric does this and offers room for extra savings (by setting higher tier levels), but is still based on the current geometry-based categories (i.e. axial, etc.). A new metric, which applies a functional pressure/volume flow approach, has been developed for use in US regulation (regulation under development). China can follow EU and USA in choosing and applying a more advanced metric.
- The adoption of international testing standards into regional standards, without adding restrictions or deviations, needs constant attention. Apply wire-to-air testing or the use of calibrated components. Further alignment is needed with the definitions in ISO and regional standards.
- When establishing MEPS avoid setting additional efficiency requirements on already regulated components of the MDU while maintaining any existing component requirements[1]. USA and China can implement and EU keeps this approach in their regulations.

Compressors

- Include in the scope the most widely and commonly used groups of air compressors, i.e. standard air compressors, further defined by the subgroups rotary and reciprocating standard air compressors. EU (draft regulation) can follow China and USA (regulation is in pre-publication stage) in establishing MEPS. Differences in the scope exist, e.g. the USA excludes piston compressors as well as oil free compressors whereas these are included in China.
- Adopt the isentropic efficiency metric for air compressor regulations to enable the comparison of performance by different products and technologies. China and EU can follow the USA[2] model where this metric is considered in the MEPS (pre-publication).
- The international test standard (ISO 1217:2009) for positive displacement compressors (which covers rotary and piston standard air compressors, oil-injected/oil-lubricated) is commonly used as basis for regional standards in China, EU and USA. Further attention can be given to including concepts like 'cycle energy requirement' (assessing transient energy losses) on 'standard air' compressor packages and measuring heat recovery performance.
- Establish mandatory information requirements to declare performance parameters based on common reference conditions.

1 When defining minimum efficiency requirements for a MDU e.g. a pump, the motor used in the pump MDU should be required to meet any existing MEPS for motors however, the pump MEPS should not put any additional requirements on the motor. This approach still provides manufacturers with the flexibility to either select motor improvements as a way to improve the wire-to-water efficiency of the pump, or to select a baseline motor (meeting the motor MEPS) and make improvements to the hydraulic efficiency of the pump, or a combination of the two.
This approach is applicable only for those MDUs whose components can be separated and tested individually. For integrated MDUs like circulators this is not the case.

2 The US final test standard is published, whereas the MEPS is a 'pre-publication' final rule stage.

1 Introduction

1.1 Background

This Policy Guideline for Motor Driven Units (MDUs) was commissioned by the Executive Committee of the International Energy Agency Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E) in 2015. The study was led by a working group of the Electric Motor Systems Annex (EMSA). This report presents the results of Part 2 'Recommendations for aligning standards and regulations for pumps, fans, compressors' with a focus on China, the European Union and the USA.

The results of this research are published in two parts:

1. Part 1: 'Analysis of existing standards and regulations for pumps, fans and compressors' (published in October 2016). Status of standards and regulations for MDUs in major global economies. Analysis of the countries covered regarding the scope, testing, metrics and methodology of Minimum Energy Performance Standards (MEPS) (available for download at www.motorsystems.org).
2. Part 2: 'Recommendations for aligning standards and regulations for pumps, fans and compressors' (this report), in particular aspects concerning product definition, scope of regulation, testing, metric used and setting mandatory requirements.

1.2 Overview of the report

Chapter 1 introduces the background, goal, scope and covered regions of this report. Chapter 2 describes the methodology of the research. Chapter 3 gives an overview of the global market of MDUs. Chapter 4 describes the benefits of alignment. Chapter 5 shows the relevant international IEC/ISO standards for MDUs. Chapter 6 presents recommendations for international standards developers and detailed recommendations for pumps, fans and compressors for policy makers.

1.3 Goal

This report on Policy Guidelines for Motor Driven Units is intended to provide guidance for policy makers involved in setting MEPS for MDUs with the ultimate goal of saving more energy, reducing cost for policy makers and market surveillance authorities, manufacturers and end users, and shortening the time to market for efficient MDUs. Furthermore, it aims to encourage countries with no MDUs regulations yet to establish these. Some recommendations are directed to international standards developers.

1.4 Scope

The motor system (see Figure 3) has a wide system border and includes several elements between the front end (e.g. electric supply grid, mains, transformers, power factor controls, uninterruptable power supply) and the use end (e.g. ducts, pipes, throttles, heat exchanger).

A Motor Driven Unit is the inner part of the motor system. A Motor Driven Unit converts electric power into mechanical power to provide the motion of a machine or the flow of material (gas/fluid/solid) and consists of the following individual components:

1. Variable frequency drive, if available
2. Electric motor
3. Mechanical components (e.g. gears, belts, clutches, brakes), if necessary
4. Driven application (pump, fan, compressor, transport, or other).

This research focuses on the Motor Driven Unit, in particular on pumps, fans and compressors.

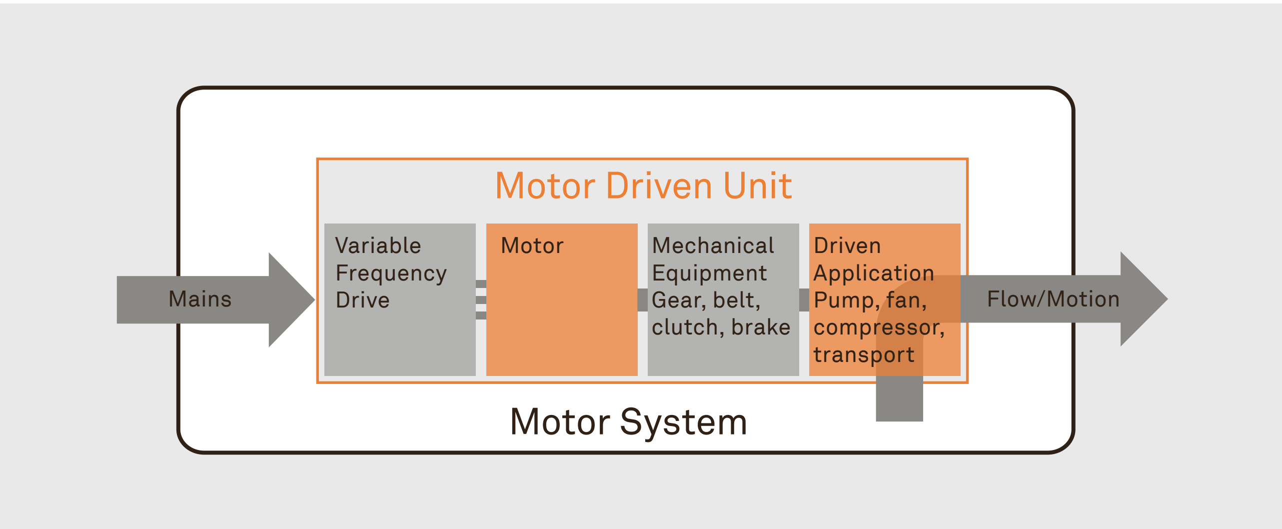


Figure 3: Motor Driven Unit. The orange boxes indicate the components that are always part of a Motor Driven Unit, the grey boxes show additional MDU components.

While the variable frequency drive is one component of the Motor Driven Unit, this research does not specifically address the technical and economic benefits of VFDs, as they are already covered in the 4E 'Energy Efficiency Roadmap for Electric Motors and Motor Systems' [3].

The main reasons for focusing on the Motor Driven Unit are as follows:

- The major driven applications used in motor systems are pumps, fans and compressors, responsible for 70% of the electricity demand by motor systems.
- The highest electricity savings potentials are in the entire motor system. On average 20% to 30% of energy can be saved through an optimised motor system [1][6].
- Electric motors have been on the policy agenda and in standards development for many years. From a regulatory point of view, the shift of attention from the individual component(s) to the MDU is a logical and also necessary step. While regulating MDUs is much more complex and challenging, it brings considerable additional energy savings which without regulation would remain unharvested.

A more detailed explanation is included in Part 1 of this research.

1.5 Covered regions

This report covers the three major economic regions of China, European Union and USA. These three regions cover 65% of the global GDP and 61% of the global electricity use.

Reasons for focusing on these three regions are:

1. They represent 58% of the total global electricity consumption of Motor Driven Units of 10 700 TWh per year (2015).
2. MEPS for all three MDUs under study (pumps, fans, compressors) are in place, under revision or under development in these three regions.
3. These three regions represent two-thirds of the world market of pumps, fans and compressors (66 billion USD; more details in section 3.2) [8].

2 Methodology

Part 1 showed the results of the survey of the state of standards and regulations concerning pumps, fans and compressors. Following the research in Part 1, experts for pumps, fans and compressors from the three regions China, EU and USA were selected and invited to participate in an intensive exchange, with the goal of identifying topics and procedures to align international standards and MEPS. The experts were carefully chosen for their knowledge of national policy, the MDU industry and their ability to develop the conceptual framework for further developments for MDU.

Three workshops with the participation of 8 experts (4 from Europe, 3 from China, 1 from the USA) were organised by EMSA, one each for pumps, fans and compressors. During these workshops, the issues of product definition, scope, testing, efficiency metrics and opportunities for global alignment of standards and regulations were discussed. The experts were contacted individually to follow up on specific questions after the workshop.

The exchange with these experts, including the results of these workshops, formed the basic material used to identify and formulate the recommendations in this report, for which the responsibility lies solely with the authors of the report.

3 The global market of MDUs

Before addressing the best policy options for transforming the market to more efficient MDUs, it is important to understand the main characteristics and trends of this market. This chapter gives an overview of the global market of electric motors and MDUs, based on data from IHS Markit [7].

3.1 Implications of different grid frequency for motors and MDUs

The different markets for electro-technical products in the three regions lead to technological differences in motors and MDUs. The difference in the grid frequencies in the EU and China compared to the USA lead to a partially differentiated motor market, and a totally differentiated driven application and MDU market in these regions. In the USA, Canada, Mexico, Brazil and South Korea, in a number of Latin American countries and in some Japanese regions, a grid frequency of 60 Hz is used. 50 Hz is commonly used in Europe, China and most of Africa and Asia. In total, an estimated 68.4%[3] of electricity for MDU is used in grids with 50 Hz (see Figure 4).

The efficiency of the motor and the driven application is affected by the frequency of the power supply grid.

Any electric motor can be operated on 50 Hz or 60 Hz, but generally motors are optimised for the grid frequency and relevant voltage in their region. The motors operated on 60 Hz have a 20% higher rotating speed and a slightly better efficiency than on 50 Hz[4]. (For example a 4 pole motor in Europe operates at a synchronous speed of 1500 rpm and in the USA at 1800 rpm.) This is the reason for different efficiency values for 50 Hz and 60 Hz motors in IEC 60034-30-1 (IE-code).

Being operated on 50 Hz or 60 Hz requires small (design) adjustments for motors, and significant adjustments for the driven application. Driven applications (e. g. pumps, fans) are designed to achieve their best efficiency point for 50 Hz or 60 Hz grid. The different 50/60 Hz grid frequencies lead to different duty points in pumps, fans and compressors. Also, the higher rotating speed can cause a higher mechanical stress, which negatively influences bearings and maintenance cycles of MDUs. This means that for the 50 Hz and 60 Hz markets the components for each MDU differ, e.g. in motor size, the impeller shape and/or the fan housing. Manufacturers need to adjust their product design and product ranges to these specific market conditions. The different grid frequencies could be seen as a large Technical Barrier to Trade in WTO[5] terms (see also section 5.3), which would need a very long time horizon to be aligned.

Using the International System of Units (SI units) has been an important alignment of standards which leads to more transparency in international trade and lowers trade barriers. Today, the USA is the only Western nation not having adopted the International System of Units. In addition, India uses mostly and Canada partly SI units. The current mix of units led to the USA measuring electric motor power in horsepower (HP) in standards and regulations, while the rest of the world uses kilowatt (kW). Many other units for describing MDU performance like temperature, pressure, dimension, etc. are also affected by the different use of units and results in confusion, extra conversions and costs in global trade. The potential alignment of these units will also need a very long time horizon.

3 Share of 50 Hz electricity use by MDU: estimate by EMSA based on IEA country Statistics 2014 and [1]

4 Ranging from appr. 4.0% for small motors up to 0.3% for large motors at 60 Hz.

5 The World Trade Organization defines Technical Barriers to Trade (TBT) and the rules to overcome them.

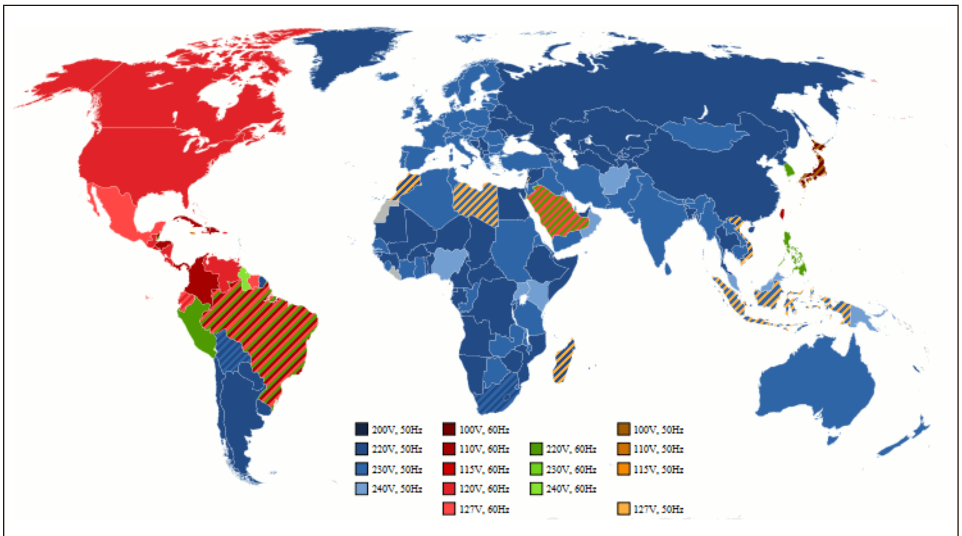


Figure 4: Global map of grid frequency and voltage. (Source http://phillihp.com)

3.2 The world market of MDUs

The global MDU market amounts to a total annual sales volume of 97.6 billion USD (2015), see Figure 5 and Table 3. The three regions Europe (29%), China (23%) and USA (14%) cover 66% of the sales volume (in USD) of the global MDU market (Figure 5 and Table 4).
The market for pumps, fans and compressors accounts for almost 80% of the sales volume (in USD) of the global MDU market, much higher than for motors and VFDs. Pumps hold, with 33%, the largest share of the global MDU market (see Figure 6).

3.3 Few large manufacturers

The global market of MDUs is dominated by a small number of large players. In most regions, only a limited number of global manufacturers of motors, VFDs and MDUs have operated successfully for many years.
The five largest producers cover between 27% and 53% of the global MDU market (see Table 5). In Europe the top five cover 33% to 70% of the market; in the USA between 43% and 69%.

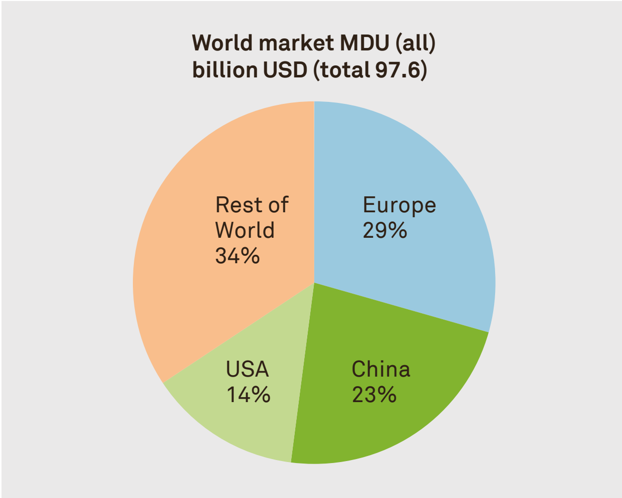


Figure 5: Market share by region in 2015 for motors, VFDs, pumps, fans and compressors (Source: IHS Markit 2017)

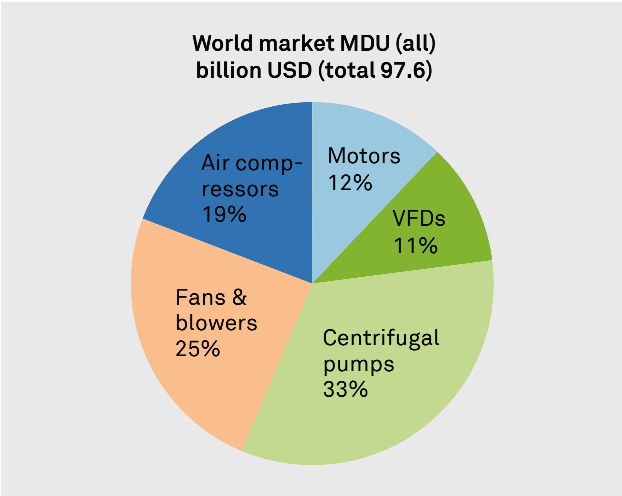


Figure 6: Global market share in 2015 by product: VFDs, pumps, fans and compressors (Source: IHS Markit 2017)

Market share by product	World (billion USD)	
Motors	11.8	12%
VFDs	10.6	11%
Centrifugal pumps	32.6	33%
Fans & blowers	23.9	24%
Air & gas compressors	18.7	19%
Total revenue (billion USD)	97.6	100%

Table 3: Global market share in 2015 by product (Source: IHS Markit 2017)

Market share by region	EU	China	USA	ROW	
Motors	27%	24%	17%	32%	100%
VFDs	31%	25%	19%	25%	100%
Centrifugal pumps	33%	14%	13%	40%	100%
Fans & blowers	24%	33%	8%	34%	100%
Air & gas compressors	30%	22%	17%	32%	100%
Total revenue (billion USD)	28,7	22,1	13,3	33,5	
	29%	23%	14%	34%	

Table 4: Market share in 2015 by region for motors, VFDs, pumps, fans and compressors (Source: IHS Markit 2017)

Market share Top 5	World	EU	China	USA
Motors	37%	45%	30%	69%
VFDs	53%	70%	30%	69%
Centrifugal pumps	37%	33%	49%	50%
Fans & blowers	28%	34%	23%	43%
Air & gas compressors	27%	45%	38%	56%

Table 5: Market share in 2015 of the top five manufacturers (Source: IHS Markit 2017)

3.4 Manufacturers moving from components to systems

The manufacturing industry for MDUs and their components is divided into 'component specialists' and 'system integrators'. Since research and development and purchasing decisions differ significantly by the type of manufacturer, this is relevant to the alignment of MDU standards and MEPS.

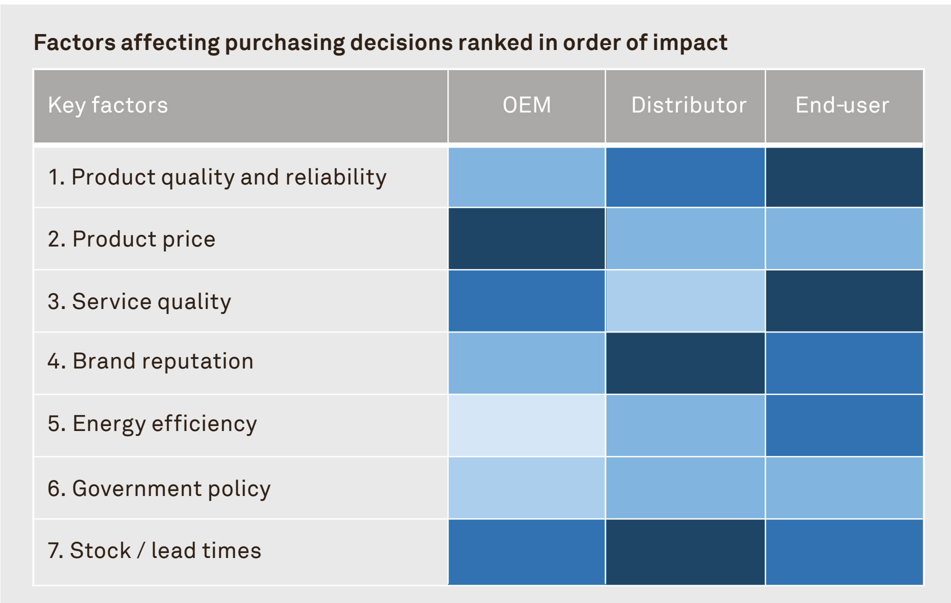
Some large global electric motor manufacturers (Siemens, WEG, ABB, others) have for some time manufactured both electro-mechanical products (electric motors and generators) as well as electronic products (controllers like variable frequency drives, starters, etc.). For these large manufacturers, it has become standard practice to sell well-matched motors plus VFDs (properly sized, adapted to production needs, efficient and well-coordinated components). While there are different approaches taken by different manufacturers, many larger manufacturers are moving from producing components only to producing more integrated products and systems.

Some global manufacturers produce all the three relevant components of a MDU in house. For example, ebm-papst produces fans, motors and VFDs; Grundfos produces pumps, motors and VFDs in-house. This full integration of the production of a MDU has the advantage of matching well-designed components already within the product manufacturers' facilities. This full integration is standard practice for small circulators, and can be done also for fans, compressors, etc. in larger assemblies. The goal of this integrated manufacturing of MDUs is to achieve lower product volume and weight, higher performance and lower production cost and sales price.

Some other specialists with global reach (e.g. SEW-Eurodrive) have a large market share for gear motors (motor, VFD and gear) which are widely used in transport machinery (conveyors, etc.). Other machine builders assemble several special components in-house for their own products like elevators, escalators, etc. (e.g. Schindler).

Many other manufacturers tend to be motor manufacturers only, buying large quantities of VFDs and driven components from other manufacturers and marketing them as matched systems. Large pump, fan or compressor manufacturers include a specified small number of motors from preferred manufacturers into their assembly. Many compressor manufacturers (Atlas-Copco, Kaeser, etc.) belong to this group. They of course also have an incentive to buy big quantities of well matching components. However, as assemblers, they lose the advantage of full integration and smaller volume and lower weight.

The remaining largest part of the global market only make one component, e.g. a pump, a gear, a compressor, a fan, a motor, or a VFD. They sell these components to Original Equipment Manufacturers (OEMs) who assemble them into larger units, or to national or international distributors who then sell them to end-users. One significant challenge is that a key factor of OEMs' purchasing decisions is a low product purchase price where efficiency is not addressed. Another challenge is that matching of individual components is in this case much more complicated. It can be assumed that the match is less perfect when components are manufactured by different producers and assembled at the end-user's factory for the first time.



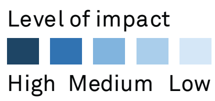


Figure 7: Factors influencing electric motor purchasing decisions ranked in order of impact (Source: IHS Markit 2014)

4 Benefits

Setting MEPS for MDUs requires consideration of aspects as:

- How the product is defined,
- Which categories of products are within the scope of MEPS,
- How the efficiency of the MDU is determined (testing),
- What metric is used for expressing the efficiency,
- What to consider when setting MEPS: information and performance requirements, tier levels (level of minimum requirement), referencing international technical standards, etc.

The 'alignment of tier level' for example proposes the tier level that supports the most advanced technology that is economically viable (in a given country).
The 'alignment of metric' proposes the most advanced metric available and in use, i. e. one that covers the complete MDU, addresses differences in constant and variable loads and – if possible – leads to a technology neutral way of expression of efficiency.
The benefits of setting MEPS for MDUs and better aligned standards and MEPS for MDU are threefold: reaping larger energy savings, lower costs and faster market transformation.

4.1 Reaping larger energy savings

The larger energy savings are predominantly due to:

- Moving from regulating components (i.e. driven application) to regulating systems (MDUs),
- A wider coverage of the number of products under the scope of the regulations,
- Stimulating the use of the most efficient MDU for specific applications,
- Introducing stepwise more stringent requirements through setting ambitious goals (efficiency class and minimum efficiency for all components), taking into account national market conditions.

While most of the savings above are directly associated with establishing MEPS for MDUs, consideration should be given to the recommendations in chapter 6 when doing so. This can set an example, making it easier for new countries to adopt regulations which will increase global savings.

4.1.1 Savings from individual measures

Capturing the greater savings available in the MDU as a whole requires a shift in attention from requirements for single components to regulating MDUs.
Two examples from the EU below illustrate the order of magnitude of the savings that can be reached:

1. In the case of fans 70% to 100% more savings: from 14 TWh/a to 24–29 TWh/a. This can be realised by extending the scope of covered product categories and increasing the stringency of MEPS levels, see Table 6.

In the EU a fan review study by VHK [10] reveals extra savings of 70% to 100% by increasing the levels of the minimum fan efficiency (N grades), further detailing and combining some categories[6] and adding an extra fan category (jet fans). The underlying metric is still on the 'fan only' level. The example of pumps below indicates significant saving opportunities for complete MDUs.

2. In the case of pumps, at least 11 times higher savings: from 3.6 TWh/a to 39–55 TWh/a. This can be reached by establishing MEPS for complete MDUs (instead of component level), differentiating between constant and variable load, extending the product coverage and increasing the stringency of MEPS levels.

In regulation EU 547/2012 clean water pumps are regulated on product-level i.e. the pump only, with identified savings of 3.6 TWh/a, as shown in Table 7. The current regulation covers 69% of the energy use by water pumps in the EU (see Appendix 8.1 Table 18 for a detailed overview).
Applying a broader product definition for the pump, i.e. including a broader power range and other pump types like waste water pumps and swimming pool pumps, increases the savings by 45% to 5.2 TWh/a. The biggest step forward, though, is to enlarge the product definition to include the MDU which brings potential savings through MEPS of 39 to 55 TWh/a, meaning an increase by at least a factor of 11.

4.1.2 Savings on a global scale

Electric motor systems consumed 10 700 TWh worldwide in the year 2015 [5]. This corresponds approximately to the combined electricity consumption of China, USA and EU (28 countries).
Based on the 2016 IEA publication 'World Energy Outlook' [5] a well-coordinated and robust set of global and regional data is available for energy savings of MDUs[7]. The estimate of future energy demand until 2040 is based on three scenarios (see detailed description in Appendix 8.2):

- Current Policy Scenario (CPS): business as usual and continuation of current policies (that are already in place by 2016), see Figure 13
- New Policy Scenario (NPS): strong national new policies enforced (based on the Paris Agreement)
- 450 scenario (450): a globally coordinated effort with

6 a) Allow a separate category for radial and centrifugal forward curved fans below 5 kW. Beyond 5 kW the same minimum efficiency requirements apply as for centrifugal backward curved fans. b) Combine centrifugal backward curved fans with and without housing into one category. It was recommended not to include a new category of 'box- and rooftop fans' or a split of the 'axial fans' above and below 300 Pa.
7 The referenced IEA data refer to energy use by electric motor systems and by definition to the MDU and all system components involved.

the target of having a 50% chance of limiting the global warming to a 2 °C temperature rise by 2100 (which is assumed to allow for a maximum concentration of 450 ppm of CO_2 equivalents in the atmosphere).

The electricity savings for MDU and their components under the CPS and the NPS scenarios between 2015 and 2040 are shown in Figure 8 and Table 8. The amount of the total global electricity savings climbs to 1 090 TWh/a in 2040 for the three regions Europe, China and USA. China delivers 82% of the electricity savings (898 TWh/a). It also shows that electricity demand from transportation, due to the growing share of electric cars, increases by 203 TWh/a in 2040[8].

The electricity savings for MDU and their components under the CPS and the 450 scenario between 2015 and 2040 climbs to 3 037 TWh/a in 2040 for the three regions Europe, China and USA. The substitution effect (switch from fuel to electricity use) by transportation grows even more rapidly, and rises to 1 474 TWh/a for the three regions. The contribution of the different types of MDU is shown in Table 9: 69.5% of the electricity savings in 2014 come from pumps, fans and compressors.

The IEA WEO data [6] for motor driven systems only distinguishes their electricity demand by sector, region and year for the three scenarios. In order to disaggregate by the driven application, data from previous IEA research (Waide & Brunner 2011 [1]) was used for determining the relative share of pumps, fans, compressors and mechanical movement[9]; see Table 9 and Figure 8.

8 Note: Electric cars and electric heat pumps use electric motors. They substitute the use of fossil gasoline by switching to electricity.

9 Other equipment driven by electric motors, for example transportation systems, industrial process equipment, etc.

The savings identified in the IEA scenarios include the impact of worldwide Minimum Energy Performance Standards for motors and for pump, fan and compressor MDUs, as well as other system-wide savings. The scenarios follow a three-step allocation of cumulated savings by different policy measures, e.g. MEPS for electric motors first, followed by MEPS for MDUs and completed with system-wide measures such as pricing, energy management systems and audits, and other (sector) specific regulatory schemes.

4.2 Lower costs

Lower costs are expected for different stakeholders. Manufacturers can profit from better alignment by avoiding multiple product performance testing and having to meet various different national certification requirements, which leads to lower transaction and product cost for MDUs. While manufacturers can bring a product to the market at lower cost, end-users profit from lower prices and reduced operational cost (life cycle cost) due to higher efficiency. Overall, these elements enhance competitiveness in markets.

Today, most economies are required to undertake an impact assessment including cost-benefit analysis when establishing new or revising existing regulations, however the methodologies differ between economies, including between China, the EU[10] and the USA. An example of the testing cost for industry – where no MEPS for compressors are in place yet – the EU Compressor Review Study [10] states:

10 Note: for example in EU Impact assessments the following aspects are included: Energy saving; Greenhouse gas emission reduction; Customer economics and affordability; Business economics and competitiveness; Employment; Technology, functionality and innovation; Health, safety and other environmental aspects; Administrative burden; Impact on trade.

Fans		Electricity use	Savings	Estimated savings	
		2010	2020 (Current regulation)	Extra (Regulation review)	Total (Current + reviewed)
Fan category		TWh/a	TWh/a	TWh/a	TWh/a
Fans driven by electric motors (EU 327/2011)	(0.125 – 500 kW)	300	28		
same, without overlap with other regulation*)		n.a.	**14**		
Regulation review				**10 – 15**	**24 – 29**
Medium sized fans	(0.125 – 10 kW)			9.1	
Other large(r) fans	(10 – 500 kW)			5 – 6	

*) i.e. EU MEPS for electric motors, ventilation units, airconditioners

Table 6: Electricity use and estimated savings for EU fan Motor Driven Units per fan category and recommended extra fan categories (Source: VHK Fan Review 2015)

Pump types and regulation	Energy use		Savings at product level		Savings at MDU level	
					Minimum	Maximum
	TWh/a	%	TWh/a	%	TWh/a	TWh/a
Clean water pumps (547/2012)	**179**	69%	**3.6**	100%	**35.4**	**47.1**
Other pumps (not regulated)	**79**	31%	**1.6**	45%	**3.7**	**7.9**
Clean water	36		0.7		3.6	5.1
Other use	43		0.9		0.1	2.8
Total	**258**	100%	**5.2**	145%	**39.1**	**55.0**

Table 7: Electricity use and estimated savings for EU pump Motor Driven Units at product and MDU level (Source: VHK/Viegand Pump Review 2015)

- Testing: it is estimated that typically 10% of the machines in series production annually put on the EU market need to pass an audit test by the manufacturer for a systematic verification of compliance with Ecodesign measures. The average test cost is 1500 EUR per test.
- Considering the extra audit tests to be performed; a need for additional testing capacity equivalent to three to four test facilities may arise. For this an average of total 4 million EUR is estimated[11].
- Regarding the aspect of lower transaction and product cost, including cost for complying with regional information requirements, no data are available.

11 Applicable to low pressure and oil free compressor packages manufacturers.

Small local manufacturers and manufacturers who do not ship globally will not directly profit from avoiding multiple product performance testing. However, they will have to deal with the same cost for multiple product performance testing and extra R&D cost to adjust the product portfolio that accompany newly introduced efficiency requirements. An impact assessment should identify this issue and assess the companies' capacity to deal with this cost; normally a transition period prior to new regulation is allowed for the manufacturers to plan the company's transition.

As the global and regional MDU market is dominated by a few key players, policy makers profit from engaging with a small number of stakeholders in the regulatory consultation process which means lower transaction and administrative costs.

Motors Driven Units MDU IEA WEO 2016	Electricity TWh/a	2025	2040
		Savings in New Policies Scenario compared to Current Policies Scenario	
Total	USA	68	116
	EU28	9	76
	China	280	898
	Total 3	358	1 090
	Rest of world	106	313
	Total all	**464**	**1 404**

Motors Driven Units MDU IEA WEO 2016	Electricity TWh/a	2025	2040
		Savings in 450 scenario compared to Current Policies Scenario	
Total	USA	134	−231
	EU28	54	−87
	China	692	1 701
	Total 3	881	1 383
	Rest of world	577	1 654
	Total all	**1 458**	**3 037**

Table 8: Electricity savings for Motor Driven Units between the CPS and NPS scenarios for different regions; and between the CPS and 450 scenarios (Source: IEA WEO 2016)

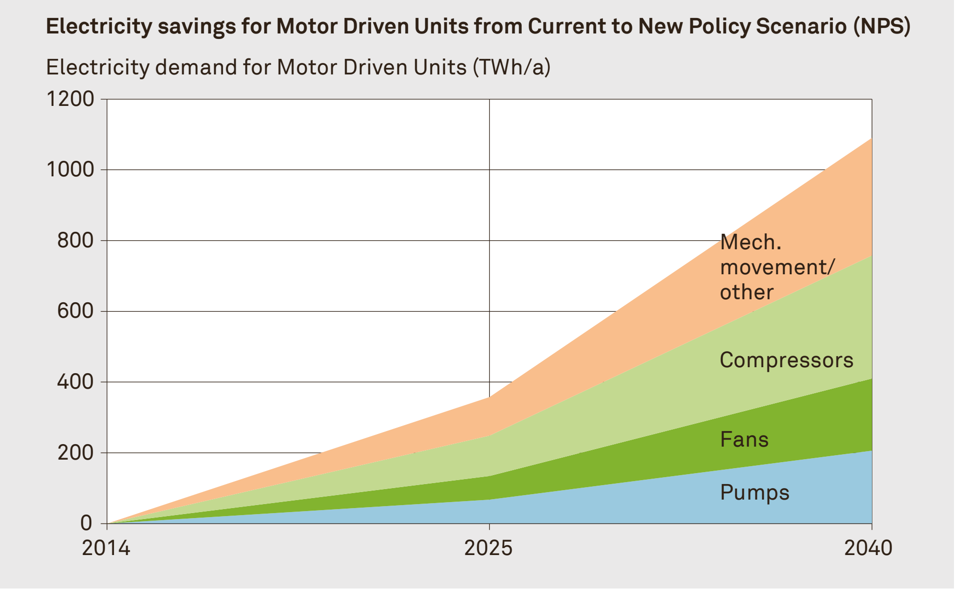


Figure 8: Global electric energy savings for Motor Driven Units with the NPS-scenario in contrast to the CPS-scenario (Source: IEA WEO 2016 and W & B, 2011)

Policy makers in countries which newly establish MEPS for MDUs can do so at lower cost relying on the experience of pioneer countries. They can profit from a set of aligned regulatory instruments, which facilitates the design, development and implementation of MEPS. In addition, market surveillance can be aided at lower cost through multinational collaboration, with the exchange of check test results and their mutual recognition between several countries. This leads to improved compliance and ultimately to fully realising the projected savings of the regulations.

4.3 Faster market transformation

- Manufacturers acting as 'role models' for local manufacturers and encouraging a subsequent introduction of MEPS in more countries,
- An earlier adoption of MEPS at lower cost in more countries,
- Higher regional and global market impact,
- Higher competitiveness of markets for highly efficient products from different regions,
- Lower global barriers to trade.

Several factors lead to a faster market transformation towards more efficient MDUs. In the case of electric motors, the development of efficiency standards on an international level and its referencing in national legislation have led to synergies and advantages in international standardisation and on the global market. Beyond electric motors, there has been a continuous effort to develop standards for new motor technologies as well as standard for MDU components such as VFDs.

4.3.1 Robust international standards accelerate increased market competitiveness

Robust international IEC/ISO standards for MDUs encourage an earlier adoption of MEPS with less time needed from standardisation to a global increase of the market share of new, more efficient products in multiple markets. While the adoption of international standards is not mandatory, developing technical standards for product information requirements, energy performance testing and efficiency classification on an international level has several benefits for national regulators [23] [24]:

- Reduced development cost and time. If governments actively participate and are directly involved in the development of international standards suitable for their purposes, they do not need to individually invest in developing such standards nationally. Instead, they can adopt or reference the international standard in national legislation.
- Governments can benefit from pooling international state-of-the-art knowledge by recognised experts in the field.
- During the standards development, governments can ensure that the international standard is truly globally applicable, i.e. taking into account regional issues (e.g. differences in climate, grid frequency, etc.).
- Mutually recognised test standards and testing results open the opportunity for exchanging check test results among multiple countries and regions.
- Uniform efficiency classes with clearly defined efficiency tier levels increase transparency of product performance. This makes international product performance comparison and benchmarking easier.
- Technology change and product performance improvements can be more easily tracked on regional and global level.
- This helps in the revision and updating of national legislation, both in terms of timeline and stringency of efficiency levels (depending on market developments).
- Clear performance targets enable manufacturers to plan and invest in product research, development and marketing and potentially benefit from economies of scale, in advance of more stringent targets becoming mandatory.
- The increased transparency of energy performance of MDUs facilitates the trade of highly efficient products from different regions and a higher degree of market competitiveness.
- The reduced number of performance requirements worldwide makes it easier for manufacturers selling products in different regions to understand and comply.

4.3.2 More effective MEPS with global manufacturers

As shown in chapter 3, since a few key manufacturers of MDU components and MDUs cover a significant part of the global and regional markets, the MEPS development, implementation and enforcement process is easier and faster. In addition, compliance and verification testing is

Motors Driven Units MDU IEA WEO 2016	Electricity TWh/a	2015	2025	2040
		Savings in New Policies Scenario compared to Current Policies Scenario		
Pumps	18.9%	0	68	206
Fans	18.7%	0	67	204
Compressors	31.9%	0	114	348
Mech. movement/other	30.5%	0	109	333
Total	**100.0%**	**0**	**358**	**1 090**

Table 9: Electricity savings for Motor Driven Units between the CPS and NPS scenarios for different MDUs (Source: IEA WEO 2016 [6] and Waide & Brunner 2011 [1])

greatly enhanced through manufacturers moving from producing components to integrated products. Benefits from a regulatory point of view include:

- Mandatory information requirements for MDUs advance the clear declaration of energy efficiency and performance characteristics resulting in higher market transparency.
- The number of stakeholders to be consulted during the development, implementation and enforcement of the regulation is relatively small and can be handled more easily.
- A significant part of the national and international market can be rapidly impacted by involving only a few market players. At the same time, regulators need to keep an eye on the position of small local manufacturers, where applicable, with regard to their capacity to bear the (first) cost for multiple product performance testing and extra cost for adjusting the product portfolio to the new requirements.
- Since most of the large market players operate globally, in many different countries, they learn to comply with the regulations in the countries which first introduce MEPS for MDUs, and can serve as 'role model' both for local manufacturers and for manufacturers in other countries.
- For any country introducing MEPS subsequently on the same basis, the process of regulation development and implementation can be faster, easier understood with potentially faster and higher compliance rates.
- The trend of manufacturers moving from producing components to producing integrated products and systems enables checking the energy efficiency of all components of the MDU as well as of the complete MDU at the point of manufacturing. Manufacturers of the driven application can check their equipment as a complete MDU by using compliant components or using default values for the missing components.

4.3.3 Reaching higher compliance levels faster, on a larger scale

Better international alignment of standards and regulations leads to more rapid market transformations and increased levels of compliant products on the market. Countries are more likely to adopt minimum efficiency requirements for MDUs because the technical hard work has been done, and manufactures are more likely to supply compliant products because the requirements are clearer and better understood, supported by compliance and verification activities which can be executed more effectively.

The timeline for the introduction or revision of standards and regulations for higher efficient products can be described in two steps:

1. Defining testing methods and efficiency classification in international standards, anticipating future technology development with increase of efficiency.
2. Based on the established international IEC and ISO standards, individual economies start to establish or upgrade their regulations (MEPS). This starts with a national market analysis, a study of benefits and disadvantages of higher efficient products, and eventually leads to minimum requirements for specific products. The requirements can be stepped: an introduction of tier 1 within two to three years, and a subsequent upgrade to tiers 2 and 3.

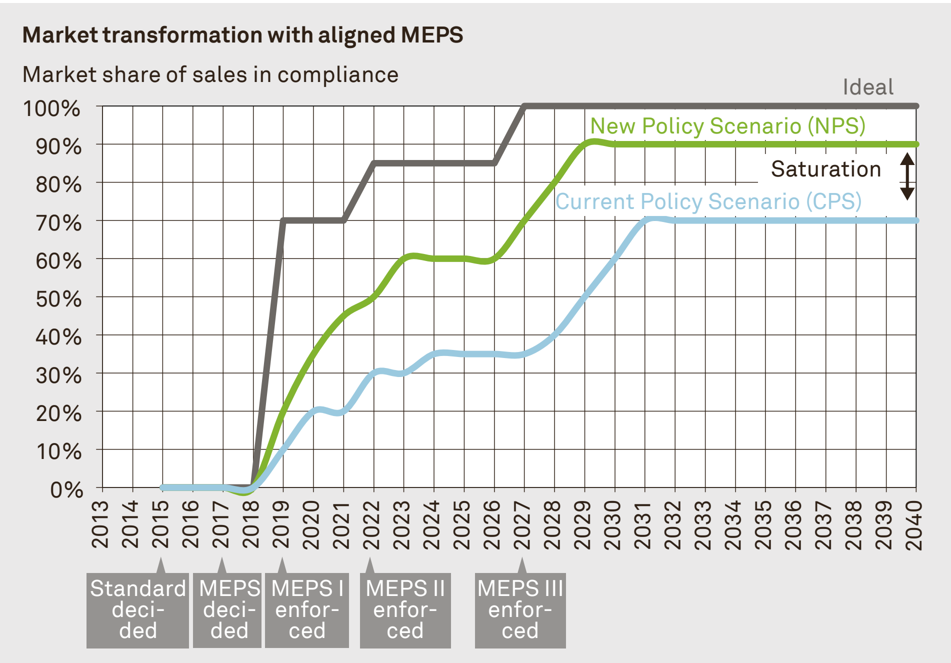


Figure 9: Schematic time lines illustrate a more rapid market transformation. Source: EMSA 2017

Figure 9 illustrates the above:

- A more rapid market transformation is possible by a shorter time for establishing MEPS (definition and publication) thanks to the availability of standards (testing and efficiency classification);
- An increased level of compliant products on the market, illustrated by the green line (NPS) – as compared to the blue line (CPS) in Figure 9.

The 'ideal line' represents a situation where all standards and the respective MEPS are fully effective in the market from the date of publication. In reality, there is a delay between establishing the standards (testing and efficiency classification), the process of establishing MEPS (definition and publication) and its enforcement. In Figure 9 the 'CPS' line illustrates the situation with 'non-alignment' of standards and regulations. The better-aligned sequence of international standards and national MEPS and their subsequent enforcement over 2 – 3 tiers is shown by the 'NPS' line. On top of this the New Policy Scenario also includes a faster and more stringent enforcement that leads to an even higher percentage of market saturation.

Overall the NPS (alignment) is 1 – 2 years faster in the MEPS decision and 1 – 2 years faster to achieve its top plateau up to a 90% market share of sales in compliance (near the saturation point of tier 3), and reaches a higher level of compliance as the CPS level that cuts off at 70% market penetration. Any new country can profit from earlier MEPS schemes in other countries, together with a pilot scheme of best practice of the introduction of MEPS.

5 International IEC/ISO standards for motors and MDU

5.1 General technical standards

International technical standards play a key role in supporting the development of policies and facilitating market development. International standards can reduce time and resources needed to develop policies, they create the certainty and clarity needed for market development and allow investors to develop viable business models [29]. Keeping pace with technological developments is a prerequisite for the standard organisations, a process that is facilitated and strengthened through international cooperation and consultation.

Certain product technicalities are defined in international (or national) standards which then serve as a reference base when setting national MEPS.

IEC and ISO share the responsibility for developing international, globally applicable product standards, with ISO focusing on mechanical products and general procedures while IEC's focus is on electrical products. They are widely adopted at the regional or national level and are applied by manufacturers, trade organisations, purchasers, consumers, testing laboratories, governments, regulators and other interested parties. Adoption is voluntary, although they are often referenced in national laws or regulations around the world. Experts from all over the world participate in the process of developing IEC and ISO international standards.

On the general level, in the field of IEC standards, IEC Guides 118 and 119 (published 2017) have laid out what needs to be clarified for any electric product with regard to energy efficiency in the respective IEC electric standards. All IEC Technical Committees are invited to use these documents as guidelines in introducing the key elements into their respective standards:

- IEC Guide 118, Edition 1: Energy efficiency aspects inclusion in electrotechnical publications
- IEC Guide 119, Edition 1: Preparation of energy efficiency publications and the use of basic energy efficiency publications and group energy efficiency publications.

Also on the general level, in the field of ISO standards, ISO 13273 contains concepts and definitions in the subject field of energy efficiency. This standard is intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 108[12]:

- ISO/IEC 13273-1 (published 2015), Energy efficiency and renewable energy sources – Common international terminology – Part 1: Energy efficiency

In order to advance the international standardisation processes in such a way that they support energy efficiency policies it is essential to both IEC and ISO to have a clear view of international policy directions and needs [30]. Simultaneously the focus on further alignment of standards will lower technical barriers to trade related to energy polices and enable the creation of a world market for energy technologies.

During standards development currently, coordination regarding the terminology used in different standards is still not unified neither inside IEC or ISO, nor between the two. Each technical committee tends to define its own terminology and is not inclined to change that later on.

To make a change in this operating principle both IEC and ISO are increasingly cooperating in the field of energy efficiency. The above mentioned IEC Guides 118 and 119 establish some general rules, in coordination with ISO, how to deal with new types of standards like system standards. Initiatives to align terminology between IEC and ISO concerning MDUs have been started recently as well.

12 IEC Guide 108 (2006): Guidelines for ensuring the coherence of IEC publications – Application of horizontal standards

Category	Scope	Definition	Testing	Efficiency Classification
Motor	Motor	IEC 60034-1:2017	IEC 60034-2-1 edition 2: 2014	IEC 60034-30-1 edition 2: 2014
VFD Motor	Motor, driven by a VFD		IEC 60034-2-3 edition 2: 2013 (under revision, CD 2017)	IEC TS 60034-30-2 Technical Specification Published: Dec 2016
VFD Motor	VFD, Motor + VFD		IEC 61800-9-2: VFD Classification/Testing edition 1: March 2017	
VFD Motor Driven Application	Motor + VFD + Driven Application (MDU)		IEC 61800-9-1: Extended Products edition 1: March 2017	

Table 10: Relevant international IEC electric performance standards for motors and motor driven units

5.2 Specific technical standards

The main elements to be defined in specific technical standards for product energy performance once the product is clearly defined are:

- Energy efficiency testing procedure
- Energy efficiency metric and classification.[13]

Table 10 and Table 11 give an overview of testing procedures and efficiency classification schemes of current relevant international IEC and ISO standards for motors and MDUs.
In the case of electric motors, a complete efficiency classification scheme has been defined in IEC 60034-30-1 (IE-code) with clear efficiency levels of IE1, IE2, IE3 and IE4. This definition includes a reference to a testing standard (IEC 60034-2-3) and tolerances (IEC 60034-1). For VFDs the IEC 61800-9-1 standard for efficiency test and classification was published in 2017. In the case of MDUs (pumps, fans, compressors) no such standard exists today, however, standards are in place for efficiency calculation methods for fans and compressors.

13 Currently, in some countries efficiency metrics and classifications are defined in regulations for energy labels or MEPS.

5.3 WTO Technical Barriers to Trade Agreement

It is important to mention the World Trade Organization's Technical Barriers to Trade (TBT) Agreement, because the WTO is the only global body between manufacturers, national governments and international standard makers that is concerned with alignment of product and system performance standards and regulations.
The WTO TBT 'aims to ensure that technical regulations, standards, and conformity assessment procedures are non-discriminatory and do not create unnecessary obstacles to trade. Through its transparency provisions, it also aims to create a predictable trading environment. At the same time, it recognises WTO members' right to implement measures to achieve legitimate policy objectives, such as the protection of human health and safety, or protection of the environment. The TBT Agreement strongly encourages members to base their measures on international standards to facilitate trade.' In particular, the WTO TBT Agreement states 'where technical regulations are required and relevant international standards exist or their completion is imminent, Members shall use them, or the relevant parts of them, as a basis for their technical regulations except when such international standards or relevant parts would be an ineffective or inappropriate means for the fulfilment of the legitimate

Category	Pumps	Fans	Compressors
Definitions	– *)	ISO 13349:2010 (edition 2, 2015) Fans -- Vocabulary and definitions of categories	ISO 5390:1977 (edition 1, 2014) Compressors – Classification ISO/TR 12942:2012 (edition 1) Compressors -- Classification -- Complementary information to ISO 5390
Testing	ISO 9906:2012 (edition 2) Rotodynamic pumps -- Hydraulic performance acceptance tests -- Grades 1, 2 and 3	ISO 5801:2007 (edition 3, 2017) Fans -- Performance testing using standardized airways	ISO 1217:2009 (edition 4, 2015) Displacement compressors – acceptance tests ISO 5389:2005 (edition 2, 2017) Turbo-compressors – Performance test code
Efficiency calculation method	–	ISO 12759:2010 (edition 1), Including Amendment 1:2013 Fans -- Efficiency classification for fans	ISO 1217:2009/Amendment 1:2016 Calculation of isentropic efficiency and relationship with specific energy
Efficiency classification	–	–	–
Audit	ISO/ASME 14414:2015 (edition 1) Pump system energy assessment ISO/ASME 14414:2015/ Amendment 1:2016		ISO 11011:2013 (edition 1) Compressed air -- Energy efficiency -- Assessment

Notes:
– no such overarching standard exists;
*) but many technical requirement standards exist on 'pump type level'.
Alternative standards for definitions of pumps exist on national level in the USA:
Rotodynamic Centrifugal Pumps For Nomenclature & Definitions (ANSI/HI 1.1-1.2–2014)
Rotodynamic Centrifugal Pumps for Design and Application (ANSI/HI 1.3-2013).

Table 11: Relevant international ISO mechanical performance standards for pumps, fans and compressors

objectives pursued, for instance because of fundamental climatic or geographical factors or fundamental technological problems' [31].
In all national product performance regulations and import licencing the WTO notification rules must be followed by the current 164 WTO member states. Proposed and implemented measures must go through a formal notification procedure and be announced to the WTO secretariat in Geneva Switzerland. They can be challenged by WTO members if they are considered to include disadvantages for imported products (barriers to trade).
In the IEC and ISO standards development process for products (like motors, VFDs) or systems (like MDUs for pumps, fans and compressors) a separate WTO Code of Good Practice for the preparation, adoption and application of standards is applied. Before publication, all international standards go through a WTO notification routine.

6 Recommendations for pumps, fans and compressors

6.1 Introduction

This chapter presents recommendations for advancing and aligning MDU standards and regulations and is structured as follows:

- Recommendations for international standards developers and policy makers concerning aspects that should be dealt with in international standards in the relevant IEC/ISO platforms.
- General recommendations for policy makers concerning pumps, fans, compressors, i.e. recommendations valid for all three MDUs.
- Detailed recommendations for policy makers concerning pumps, fans, compressors.

6.2 Recommendations for international standards developers and policy makers

Key issues should be addressed within relevant IEC/ISO-standards for MDUs in order to establish one globally applicable reference that can serve as a basis for national regulations and promote global alignment. The recommendations are covered in nine steps, based on the more than 10 years' experience with electric motors, and are shown in Figure 10.

Step 1: Ensure that regulatory objectives are reflected in the standards development process. Involve more independent members. Ensure adoption of international standards into regional and national standards as per IEC/ISO statutes.

International (and regional) standards are usually developed by a group of industry representatives, i.e. manufacturers of the product concerned, in technical committees and working groups. By nature, this means that the whole

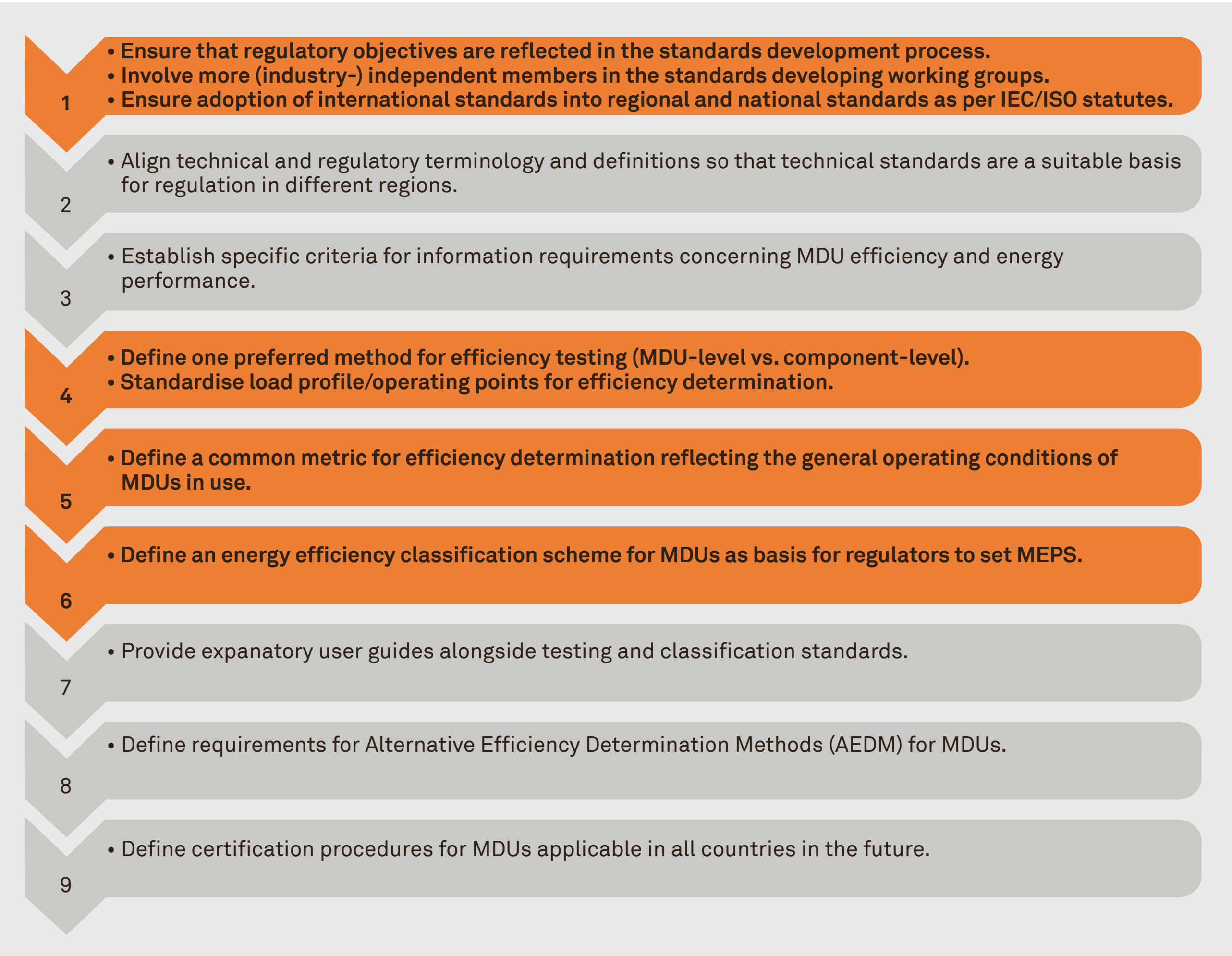


Figure 10: Recommendations for the process and steps of MDUs to be included in IEC / ISO standards. The four most important recommendations are marked orange.

standards development process and its result are driven by the interests and requirements of this industry-dominated group. In order to ensure that international standards are a suitable basis for national regulations, it is important to include the views of government regulators in the standards development process as well. As the case of electric motors has shown, involving independent experts as national representatives e.g. from government agencies, NGOs, universities, research labs, helps to better reflect policy interest and regulatory objectives. Independent experts can bring in transparent scientific evidence which makes international standards sufficiently reliable, robust and more fit for national policy implementation. Each country and region has its own system for appointing experts to work on national and international (IEC/ISO) standards.

To date, representatives of 4E EMSA have been participating as national standardisation representatives in the relevant international standardisation groups. They have been instrumental in bringing in an independent voice and the policy perspective into the development of standards for electric motors and motor plus VFD combinations. This has been achieved by bringing independent testing evidence into the standards development process and providing updates on the standards development process to a wide range of stakeholders through the Motor Summit conferences and EMSA Newsletters.

Once reliable and adequate international standards are available, it is important to ensure that they are adopted on regional and/or national level as well. This would alleviate a great deal of confusion with different standards that are used at the same time, for instance in Europe: CENELEC (European Committee for Electrotechnical Standardization) and IEC; and in the USA: IEEE (Institute of Electrical and Electronics Engineers), ANSI (American National Standards Institute), NEMA (National Electrical Manufacturers Association) and IEC, etc.

The WTO TBT Agreement encourages the use of coordinated international standards, which is in line with the above recommendation. In the future development of global trade rules, WTO could be encouraged to take a stronger role in ensuring that international standards are being applied and older national standards are systematically withdrawn once they are superseded by international standards. According to CEN and CENELEC the European standardization system requires that after the publication of a European standard, each national standards body or committee is obliged to withdraw any national standard which conflicts with the new European standard[14]. Thus, one European standard becomes the national standard in all the 34 member countries of CEN and/or CENELEC [18]. Upon the publication of an international standard like IEC and ISO, CEN/CENELEC standards should therefore rapidly adopt the international standard (which is not always the case and leads to diverging parallel standards).

Step 2: Align technical and regulatory definitions.

Currently, there is often a mismatch of terms and definitions between technical standards and regulations that could be optimised through a more collaborative effort by industrial stakeholders and policy makers in both the standards and regulation development stage. This can be achieved by enabling a dialogue of these interests, through direct involvement of regulators and/or their representatives in the international standards development committees and working groups. During the development of international standards, it is important to take into consideration any regional differences in order to make the standards globally applicable.

The terminology and definitions agreed upon and used in the technical standards are, by nature of the industry-dominated composition of the standards developing committees and working groups, market-oriented and rather technical. Even within IEC and ISO, terminology is often not fully aligned (e.g. between motors and VFDs).

On the other hand, regulations serve the purpose of imposing legally binding obligations on market players that can be enforced, and therefore terminology and definitions in MEPS need to be comprehensive and clear enough to stand up in court in case of doubt.

Step 3: Establish information requirements.

Manufacturers already need to meet certain information requirements for a number of products. For electric motors and MDUs these information requirements may concern what is shown on the rating plate (for motors see IEC 60034-1, clause 10), in the technical documentation, available online, or on the QR code (if available) of the product. Information requirements are essential for market transparency so that products are well recognised and identified as within the scope of MEPS nationally and when shipped to other countries.

14 In the European Union, CEN and CENELEC are officially recognised as European Standardization Organizations (alongside ETSI, the European Telecommunications Standards Institute). CEN and CENELEC are international non-profit associations whose national members and committees jointly develop and define standards that are considered necessary by market actors and/or to support the implementation of European legislation. Around 30% of European Standards are mandated by the European Commission in the framework of EU legislation, also in the Ecodesign context.

Step 4: Define one preferred method for efficiency testing. Standardise load profile/operating points for efficiency determination.

Several testing methods are usually required for each product or system for different purposes (type testing, delivery testing, quality control, check testing, etc.). One preferred accurate and repeatable testing method needs to be defined internationally as a reference for national legislation (MEPS).

In the case of electric motors, one preferred method was defined in IEC 60034-2-1.

IEC 61800-9-2, IEC 60034-2-3 and IEC 60034-30-1 (see Table 10) have defined standard operating points (torque and speed) that are characteristic for motors and VFDs and relevant for both linear and square torque applications. They need to be unified and applied also in ISO for all MDUs to make performance testing comparable.

Step 5: Define a common metric for efficiency determination. Reflect general operating conditions of the use of MDUs.

One common energy efficiency metric needs to be defined in international standards as a reference for national legislation (MEPS). The metric should make global application possible[15]. Developments of such metrics are ongoing. Metrics for fans and compressors have recently been taken up by ISO standards. The metrics for pumps are defined on a regional level, but not yet taken up on ISO level.

The standards define the efficiency of motors and generally of MDUs at full load (except the new US pump regulation[16]) while many motors and MDUs in reality are oversized and run most of the time at partial load [5]. This means that end-users buy a product that is rated for an efficiency at a different load than applied under real operating conditions, thereby hampering market transparency. Standards should account for fixed speed and variable speed machines under typical operating conditions of MDUs, including a distinction between linear and square torque applications.

Step 6: Define an energy efficiency classification scheme.

The IE-code for electric motors with classes IE1, IE2, IE3, IE4, as defined in the international standard IEC 60034-30-1, is a good example of an international scheme that can be used as reference for setting the level of national minimum requirements and provide a pathway for more stringent requirements over time. National MEPS levels can and need to be differentiated according to the economic and market situation of the country concerned. No energy efficiency classification schemes for MDUs on ISO level are available yet. This issue should be further investigated for potentials and benefits. Establishing a (voluntary) energy efficiency classification scheme for pumps, fans and compressors should be addressed in the relevant ISO technical committees.

Step 7: Provide explanatory user guides.

While the goal is that technical standards are clear and concise, there is often a need for additional explanation on their actual use which can be clarified through an accompanying (informative) explanatory guide, such as the IEC 60034-31 Selection of energy-efficient motors including variable speed applications – Application guide.

Step 8: Define requirements for Alternative Efficiency Determination Methods (AEDM) for MDUs.

An AEDM is a calibrated calculation method [17] to determine the energy efficiency of a product, as an alternative to having to perform tests for every basic model. The AEDM may be developed by the manufacturer with the objective to lower its burden of testing time and cost. AEDMs are currently used in the USA for a number of products including electric motors. The US Department of Energy (DOE) has established certain accuracy and reliability requirements for each specific AEDM, in conjunction with the relevant certification sampling plans and statistics. IEC is currently investigating the provision of an IEC standard to guide AEDM definition, i.e. AEDM and certification requirements and verification procedures. The same model should be applied for MDUs.

Step 9: Define certification procedures for MDUs applicable in all countries in the future.

For manufacturers the specification of compliance with the requirements of a regulation (MEPS) for a specific product differs per country. This procedure can be a 'certification procedure' as in the US where DOE has defined specific Compliance Certification requirements for each basic model, or e.g. specific information requirements, as is the case in the EU MEPS (for electric motors as an example). The IEC System of Conformity Assessment Schemes for Electrotechnical Equipment and Components (IECEE) launched the Global Motor Energy Efficiency Programme (GMEE) in 2015, based on the IECEE Certification Body Scheme. The goal of GMEE is to address trade barriers due to differing national regulations for motor efficiency, aiming to set up a globally aligned and applicable programme. The Certification Body Scheme is based on IEC standards, with the main objective of realising the concept of 'one product, one test, one certificate' through promoting the alignment of national standards with international standards [15][16]. Electric motors are the first product based on energy efficiency criteria to be included in the scheme. Policy makers should adopt/include certification scheme(s) based on these international programmes where appropriate. MDUs should be included under future IECEE programmes.

15 The problem with different grid frequency of 50 and 60 Hz is addressed in chapter 3.1.

16 Which has a load profile: 'at rated points i': i = 25%, 50%, 75%, 100% of BEP (Best Efficiency Point)

6.3 General recommendations for policy makers

The development and revision process of MEPS bring many opportunities for making steps towards the next generation regulation, based on new, updated standards with definitions, metrics, classification and information requirements. The first generation of MEPS focuses on the driven application itself only (China, EU pumps) leaving other components like the motor, VFD out of scope. The EU MEPS for fans are more advanced since they incorporate the other components as well, through calculated values. The EU MEPS for circulators was the first integral MDU MEPS developed. Since the circulator has all components (VFD, motor, pump) built into the product and the components cannot be tested separately, it was logical to develop MEPS for the complete MDU.

Where China has been leading as first mover in many MEPS for all three MDUs, the EU has followed by making improvements in the metric and differentiation (fans, pumps), and the USA has then built on these experiences to incorporate the next generation metric for pumps in their MEPS.

The regulations referred to in the following sections (see Table 12) are either 'in effect' (as of end of 2017) or 'under revision' or 'under development'. It should be noted that the final regulation can have small to substantial differences compared to the draft document.

This report suggests policy makers consider the recommendations detailed in Table 13 and explained in the following sections when considering establishing or revising MEPS for pumps, fans and compressors. The recommendations address the following main elements:

1. International standards
2. Product definition
3. Scope of MEPS
4. Test procedure
5. Metric
6. Setting MEPS

The most important short-term action for policy makers concerns international standards. Policy makers should ensure that regulatory needs are accommodated in the standards development process and that the process is not only driven or dominated by industry requirements, due to the composition of the standards development working groups. The experience with electric motors has shown that for this it is essential to involve (industry-)independent experts as national representatives in the relevant technical committees and working groups of IEC and ISO. It is also an important step for aligning terminology and definitions between technical standards and regulations, through a better dialogue between different stakeholders within the working groups.

The following chapters present detailed recommendations for each MDU. Each chapter is structured as follows:

- First, it gives an overview of the main characteristics of the MEPS per region in a summary table. The region with the most advanced MEPS, i.e. MEPS with a metric at true MDU level, is identified.
- Second, a set of recommendations for the respective MDU is described, identifying the five steps with the highest impact. These recommendations can be taken up by regulators and policy makers in the short term, and cover the main elements to progress to further global alignment for MDUs.
- Third, recommendations are made that are important to support the high impact recommendations, but which may require longer lead times.

	Pump*	Fan**	Compressor***
China	In effect (GB 19762-2007)	In effect (GB 19761-2009)	Under revision (GB 19153-2009)
EU	Under revision (547/2012)	Under revision (no 327/2011)	Under development
USA	In effect per 2020 (10 CFR Parts 429 and 431)	Under development	Pre-publication

Notes:
*) Clean water pumps. Circulators: in the EU under revision (641/2009); in the USA under consideration.
**) Industrial fans (CN, USA), Fans driven by motors (0.125–500 kW) (EU). USA and China also MEPS in effect for residential fans:ceiling fan, cooktop, duct fan; and in EU for ventilation units (buildings). There is no draft regulation for fans in the USA.
***) Air compressors. There is currently no regulation for compressors in the USA.

Table 12: Regulations and their status for pumps, fans, compressors in China, the EU and USA

General recommendations for policy makers		To be addressed at IEC/ISO level	Additional energy savings
International standards	Bring the policy perspective into the standards development process by involving more (industry-)independent members.	X	high
	Align terminology and definitions used in technical standards and in regulations.	X	low
Product definition	Include the main components of the MDU in the product definition, i.e. the motor, the driven application and if applicable a VFD and a transmission.		high
Scope	Include in the scope the most commonly used MDUs.		high
	Include other categories in the regulation as suited to regional markets.		medium
Test procedure	Ensure that the international test standards are adopted into local regulations without adding restrictions and/or deviations.		low
Metric	Use one common metric for the MDU efficiency that includes all components of the MDU and is suitable for a classification scheme.	X	high
Setting MEPS	Establish mandatory information requirements for manufacturers to declare the efficiency and performance parameters of the product/MDU.	X	medium
	Apply minimum requirements for the MDU when it is included in another product.		medium
	Establish MEPS tiers based on the international efficiency classification standard.	X	medium

Notes:
- Darker orange colour means higher importance: ■ high ■ medium ■ low
  Colour scheme: savings estimates based on identified benefits, see section 4.1
- Recommendations to be addressed also on IEC/ISO level are marked with 'x'

Table 13: General recommendations for policy makers for further alignment of standards and regulations for pump, fan and compressor MDUs

6.4 Detailed recommendations for pumps

Table 14 gives an overview of the main characteristics of the pump MEPS per region. It can be seen that the US MEPS is currently the most advanced MEPS.

6.4.1 Priority recommendations

1. Include the main components of the MDU in the product definition, i.e. the motor, pump and if applicable a VFD and a transmission.

Switching from component optimisation to MDU will greatly increase the possible energy savings. Comparison of the two types of MDU definitions shows a potential increase by a factor 10 (if combined with applying the appropriate metric, see recommendation 4) [10]. China and EU can adopt these definitions in the next/current revision cycle. The USA has already implemented these.

2. Include in the scope 'clean water pumps' as the most widely and commonly used category of pumps. Apply other categories like wastewater pumps, circulators and swimming pool pumps into regulation as suited to regional markets (and determined by the testing standards and efficiency requirements).

Establishing and applying MEPS to the largest group/subgroups of clean water pumps on the market optimises the extent of energy savings; e.g. for EU up to 25% extra savings (component level) for clean water pumps and 25% for including other pump categories (totaling 50% savings), compared to current MEPS. The 'range extension' includes the range of power, flow, head and speed, etc. per pump type, and addresses other categories as applicable for regional markets. Some pump types are market specific (like wastewater pumps in USA and EU, and multi-stage submersible borehole pumps in EU and China (and not in use in USA)) and need only be dealt with there.

A possible range extension will bring benefit to all three regions, for clean water pumps and other categories.

3. Ensure that the international pump test standard serves as the basis for local regulations either directly referenced, or published as a regional/local standard, without adding restrictions and/or deviations.

Include the motor, transmission and VFD into the testing procedure by defining wire-to-water testing, or the use of individual component testing results with calibrated components, to get measured efficiency data.

The ISO 9906 pump test standard is fit for purpose. It defines test procedures with either a calibrated motor or wire-to-water, as is the case in the USA.

EU and China can follow this example and define an MDU

level test procedure in their regulation. The US regulation defines standard efficiency default values for missing components for use in the calculation of the MDU efficiency. The specification of these default values, and the calculation model, are regionally defined.
For wastewater pumps, the EU industry is assessing the need and potential for developing a test standard. Further alignment efforts can be done e.g. with Chinese and US experts in the relevant ISO committees.

4. Use one common metric for the MDU efficiency as defined in an international standard, one that includes all components of the MDU and is suitable for a classification scheme. Differentiate the metric for constant load and variable load by using a standard load profile for fixed speed conditions (actual duty points) and one for variable load conditions.
The use of one common metric for MDUs eases the testing burden and enlarges the transparency for all stakeholders. The differentiation between constant and variable load unlocks great energy savings potentials, by a factor 2 to 10 (see chapter 4.2).
The US regulation on clean water pumps contains the most advanced metric and differentiates between constant and variable load. See Appendix 8.3 for further details on MDU metrics. Definitions for constant and variable load and the calculation method can be set in the test standards in the EU and China, to be adopted by regulators when revising MEPS for clean water pumps.

5. Establish minimum energy efficiency requirements for the complete MDU and keep the minimum efficiency requirements for those components which are already covered in separate MEPS, e.g. the motor, pump and if applicable the VFD.
Since the use of energy efficient components makes for an efficient MDU, this prevents the application of low efficiency components. This principle does not lead to additional requirements on the motor. For example in the US pump regulation, the MEPS for pumps were set based on cost-effective improvements in the hydraulic efficiency of the pump head only, the pump being fitted with a motor that is required to meet the current US motor MEPS. This approach still provides manufacturers with the flexibility to either select motor improvements as a way to improve the wire-to-water efficiency of the pump, or to select a baseline motor (meeting the motor MEPS) and make improvements to the hydraulic efficiency of the pump, or a combination of the two.
A second argument is that exclusions provide loopholes. Exclusions give disadvantages to manufacturers located within the regulated region compared to those outside the region and exporting to this region.
See section 4.2 for a discussion on the potential benefits and burdens for manufacturers with regard to testing costs involved with securing their compliance to MEPS.

6.4.2 Additional recommendations

The following additional recommendations are targeted at the process of establishing MEPS.

Establish mandatory information requirements for manufacturers to declare the efficiency and details of the product/MDU (to be established on and/or referenced by IEC/ISO level).
Include the obligation for manufacturers to declare whether the product falls within the scope of a specific regulation.
Market surveillance authorities as well as end-users benefit from transparency of the product's key characteristics and compliance with legal requirements. Comparability of products will be enhanced and stakeholder time and costs will be saved e.g. when performing checks on information requirements and further compliance activities. Transparency and comparability of performance characteristics stimulate market competition and thus higher quality, improvement of performance and lower prices.
QR codes can be an effective tool in this context. They are already used by industry to show part numbers, serial numbers and manufacturing date codes, and this practice can relatively easily be transferred to the IEC/ISO-platforms.

	China	EU	USA
Metric	Pump only	Pump only	MDU
	EI Efficiency Index	MEI Minimum Efficiency Index	PEI EEI Pump/Energy Efficiency Index
MEPS status (clean water)	In effect	In effect (under revision)	Published, in effect per 2020
Input	Mechanical	Mechanical	Electrical
Output	Hydraulic (fluid)	Hydraulic (fluid)	Hydraulic (fluid)
Motor, VFD, transmission included	no	no	calculated values, if not present

Table 14: Metrics for clean water pump MEPS in China, EU and USA. Darker orange colour means more advanced MEPS.

Establish 'technology-neutral' minimum requirements to stimulate innovation and the application of optimal efficient MDUs.
This is currently applied on the level of 'families of pumps' being the single stage pumps, multistage pumps (for clean water), booster systems for drinking water in buildings, waste water pumps and derivatives, to suit certain special applications. However there is a trade-off between lowering the numbering of 'families of pumps' and preserving the consumer's / end-user's utility.

Product information pumps

Product definition
ISO standards for (technical) definitions are available for specific pump types. ISO standards are adopted at regional or national level and are applied by manufacturers, trade organizations, purchasers, consumers, testing laboratories, governments, regulators and other interested parties – e.g. by the ANSI/HI (USA), GB (China) and EN (EU) standardisation platforms. This adoption can lead to non-comparability when extras and/or special elements or changes in vocabulary are added.
The IEC develops International Standards for all electrical, electronic and related technologies. Adoption is voluntary, although they are often referenced in national laws or regulations around the world. Experts from all over the world develop IEC International Standards.'

Scope
Clean water pumps are included in the current MEPS in China, EU and USA. In the USA and EU this includes six pump types, in China three pump types, whilst the actual nomenclature for most of the pump types differs (see Appendix 8.2, Table 17). Wastewater pumps (three types) are regulated in China, and are under development in EU (a testing standard is not yet available). Regulations for swimming pool pumps are under development in USA and EU. Circulators are regulated in EU and under development in US. The latter two products are not to be regulated in China.

Test procedure
The ISO testing standard (ISO 9906:2012) is available and globally applied by standardisation bodies and regulators. The bare pump is tested with the use of a calibrated default motor and VFD. Regional regulations define the calculation methods and how to use these testing values within the calculations to check compliance. For some applications like wastewater pumps a potential international testing standard is considered to be under development.

Metric
The metrics in use in the USA and EU (for circulators and in preparation for clean water pumps) are based on the same methodology, but with some different algorithms behind them. Also different load profiles are used. The metric in China is based on the pump only (Efficiency Index) and does not include other MDU components.
Applying a pump-MDU into a pump application for variable loads, considerable savings are possible by applying a pump-MDU with a variable speed drive (VFD), compared to a fixed speed pump.
The legislative framework in place in EU, USA and China defines the impact of the regulation and the potential energy savings. In the EU the legislation sets minimum efficiency performance requirements for pumps 'installed in a variable flow system' or 'installed in a constant flow system', thus excluding the worst pumps for both categories and excluding fixed speed pumps for variable flow systems. In the USA and China the MEPS are applicable for pumps manufactured/sold on the market, and the worst pumps for both categories are excluded.

Setting Minimum Energy Performance Standards
For the VFD only recently an IEC test standard and efficiency classification (IEC 61800-9-2) has become available. This standard can be included in the Chinese, EU and US regulation. For transmission components no test standards or efficiency classifications exist, but the regulations provide values for use in the efficiency calculations.

6.5 Detailed recommendations for fans

Table 15 gives an overview of the main characteristics of the fan MEPS per region. It can be seen that the EU MEPS is currently the most advanced MEPS.

6.5.1 Priority recommendations

1. Include the main components of the MDU in the product definition i.e. the motor, fan and if applicable a VFD and a transmission.

Taking up all MDU components into the scope increases the possible savings. A stepwise increase of tier levels brings more savings – for example a study for the EU MEPS revision shows an increase of savings of 70% to 100% [13]. Applying a metric which values the benefits of variable loads and/or optimum choice based on operational parameters would be the next step forward (see recommendation 5).

China could adopt the MDU definitions in the next revision cycle. The EU MEPS include the complete MDU – however without the 'optimal' metric yet. In the USA, the preliminary analysis of potential MEPS (under development) covers the complete MDU [17].

2. Include in the scope the most commonly used category of fans, i.e. axial, centrifugal and mixed flow fans. Apply other special and/or regional applications (with separate definitions and verifiable, measurable definitions) in the regulation as suited to regional markets. Be cautious about exclusions in the regulation, as these are potential loopholes.

By establishing and applying MEPS to the largest group of fans in use, the potential savings can be maximised. Within the main fan categories differences can be applied to reflect regional markets; and by establishing exemptions to the regulation.

The risk of diverging scopes between regions is present, but the different time paths for regulating markets give opportunities for alignment. Some examples of a diverging scope are including jet fans in the EU revision, where these are excluded in China and the USA (under development); merging centrifugal fans with and without housing into one category in the EU; combining the Forward Curved Centrifugal Housed fans with Backward Curved Centrifugal Housed fans into one potential single 'centrifugal housed fan' category in the USA (under development), but not proposed in the EU revision.

Separate regulations are in place or under development for residential applications like ceiling fans, cooker hoods and furnace ducts (in USA, China and EU), as well as for ventilation units in the EU.

When defining exclusions in the regulation, note that even exemptions need a verifiable, measurable definition if it is not to be turned into a loophole.

3. Ensure that the international fan test standard serves as the basis for local regulations without adding restrictions and/or deviations.

Include the motor, transmission and VFD into the test procedure by defining wire-to-air testing, or individual testing results/use of calibrated components, to get measured efficiency data.

The ISO 5801 standard is the international testing standard for fans and is fit for purpose. In China, EU and the USA the standard is adopted into regional standards with some minor adjustments.

The current EU MEPS uses a compensation factor – if applicable – for a VFD and default values for the motor and transmission. In the EU the MEPS revision focus is on applying direct measurement of the complete MDU only.

Manufacturers of fans without a motor can measure the fan in a defined way and declare compliance; the OEM and end-user are required to use this fan with the same drive mechanism and IE motor rating or better. However the manufacturer can also declare the fan as intended to be used with a VFD and therefore calculate a higher efficiency value, leaving it to the end-user to actually add the VFD. This solution turns into a potential loophole if the VFD is not later added, or the VFD is one with low efficiency.

A possible solution is to only allow direct measurement and the use of scaled models for the larger fans. This can be potentially supplemented with a separate MEPS for VFDs based on the new IEC standard (see Table 10).

The introduction of a metric and test procedures that include part loads can support this solution. The efficiency values for part load can only be met by using a VFD, as is

17 In the US there are currently no MEPS for fans.

	China	EU	USA
Metric	Fan only	MDU	MDU
	FEG Fan Efficiency Grade	FMEG or N Fan motor efficiency grade	FEP, FEI Fan electrical power; fan efficiency index
MEPS status (Ind. Fans)	In effect	In effect (under revision)	Under development
Input	Mechanical	Electric	Electric
Output	Hydraulic (gas)	Hydraulic (gas)	Hydraulic (gas)
Motor, VFD, transmission included	no	calculated values, if not present	calculated values, if not present

Table 15: Metrics for industrial and commercial fans MEPS in China, EU and USA. Darker orange colour means more advanced MEPS.

the case with circulators and water pumps (variable load). In the US (under development) the approach voted on by the fan working group[18] is either measurement of wire-to-air performance or a mix of measurement of mechanical input power to the fan and calculations with default values for motor and VFD (if any).

4. Use one common metric for the MDU efficiency, one that includes all components of the MDU, is suitable for a classification scheme, and is defined in an international standard.

The EU metric has proven itself in the current MEPS, but will reach its limits (within the Ecodesign legislation) with the recommended increase of tier levels. A need has been identified for a metric that explores the potential of variable speed control, and the optimum choice of products on the basis of performance parameters (pressure, flow rate, noise). This could incorporate a change from the current geometry-based categories (i.e. axial, etc.) to a functional pressure/volume flow approach.

In the USA, in response to the fan working group's recommendations, a potential metric has been developed that assesses the fan as a complete MDU for each applicable operating point (as opposed to the EU metric which values the fan at its peak efficiency point). Advantages and disadvantages of this new metric for industry and stakeholders should be further identified, and include discussion of the following issues 1) does it lead to increase of energy savings and decrease in total cost of ownership? 2) what is the need and cost for measuring the multiple points by industry and compliance authorities? See Appendix 8.3 for further details on MDU metrics.

5. Establish minimum energy efficiency requirements for the complete MDU and keep the minimum efficiency requirements for those components, which are already covered in separate MEPS. Apply minimum requirements for the MDU when it is included in another product.

This prevents the application of low efficiency components and potential loopholes through exclusions. This principal does not lead to additional requirements for components, as these components are required to meet the MEPS in place e.g. the minimum requirements for motors. By applying direct measurement of the MDU (wire-to-air, in a defined way) the manufacturer can declare compliance of the MDU including the specification of the actual VFD (if applicable) and motor rating used. Those significant elements must then be used into the final product.

When a MDU is included in another product the minimum requirements for the MDU still apply. For example, in the EU MEPS for ventilation units, the manufacturer has to apply compliant components if applicable, for instance specific types of fans and/or motors, which he can demonstrate through references to test reports, IE ratings, or other compliance marks. See section 4.2 for a discussion on the potential benefits and burdens for manufacturers with regard to testing costs involved with securing their compliance to MEPS.

China could implement and EU and USA should keep this approach in their regulations.

6. Align the definitions of fan categories, e.g. by power range and/or other features.

Further alignment is possible and needed on the definitions (names of fan categories) and power ranges.

ISO definitions have been updated recently, to include 'bare shaft fan' or 'non-driven fan' and 'Driven Fan'. However, at the regional level differences still occur; e.g. the ISO definitions are not fully adopted by the CEN committee, and in the USA, the AMCA 99 includes the 'non-driven' definition.

Further international standardisation work is needed for components and MDUs, as well as on fan categories by power range and/or other features.

6.5.2 Additional recommendations

The following additional recommendations are targeted at the product definition and process of establishing MEPS.

Bring the policy perspective into the standards development process by involving more (industry-) independent members.

Align terminology and definitions used in technical standards and in regulations.

Ensure adoption of international standards into regional and national standards.

The recently revised ISO vocabulary standard (ISO 13349:2010) includes two new definitions: 'Bare shaft fan' and 'Driven fan[19]', but these are still not fully supported by regional representatives. However, in the end these definitions should be unified in IEC/ISO standards and adopted into regional standards and used in subsequent regulations. In all three regions, China, EU and USA, this standard is used as the basis for product definition.

Establish mandatory information requirements for manufacturers to declare the efficiency and details of the product/MDU (to be established on IEC/ISO level) and to categorise the MDU in the same way as in the regulation.

Market surveillance authorities as well as end-users benefit from transparency of the product's key characteristics. Comparability of products will be enhanced and will save time and money for stakeholders involved e.g. when performing checks on information requirements and further compliance activities like compliance tests. Manufactur-

18 See Part 1 of Policy Guidelines for Motor Driven Units

19 'Bare Shaft Fan – without drive and motor', and 'Driven Fan – one or more impellers fitted to or connected to a motor, with or without a drive mechanism, a housing and a means of a variable speed drive'; ISO 13349:2010.

Product information fans

Product definition
In the Chinese regulation the definition includes the fan only. The definition as used in the EU regulation (under revision) and in the envisaged US regulation (under development) includes all main components.

Scope
The current regulations in EU and China and the envisaged US regulation (under development) include the main product families and 7 to 8 main fan categories, with differences in the types included, e. g. with cross flow (EU only), rooftop (USA) and mixed flow (EU, USA) fans. The applied names do show some differences between the 3 regions.
Figure 11 gives an overview on the most common fan rotor types and the main flow-path of the gas through the rotor or impeller.

Metric
The metrics for fan efficiency in use (China, EU, USA – state level) are of the first generation. They address the total peak efficiency of the fan and are applicable for each different fan type (axial, mixed flow, centrifugal, cross flow). A next generation metric is needed to incorporate a wire-to-air or MDU-approach. This could incorporate a change from the current geometry-based categories (i.e. axial, etc.) to a functional pressure/volume flow approach.
The recently developed FEP/FEI metric, i.e. Fan Electrical Power and Fan Electrical Index, by AMCA (Air Movement and Control Association) defines minimum efficiency and power levels for each applicable operating point and is applicable to the driven fan. Advantages and disadvantages are under debate within industry and stakeholders, and include issues such as addressing the lowest total cost of ownership for the end-user and procedures to secure the compliance of fans.

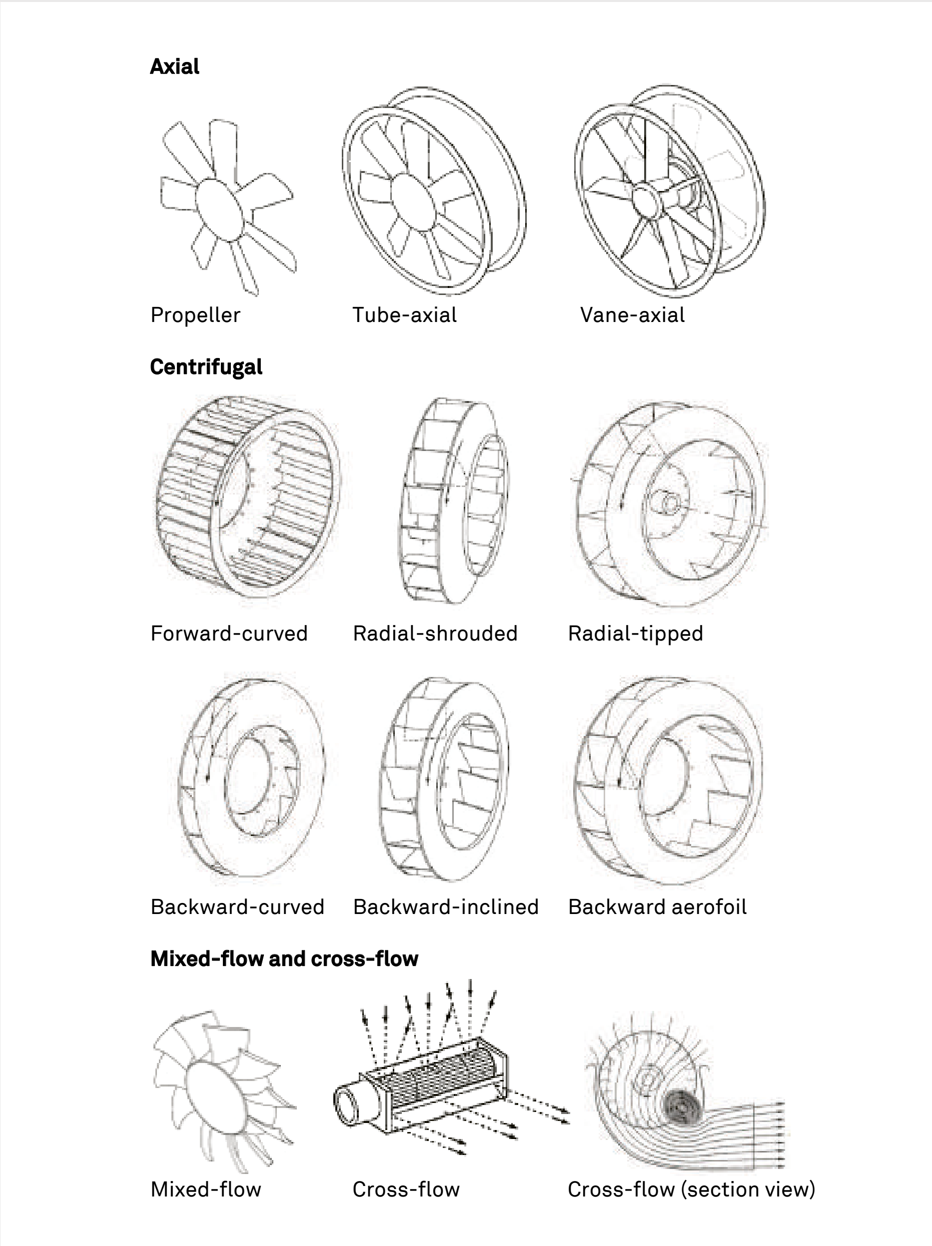


Figure 11: Most common fan rotor types (Source: Ecodesign Fan Review, VHK, 2015)

ers and users will be encouraged to apply the right fan to be used in the optimum way.
QR codes can be an effective tool in this context. They are already used by industry to show part numbers, serial numbers and manufacturing date codes, and this practice can relatively easily be transferred to the IEC/ISO-platforms.

6.6 Detailed recommendations for compressors

Table 16 gives an overview of the main characteristics of the compressor MEPS per region[20]. Only the Chinese have a MEPS for compressors in effect.

6.6.1 Priority recommendations

1. Include in the scope the most commonly used compressor categories, i.e. standard air compressors, and their subgroups: rotary and reciprocating standard air compressors – oil-injected/oil-lubricated; oil free and low pressure standard air compressors.

2. Add other groups of compressors into regulation to reflect regional markets, e.g. compressors for use in vapour compression cycles used for generation of heat or cold.
Establishing and applying MEPS to the largest group/subgroups of standard air compressors on the market increases the extent of energy savings. In the USA, the final ruling (pre-publication) includes standard air lubricated rotary air compressors and excludes piston compressors. In the EU, regulation is under development, whereby a proposal for regulating 'standard air compressors' (lubricated rotary and reciprocating machinery) was presented to the Consultation Forum in October 2014, and has since been undergoing an impact assessment.

3. Ensure that the international preferred compressor test standard is applied into regional/local regulations without adding specifications that lead to extra economic burden for market parties.
The international test standard (ISO 1217:2009) for positive displacement compressors (which covers rotary and piston standard air compressors, oil-injected/oil-lubricated) is adopted into (or used as basis for) regional standards in China, EU and USA[21]. Work is progressing to include within the ISO standard concepts like the 'cycle energy requirement' (assessing idle energy losses) on 'standard air' compressor packages. For some concepts like measuring heat recovery performance no standard exists yet.

4. Use one common metric for the MDU efficiency, one that includes all components of the MDU (compressor package), is suitable for a classification scheme, and is defined in an international standard.
The isentropic efficiency metric qualifies best for use in MEPS for standard air compressors, as it makes it pos-

20 The US final test standard is published, whereas the efficiency standard (regulation) is a 'pre-publication' final rule.
21 The ISO 5389:2006 test standard applies to turbocompressors and neither China, USA nor EU has presented regulations for this group (not even drafts). However they have been studied (together with oil-free positive displacement machinery) in the EU and (partly) in the USA.

sible to easily identify the losses of the compressor [22]. This metric represents the ratio of power input needed for a specific compression cycle by an actual compressor compared to the work needed by an ideal isentropic compression. This metric enables the comparison of performance across different products and technologies. See Appendix 8.3 for further details on MDU metrics.

The turbo-compressor industry is acquainted with this metric, however it is less well known within the rotary positive displacement industry which currently uses the specific power requirement (kW/(m^3/min)). Both metrics though can be calculated based on the applicable ISO standards. Aspects that can be included into standards for regulatory purposes are cycle energy requirement [23] (as information requirement) and specification of heat recovery performance [24] (as design requirement).

22 The isentropic efficiency makes it possible to easily identify the losses of the compressor when compared to an ideal isentropic process. The higher the efficiency, the fewer losses occur. The isentropic efficiency is unaffected by differences in outlet pressure levels, and cannot be misunderstood as no conversion of units (from imperial to SI, etc.) is required [10]

23 Each full cycle from standstill over start-up to full load and back via venting and idling to standstill results in an additional energy requirement equivalent to about 15...20 seconds full load operation (for modern designed compressors). This is the 'cycle energy requirement'; applicable only to fixed speed screw and vane compressors.

24 As much as 80 – 93% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a properly designed heat recovery unit can recover anywhere from 50 – 90% of this available thermal energy and put it to useful work heating air or water [10].

	China	EU	USA
Metric	**Compressor package**	**Compressor package**	**Compressor package**
	Compressor Efficiency Grade Specific power, isothermal efficiency	Isentropic Efficiency Actual vs. ideal isentropic compressor	Isentropic Efficiency Actual vs. ideal isentropic compressor
MEPS status	In effect	Under development	Under development (pre-published)
Input	Electric	Electric	Electric
Output	Flow, pressure	Isentropic	Isentropic
Motor, (VFD), transmission, ancillary equipment incl.	Yes	Yes	Yes
Tier levels	Tables per category	Curves per category	Curves per category

Table 16: Metrics for air compressor MEPS in China, EU and USA. Darker orange colour means more advanced MEPS. The regulation for compressors in the EU is in draft stage, in the USA there is currently no regulation for compressors, therefore not marked with colour in the table.

Product information compressors

Product definition

In China from the standard air compressors certain piston (oil free and lubricated) compressors are covered as well as rotary lubricated compressor types. In the USA the final ruling (pre-publication) includes standard air lubricated rotary air compressors and excludes piston compressors. In the EU regulation is under development, whereby a proposal for regulating 'standard air compressors' (lubricated rotary and reciprocating machinery) has been presented to the Consultation Forum October 2014, and has since been in impact assessment phase.

Other subgroups such as vacuum pumps and compressors for process gases have been excluded for regulation purposes (all three regions) based on the application of different technical principles, lack of agreed methods for performance comparison, possibly small disparity in product performances (lowering the savings potential), market sizes and/or small number of products.

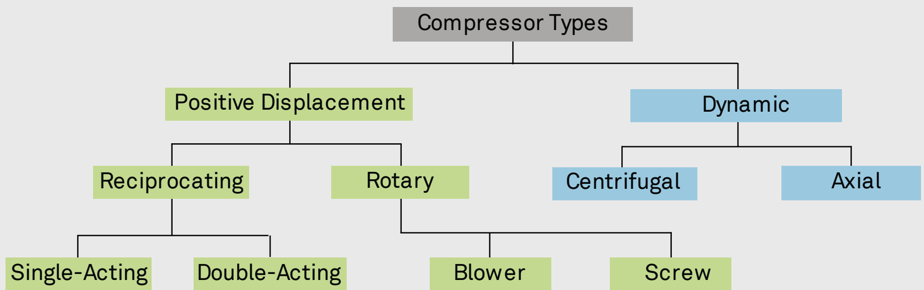


Figure 12: Typology of compressors for air and gases

5. Establish mandatory information requirements for performance parameters based on common reference conditions. Include specific (design) requirements to ensure that heat recovery can be installed easily. Align these requirements with information requirements for similar product groups such as electric motors, fans and pumps.

These information requirements will allow easier comparison of performances of products and will facilitate effective market surveillance.

Examples of the product information sheets are available in US final regulation (pre-publication) and EU review studies as well as from voluntary initiatives like the CAGI (Compressed Air and Gas Institute) verification program. These could be based on common reference conditions, and included in IEC/ISO standards and local regulation.

6. Introduce the minimum efficiency levels that avoid large differences between regions, taking into account the impact on industry and end-users.

Large differences between regions can lead to the undesired effect of certain regions with less stringent (or no) MEPS becoming a dumping ground. The EU Compressor review studies noted the differences as follows: for rotary (screw, vane), lubricated, air-cooled packages the EU proposed requirements are more stringent than elsewhere (except for some Chinese requirements on low flow equipment). For rotary (screw, vane), lubricated, water-cooled packages the Chinese requirements (Grade 2) are slightly lower but are not sufficient to change the market significantly. When the Chinese requirements increase to Grade 1, they become comparable to EU/US requirements. The US minimum requirements in the final rule (pre-publication) are less stringent than those of the EU [10].

6.6.2 Additional recommendations

The following additional recommendations are targeted at the product definition and process of establishing MEPS.

Include in the MDU definition the main components (or packaged product) including the compressor, motor, transmission, VFD (if applicable) or switchgear and auxiliary equipment required for safe functioning as intended.

The definitions as used in the US draft regulation[25] as well as in the EU draft regulation (Working Document) and the Chinese regulation are quite similar to each other and include the main above-mentioned components in the 'compressor package' or 'basic package compressor' [10] [26].

Align the technical definitions for the compressor package and values per specific group of compressors, e.g. outlet pressures, volume flow rates and/or other features.

Bring the policy perspective into the standards development process by involving more (industry-)independent members.

Align terminology and definitions used in technical standards and in regulations.

The technical report ISO/TR 12942 can serve as a basis for a practical multi-dimensional classification system of compressor equipment. It provides a classification and categorisation based on working principle, but also on design classes and functional classes. The ISO testing standards include[26] definitions of compressor types and components, but no generally applicable 'Vocabulary and definitions' standard is available for adoption into regional standards and subsequent regulations.

Apply minimum requirements for the MDU also if it is included in another product.

This prevents loopholes through exclusions, and reinforces the point that efficient components make an efficient product.

25 The US test standard is published, whereas the efficiency standard (regulation) is a 'pre-publication'.

26 ISO 1217 (displacement compressors) and ISO 5389 (turbo compressors); Compressors – Classification – Complementary information to ISO 5390.

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8 Appendix

8.1 Overview pumps: types, regulations, energy use

This Appendix gives an overview of the different pump types included in regulations (MEPS) and under study, in China, EU and USA, see Table 17. Table 18 gives an overview of the energy use of the different pump types in the EU, and the potential energy savings on product and MDU level. Not included: Pumps for clean water at temperatures below – 10 °C or above 120 °C; Designed only for fire-fighting applications; Displacement water pumps; Self-priming water pumps; Pumps for other liquids; Circulators.

Overview of pump types in legislation and under study								
	EU				USA		China	
Regulation	**547/2012**	**641/2009**	**Study Lot28**	**Study Lot29**	**Subpart Y of 10 CFR Part 431**	**in prep.**	**GB 19762-2007**	**GB 32031-2015 GB 32030-2015 GB 32029-2015**
Clean water pumps								
End suction own bearing pumps/ End suction frame mounted/own bearings	ESOB			(150 kW–1 MW)	ESFM		(*)	
End suction close coupled pumps	ESCC			(150 kW–1 MW)	ESCC		(*)	
End suction coupled inline pumps/ In-line	ESCCi			(150 kW–1 MW)	IL		(*)	
Vertical multistage pumps/Radially Split multi-stage vertical in-line diffuser casing	MS-V			(>25 bar)	RSV			
Borehole submersible multistage water pump/Submersible Turbine	MSS (4' or 6')			(8', 10', 12', 12'+)	ST			32029/ 32030 (*)
Pumps for private and public wastewater management and disposal, and for fluids with high solids contents								
Centrifugal submersible pumps (radial sewage pumps up to 160 kW)			X					32031(*)
Centrifugal submersible pumps (mixed flow & axial pumps)			X					
Centrifugal submersible pumps (once a day operation, up to 10kW)			X					
Centrifugal submersible domestic drainage pumps (<40 mm passage)			X					
Submersible dewatering pumps			X					
Centrifugal dry well pumps			X					
Slurry pumps (light duty), (heavy duty)			X					
Swimming pools, ponds, fountains and aquariums water pumps								
Swimming pool integrated motor & pumps with build-in strainer				X	X			
Fountain & pond pumps (up to 1 kW)				X				
Small aquarium pumps for domestic/small/non-commercial applications				X				
Aquarium power head pumps (up to 120 kW)				X				
Spa pumps for domestic and commercial use				X				
Counter current pumps				X				
Circulators								
Glandless standalone circulators and glandless circulators integrated in products		X				X		
Other pumps								
Fire pumps								

Note: (*) Not a 1-to-1 coverage

Table 17: Overview of pump types included in regulations and under study.

Pump type	Lot 11		Energy use		Savings at product level		Savings at EPA level	
	part of EU reg.	Intended Use					Min.	Max.
			TWh/year	%	TWh/year	%	TWh/year	TWh/year
End suction pump for clean water								
ESOB (<=150 kW)	x	Clean Water	53.7		1.12		11	14
ESOB (>150 kW)		Clean Water	4.7		0.06		0.3	0.4
ESCC (<=150kW)	x	Clean Water	52.6		0.92		12	16.4
ESCCi (<=150kW)	x	Clean Water	21.3		0.72		5.7	7.2
Submersible borehole pumps for CW								
Borehole MSS (<=6")	x	Clean Water	24.5		0.67		0.8	1.9
Borehole MSS (>6" and <=12")		Clean Water	17.3		0.42		0.6	1.4
Borehole MSS (>12")		Clean Water	4.1		0.07		0.1	0.1
Vertical and horizontal multistage pumps for clean water								
MS-V (<=25bar)	x	Clean Water	27.2		0.16		5.9	7.6
MS-V (25–40)		Clean Water	6.4		0.16		1.6	2
MS-H		Clean Water						
MS-H		Clean Water						
Other pumps for clean water								
Self-priming pumps (<=22kW)		Clean Water						
Self-priming pumps (22–150kW)		Clean Water						
Booster-sets pumps (<=150kW)		Clean Water	3.7				1	1.2
Pumps for swimming pools								
Small (<=2.2 kW)		SPW	6.9		0.14		0	0.41
Large (>2.2kW)		SPW	2		0.05		0	0
Submersible pumps for waste water								
Radial vortex pumps (<=10kW)		waste water	3.3		0.06		0	0.24
Radial vortex pumps (10–160kW)		waste water	0.5		0.01		0	0.04
Radial channel pumps (<=10kW)		waste water	3.3		0.06		0	0.24
Radial channel pumps (10–25kW)		waste water	2.1		0.06		0	0.16
Radial channel pumps (25–160kW)		waste water	6.6		0.18		0	0.4
Axial		activated sludge	0.2		0.002		0	0.02
Mixed flow		rain, storm, effluent	1.2		0.015		0	0.1
Dry well								
Mixed flow & axial		rain, storm, effluent	0.07		0.001		0	0.005
Radial vortex pumps (<=10kW)		waste, sand, grid, etc.	0.9		0.01		0	0.07
Radial vortex pumps (10–160kW)		waste, sand, grid, etc.	0.3		0.002		0	0.02
Radial channel pumps (<=10kW)		waste, sand, grid, etc.	0.9		0.01		0	0.07
Radial channel pumps (10–25kW)		waste, sand, grid, etc.	1.3		0.02		0	0.1
Radial channel pumps (25–160kW)		waste, sand, grid, etc.	2		0.04		0	0.12
High solid content water pumps								
Submersible dewatering pumps		sand water & grit water	5.8		0.15		0	0.41
Slurry pumps								
Slurry pumps light duty		slurry	4.7		0.08		0.05	0.38
Slurry pumps heavy duty		slurry	0.5		0.01		0.01	0.04
TOTAL			**258**		**5.20**		**39.1**	**55.0**
Sub 1		**Lot 11 (2007)**	**179**	**69%**	**3.6**	**70%**	**35.4**	**47.1**
Sub 2		**Lot28,29 (2011)**	**79**	**31%**	**1.6**	**31%**	**3.7**	**7.9**
TOTAL		**Lot 11, 28, 29**	**258**		**5.20**		**39.1**	**55.0**

Table 18: EU water pumps – energy use and savings on product and extended product level

8.2 Definition of scenarios in IEA WEO 2016[27]

- **CPS:** The Current Policy Scenario according to the IEA WEO 2016 is defined as including a path for global energy system without the implementation of any new policies or measures beyond those already supported by specific implementation measures by mid-2016 (Business as Usual). No new policy targets are introduced. In current policy it is included that some of the measures are specifically time-bound and will subsequently expire.
- **NPS:** The New Policy Scenario is based on a detailed review of policies and plans that governments see their energy sectors developing over the coming decades. It takes into account in full or in part, the aims, targets and intentions that have been announced, even if these have not been put into legislation or the means of their implementation have not been fully assured.
- **450:** The decarbonisation scenario is defined differently: this scenario starts from a vision where the energy sector needs to end up and then work back to present times. The objective of the '450 Scenario' is to limit the global temperature increase in 2100 to 2 °C above pre-industrial levels. The concentration of greenhouse gases in the atmosphere needs to be limited to 450 parts per million of CO_2 equivalent.

The electricity savings between the CPS and the NPS scenario from 2015 to 2040 for MDU and their components are shown in Figure 8 and Table 19[28]. The amount of the to-

27 IEA: World Energy Outlook 2016, Definition of Scenarios, Chapter 1.1., Paris 2016

28 The referenced IEA data refer to energy use by electric motors and by definition to all the MDU and system components involved.

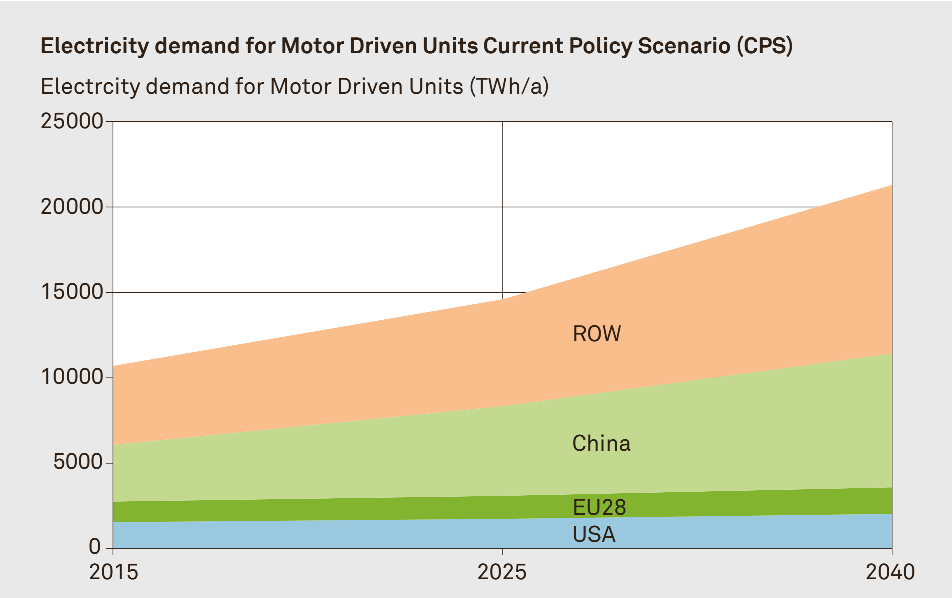

Figure 13: Global electric energy demand by Motor Driven Units in the Current Policy Scenario (Source: IEA WEO 2016)

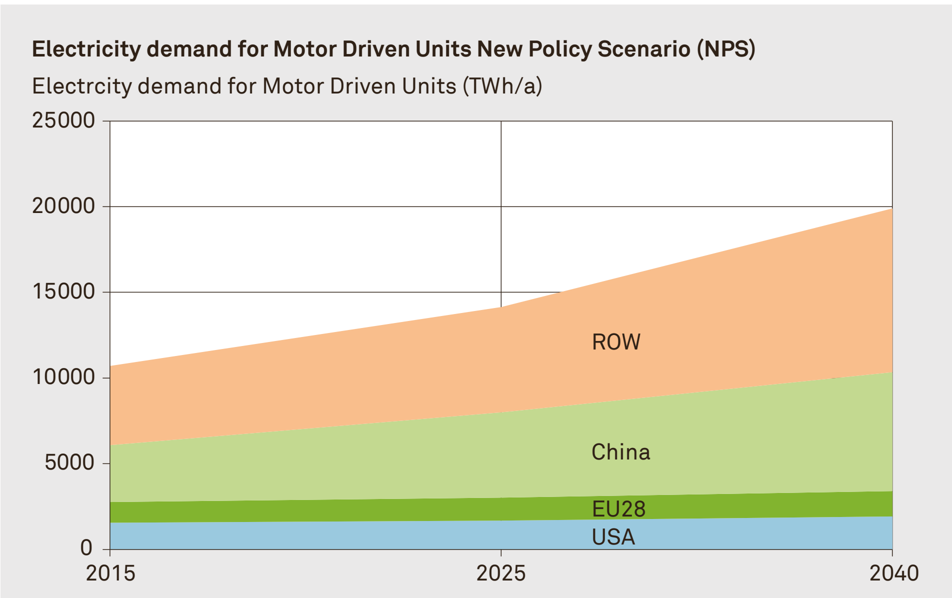

Figure 14: Global electric energy demand by Motor Driven Units in the New Policy Scenario (Source: IEA WEO 2016)

tal global electricity savings climbs to 1 090 TWh/a in 2040 for the three regions Europe, China and USA. China delivers with 898 TWh/a (82%) by far the largest contribution of the electricity savings. It also shows that transportation – due to growing share of electric cars – has an increase in electricity demand of 203 TWh/a in 2040.

Motors Driven Units MDU IEA WEO 2016	Electricity TWh/a	2015	2025	2040
		Savings in New Policies Scenario compared to Current Policies Scenario		
Total	USA	–	68	116
	EU28	–	9	76
	China	–	280	898
	Total 3	–	358	1 090
	Rest of world	–	106	313
	Total all	**–**	**464**	**1 404**
Industry	USA	–	6	12
	EU28	–	11	29
	China	–	176	758
	Total 3	**–**	**194**	**799**
Buildings	USA	–	71	174
	EU28	–	12	67
	China	–	124	225
	Total 3	**–**	**206**	**465**
Transport	USA	–	−11	−73
	EU28	–	−15	−21
	China	–	−28	−109
	Total 3	**–**	**−54**	**−203**
Agriculture	USA	–	2	4
	EU28	–	0	1
	China	–	9	24
	Total 3	**–**	**11**	**29**
Total	USA	–	68	116
	EU28	–	9	76
	China	–	280	898
	Total 3	**–**	**358**	**1 090**

Table 19: Electricity savings for motor driven units between the CPS and NPS scenarios for different regions and sectors (Source: IEA WEO 2016)

8.3 Overview of MDU metrics

This Appendix gives an overview of the different metrics in use and under development for pumps, fans and compressors per region and gives on overview of the 'level of MDU coverage' of the different metrics (i.e. the coverage of components of the MDU). The paragraph concludes with a short description of potentials for a more generic method for defining the energy efficiency of motor driven units.

Development of metrics for MDUs, an overview

The metrics currently in use for pumps and fans allow comparison across all configurations of MDUs as they cover different combinations of components, from the bare driven application to the complete MDU. The applicable input/output parameters have evolved from mechanical/hydraulic towards electrical/hydraulic. This development can be seen in Table 20 where the 'metric generation' for the three MDUs evolves from a light coloured metric to a darker coloured metric; from a component-only metric (light) towards a more integral metric (darker, applied in a regulation).

Table 21 shows more specific details of the most advanced metric for the pump, fan and compressor. For all MDU – pumps, fans and compressors – the metric is differentiated into product categories.

The newest metric for (clean water) pumps differentiates for full load and part load operating conditions, thus making an important step towards assessing the right pump solution based on practical operating conditions (being constant load or variable load). This is applicable to geometry-based pump categories.

The FMEG metric for fans in use in the EU will reach its limits with the recommended increase of tier levels in the current EU MEPS revision process. The issue of differentiating for a constant load or variable load is not addressed yet. The recently developed FEI/FEP metric offers a functional pressure/volume flow approach and may enable capturing additional energy savings by shifting from requirements for the best operating point only, to requirements at any operating point.

For compressors, the metric for standard air applications is defined and differentiated between compressor categories.

Developments in the field of metrics

A more generic metric for the output/input efficiency of a MDU could facilitate innovation of MDUs towards high efficiency solutions leading to lower cost of ownership of MDUs for end-users, with the least possible technology bias. An example of technology bias is for instance with fans, where the geometry of the flow or the shape of the impeller has a physical optimum which certain other geometries and shapes cannot reach. A product classification based on these certain geometries and shapes bears in itself a technology bias. A generic metric has the advantage of encouraging the comparison of system performance in an open and technology-neutral way.

The metrics as described can all be used to define a 'technology neutral requirement'. However by doing so there is a certain risk that a number of product categories (for pumps, fans and compressors) will be excluded from the market as these cannot comply to the minimum efficiency requirements, due to physical limits of the specific design. This can reduce the consumer utility, for instance end users and OEM will have less choice of products and manufacturers will have to rearrange their portfolio with all the accompanying costs.

Developments in the field of metrics for the different MDUs, the pump, fan and compressor, are specifically on issues like differentiation towards operating conditions (constant and variable load), using definitions based on global standards. Further developments of metrics can focus on methods that can be used for establishing requirements for the highest energy efficiency and lowest total cost of ownership of a MDU in truly daily operating conditions.

MDU type			Metrics in regulations in China, EU and USA			
Pump			**Pump only**		**MDU**	
	Metric	acronym	EI	MEI	PEI EEI	
		full name	Efficiency Index	Minimum Efficiency Index	Pump/Energy Efficiency Index	
	Region in use		China	EU (clean water)	USA, EU (circulators)	
	Input		Mechanical	Mechanical	Electrical	
	Output		Hydraulic (fluid)	Hydraulic (fluid)	Hydraulic (fluid)	
	Motor, VFD, transmission incl.		no	no	yes	
Fan			**Fan only**		**MDU**	
	Metric	acronym	FEG		FMEG or N	FEP FEI
		full name	Fan Efficiency Grade		Fan Motor Efficiency Grade	Fan electrical power; fan efficiency index
	Region in use		China		EU	(USA under dev.)
	Input		Mechanical		Electric	Electric
	Output		Hydraulic (gas)		Hydraulic (gas)	Hydraulic (gas)
	Motor, VFD, transmission incl.		no		calc. values, if not present	calc. values, if not present
Compressor					**Compressor package**	
	Metric				Compressor Efficiency Grade	Isentropic Efficiency
	Details				Specific power, isothermal efficiency	Actual vs. ideal isentropic compression cycle
	Region in use				China	USA pre-publ. (EU under dev.)
	Input				Electric	Electric
	Output				Flow, pressure	Isentropic
	Motor, (VFD), transmission, ancillary equipment incl.				Yes	Yes

Table 20: Overview of metrics per MDU and region, with the level of 'MDU coverage'. Darker colour = metric more advanced to MDU level. The regulation for fans in the USA is in draft stage, therefore not marked with colour in the table.

	Pump	**Fan**		**Compressor**
	MDU	**MDU**	**MDU**	**Compressor package**
Metric	PEI, EEI Pump/Energy Efficiency Index	FEP, FEI Fan electrical power; fan efficiency index	FMEG or N Fan motor efficiency grade	Isentropic Efficiency Actual vs. ideal isentropic compression cycle
Input Output	Electrical Hydraulic (fluid)	Electric Hydraulic (gas)	Electric Hydraulic (gas)	Electric Isentropic
Parameters for defining the metric	▮ flowrate ▮ speed ▮ c-value (per pump type, speed)	▮ flowrate ▮ pressure	▮ N-value (efficiency grade) ▮ per power range ▮ per measurement category	▮ volume flow rate ▮ d-value
Load differentiation Variable flow	Yes 25%, 50%, 75%, 100% flow + weight factors	No No	No No	Yes 40%, 70%, 100% flow + 0.25, 0.5, 0.25 weight factors
Constant flow	75%, 100%, 110% flow	Operational point at choice	At Best Efficiency Point	100% full-load
Technology neutral	No, different c-values per pump type	Can be applied as such; But can also be differentiated per fan type	No, different values per fan type	No, curves per category
Tier levels	Per pump category	Per fan category	Varies with flow and pressure	Curves per category
Motor, VFD, transmission included	Yes, calculated values, if not present	Yes, calculated values, if not present	Yes, calculated values, if not present	Yes (+ ancillary equipment included)

Table 21: Overview of details of advanced metrics for the pump, fan and compressor MDU

The IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E)

4E is an International Energy Agency (IEA) Technology Collaboration Programme established in 2008 to support governments to formulate effective policies that increase production and trade in energy efficient end-use equipment. As the international trade in appliances grows, many of the reputable multilateral organisations have highlighted the role of international cooperation and the exchange of information on energy efficiency as crucial in providing cost-effective solutions to climate change. Twelve countries from the Asia-Pacific, Europe and North America have joined together under the forum of 4E to share information and transfer experience in order to support good policy development in the field of energy efficient appliances and equipment. They recognise the huge benefits for energy security, economic development and greenhouse gas abatement from maximising the use of energy efficiency to meet future energy demand. 4E focuses on appliances and equipment since this is one of the largest and most rapidly expanding areas of energy consumption. With the growth in global trade in these products, 4E members find that pooling expertise is not only an efficient use of available funds, but results in outcomes that are far more comprehensive and authoritative. However, 4E does more than sharing information – it also initiates projects designed to meet the policy needs of participants, enabling better informed policy making. The main collaborative research and development activities under 4E include:

- Electric Motor Systems (EMSA)
- Solid State Lighting
- Electronic Devices and Networks
- Mapping and Benchmarking.

Current members of 4E are:

Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, Sweden, United Kingdom and USA.

Key achievements by 4E members include:

- The platform provided by 4E has given member governments a deeper understanding of the current and future priorities for energy efficiency policies within each country, which they use as a basis for making informed choices about national policy options.
- The 4E platform promotes knowledge sharing, and equally importantly, develops contact amongst peers which engenders on-going communication beyond the 4E environment.
- 4E's reports have enabled 4E countries to compare the performance of locally available products against those in the rest of the world and to identify global trends in different technology areas. These have assisted governments to set national policy priorities.
- 4E has developed best practice methodologies for building national scenarios, as well as the collection and analysis of data. These have helped governments to improve their evaluation of national program impacts.
- 4E provides a forum collaborative opportunities for research or policy development on specific products through multi-lateral or bi-lateral arrangements.
- 4E projects have supported national capacity building in high quality accredited testing laboratories for appliances and equipment.
- 4E has provided governments with representation at international appliance standards forums, making these more relevant to the needs of policy makers.
- The outputs of 4E have provided tangible evidence of the benefits of energy efficiency and assisted members to reinforce the rationale for their own program renewal and boost the allocation of resources.
- Between 2008 and the current time, there have been a total of 770 publications, workshops, presentations and other outreach activities undertaken by 4E aimed at government officials and industry.

Further information on 4E is available at:
www.iea-4e.org

4E Energy Efficient End-use Equipment
International Energy Agency