Accelerating the global adoption of energy-efficient electric motor systems

Policy Guide

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Glossary

Compliance: conforming to a rule, such as a law, policy, specification or standard. Also, fulfilment by countries/businesses/individuals of emission reduction and reporting commitments under the UNFCCC and the Kyoto Protocol. (UNFCCC)

Conformité Européenne marking (CE Marking): states that a product is assessed before being placed on the market and meets European Union safety, health, and environmental protection requirements. Used in the European Economic Area (EEA), consisting of the 28 European Union Member States, and the European Free Trade Association (EFTA) countries i.e. Iceland, Liechtenstein, and Norway. Per decision No 768/2008/ EC of the European Parliament and of the Council of 9 July 2008 on a common framework for the marketing of products, and repealing Council Decision 93/465/EEC.

Cooling: a procedure by means of which heat resulting from losses occurring in a motor is given upto a primary coolant, which may be continuously replaced or may itself be cooled by a secondary coolant in a heat exchanger.

Direct efficiency determination: method by which the determination of efficiency is made by directly measuring the input power and the output power.

Duty: the statement of the load(s) to which the motor is subjected, including, if applicable, starting, electric braking, no-load and rest and de-energised periods, and including their durations and sequence in time.

Duty type: a continuous, short time or periodic duty, comprising one or more loads remaining constant for the duration specified, or a non-periodic duty in which generally load, and speed vary within the permissible operating range. Duty type S1 – Continuous-running duty: Operation at a constant load maintained for sufficient time to allow the motor to reach thermal equilibrium.

Full load: the load that causes a motor to operate at its rating.

Full load value: a quantity value for a motor operating at full power, torque, current or speed.

Greenhouse gases (GHGs): The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20). Less prevalent but very powerful GHGs are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6). (UNFCCC)

Indirect efficiency determination: method by which the determination of efficiency is made by measuring the input power or the output power and determining the total losses. Those losses are added to the output power, thus giving the input power, or subtracted from the input power, thus giving the output power.

Load: all the values of the electrical and mechanical quantities that signify the demand made on a rotating machine by an electrical circuit or a mechanism at a given instant.

Minimum energy performance standard (MEPS): a mandatory minimum performance level that applies to all products sold in a market, whether imported or manufactured domestically.

Power factor: the ratio of 'active' or 'real' power (i.e. useful power) to 'apparent' power drawn by a motor from the mains.

Rated output: the value of the output included in the rating.

Rated value: a quantity value assigned, generally by a manufacturer, for a specified operating condition of a motor. NOTE The rated voltage or voltage range is the rated voltage or voltage range between lines at the terminals.

Rating: the set of rated values and operating conditions.

Registration verification: process of confirming that registered products meet the requirements of a programme's entry conditions.

Routine test: a test to which each individual motor is subjected during or after manufacture to ascertain whether it complies with certain criteria.

Self-certification: practice of submitting information about one's product in a formal statement rather than being obliged to ask a third party to do so.

Single-speed motor: motor rated for 50 Hz and/or 60 Hz on-line operation.

SI unit : any of the units adopted for international use under the Système International d'Unités.

Tolerance: the permitted deviation between the declared value of a quantity and the measured value.

Type test: a test of one or more motors made to a certain design to show that the design meets certain specifications.

Abbreviations

AC	Alternating Current
CO2	Carbon dioxide
DC	Direct Current
DSM	Demand Side Management
EASA	Electrical Apparatus Service Association
EEM	Energy-Efficient Motors
ESCO	Energy Services Company
FAQ	Frequently Asked Questions
FD fan	Forced Draft fan
GEF	Global Environment Facility
GW	Gigawatt (109 Watts)
HVAC	Heating, Ventilation, Air-conditioning
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
ID fan	Induced Draft fan
IM	Induction Motor
kW	Kilowatt (103 Watts)
LV	Low Voltage
Motor	Low Voltage Electric Motor
MEPS	Minimum Energy Performance Standards, Note: mandatory MEPS only in this Guide
Mt	Mega-tonnes (106 tonnes)
MV	Medium Voltage
M&V	Measurement and Verification (e.g., of energy savings)
MVE	Monitoring, Verification and Enforcement
MW	Megawatt (106 Watts)
NAMA	Nationally Appropriate Mitigation Actions
NDC	Nationally Determined Contributions
NGO	Non-governmental organization
O&M	Operation and Maintenance

OECD Organization for Economic Co-operation and Development

PM Permanent Magnet

PPP Public Private Partnership

QR Quick Response (QR code)

RM Reluctance Motor

S&L Energy Efficiency Standards & Labelling Program for Appliances and Equipment

SEAD Super-efficient Equipment and Appliance Deployment

SEC Specific Energy Consumption

SEforAll Sustainable Energy for All Initiative

SME Small and Medium Enterprises

SMPS Switch Mode Power Supply

TWh Terawatt-hour (1012 Watt-hours = 1 billion units of electricity)

U4E United for Efficiency

UNDP United Nations Development Programme

UNEP UN Environment Programme

UNIDO United Nations Industrial Development Organization

VFD Variable Frequency Drive

VSD Variable Speed Drive [also known as 'Variable Frequency Drive (VFD)','Inverter', 'Complete Drive Module' (CDM) or 'Drive']

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Structure

The U4E documents for “Accelerating the Global Adoption of Energy-Efficient Electric Motor Systems” comprise:

The U4E ELECTRIC MOTOR SYSTEMS POLICY GUIDE (this document)

It provides an overall reference source for policymakers in developing country and emerging economies to transition to energy-efficient motor systems. It offers an overview of all key elements for transforming a national motors market towards higher efficiency through the application of the Integrated Policy Approach. It notes the many existing best practice examples, resources, and tools that are available for policymakers to use.

It includes a technical annex that provides a basic overview of the products, efficiency metrics, and technical terms and concepts used in the U4E Electric Motor Systems Policy Guide and the U4E Model Regulation Guidelines.

Supplement : U4E MODEL REGULATION GUIDELINES

It provides model regulations to serve as guidelines and templates for use by regulatory authorities in emerging markets and developing economies that are considering a legislative framework to promote energy-efficient electric motors, variable-speed drives, and driven applications such as fans, pumps, and air compressors, or those that have a legislative framework but have not yet developed relevant regulations. The model regulations are structured as standalone sections for building blocks that may be combined based on the market structure and practices in each country or region.

Preface

Improving energy efficiency is the fastest, cleanest, and most cost-effective way to save energy, lower costs, and reduce greenhouse gas (GHG) emissions. Over half of the world's electricity is used in just four products: electric motor systems, lighting, room air conditioners, and residential and commercial refrigerators. These products and the transformers that carry electricity often waste significant amounts of energy due to poor designs and improper use. As a result, consumers and businesses face higher electricity bills, utilities struggle to meet excessive power demand, governments are burdened with additional economic development challenges, and the planet suffers from worse pollution and GHG emissions.

At the 2023 United Nations Climate Change Conference or Conference of the Parties of the UNFCCC (COP28), over 100 countries came together to sign the Global Renewable Energy and Energy Efficiency Pledge. The Pledge notes that to limit global warming to 1.5°C, the world must double the global average annual rate of energy efficiency improvements from around 2 per cent to over 4 per cent annually until 2030. Action on motor systems provides a significant opportunity for governments to meet this Pledge. Most developed countries are well underway in transitioning their markets to energy-efficient electric motors and, to a lesser extent, to energy-efficient motor systems. However, many emerging markets and developing economies are just starting to explore such opportunities. A well-designed set of policies can help transform these markets by enabling them to leapfrog past outdated technologies to superior, cost-effective alternatives.

United for Efficiency (U4E) is a global initiative launched in 2015 to accelerate such a transition and unlock lasting economic, health, environmental, and climate benefits. UNEP leads U4E, with funding from the Global Environment Facility (GEF) and steadfast support from the UN Development Programme, CLASP, the International Copper Association, the Natural Resources Defense Council, and various partners.

This report aims to guide policymakers in developing countries and emerging economies on ways to transition their respective markets to energy-efficient motor systems. It is based on U4E's Integrated Policy Approach, which has been applied around the world to bring about sustainable market transformations. The content was developed based on expert insights from over 20 organizations, ranging from motor system component manufacturers and industry associations to environmental groups, academia, and governments. This balanced cohort offers credible guidance to address common questions. The current publication is an update of the original guide published in 2017 and is part of a series of U4E guides covering electric motor systems, lighting, room air conditioners, refrigeration, and distribution transformers. The revision reflects the improvements in technology and policies for motors and motor systems.

Where energy efficiency standards & policies for motors have proven to be a logical first effective step for governments, the next step to harvest more savings potential is to extend energy efficiency policies to include the driven equipment. Therefore, the guide and the accompanying model regulations detail the main driven applications i.e., fans, water pumps, and air compressors, in addition to motors and variable speed drives at a component as well as at a system level.

A wealth of additional resources and information on how to get involved in U4E is available at www.united4efficiency.org. U4E supports the implementation of Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all. U4E is supporting the target of SDG 7.3, which calls for global progress on energy efficiency by doubling the rate of improvement in energy efficiency globally by 2030.

Executive Summary

Electric motors are everywhere, from small motors in domestic appliances to medium and large motors in commercial buildings and factories. An electric motor system (see Figure 1) includes power supply equipment, motor controls, mechanical transmission equipment, driven equipment (e.g., pumps, fans, and compressors), and downstream process components. A fraction of the energy drawn by a motor system from the power supply is lost at each energy transmission and conversion stage, with the remaining energy being delivered to the application for productive use.

Energy-efficient motor systems deliver a higher proportion of useful energy to the application by minimising losses. There are many technical solutions to reduce energy losses. These solutions typically add to the initial price of the equipment. Still, they yield energy savings that lower utility bills, resulting in a lower total cost of ownership of the motor system. The classical metric for the energy performance of equipment is energy efficiency, but for any user (and policymaker) the key performance indicator is the total energy used during a specific period or even over the equipment's lifetime. Both criteria (energy efficiency and total energy used) must be applied to optimize motor systems.

Per U4E's country savings assessment, the electricity consumption of industrial motors in 156 emerging and developing economies is forecasted to increase by 40 per cent by 2040 from the 2022 consumption levels. However, adopting the MEPS as prescribed in the model regulation guidelines would result in annual electricity savings of up to 187 TWh, equivalent to US$26 billion savings on electricity bills and reduction of 185 million tonnes of carbon emissions and avoiding the establishment of 85 mega power stations (500 MW) in 2040. Furthermore, introduction of variable speed drives in various applications such as compressors in cooling and refrigeration, pumps, fans/blowers and material handling could provide additional annual electricity savings up to 253 TWh in 2040.

Extrapolating from IEA data, it is estimated that more than 50 per cent of all electrical energy i.e., 12,400 TWh (2021)[1], is used by electric motor systems globally mostly in the industrial and building sectors, giving rise to 6.5 Gt of carbon dioxide (CO2) emissions2 (equivalent to the annual electricity generated by approximately 2,900 fossil fuel-fired power plants with a capacity of 1,000 MW).

IEA projects the global electricity demand to rise by 25 to 30 per cent by **2030** (relative to 2021) due to an increase in motor systems in industry and buildings, a shift to the use of electric heat

1 IEA World Energy Outlook 2022, plus IEA World Energy Outlook 2016 and U4E analysis.

2 The global average CO2 intensity of electricity generation amounts 459 grammes of carbon dioxide per kilowatt-hour (g CO2 /kWh). This number varies widely today; in advanced economies the average number is between 210 - 450 (g CO2 /kWh) (i.e. European Union, United States of America, Japan, and Republic of Korea), in emerging market and developing economies the number is between 550 – 700 (g CO2 /kWh) (i.e. Africa, Middle East, China, Southeast Asia, India). The rapid growth of power systems in emerging markets and developing economies and higher use of unabated coal results in a 70 per cent higher average CO2 intensity of electricity generation than the average in advanced economies [IEA WEO 2022].

pumps, and increased use of electric vehicles and hydrogen (production). The main growth contribution i.e., 70 to 80 per cent, will come from China, India, and other emerging markets and developing economies.

According to modelling done by CLASP[3] policy actions to double the efficiency of new industrial motor systems[4] and greatly accelerate the replacement of existing industrial motor systems stock by 2030[5] could mitigate 3.4 Gt CO2 emissions by **2040** and 5.1 Gt by **2050**. This is even more than the mitigation potential of all other appliance groups including cooling and lighting combined i.e., 3.3 Gt and 4.1 Gt CO2 emissions.

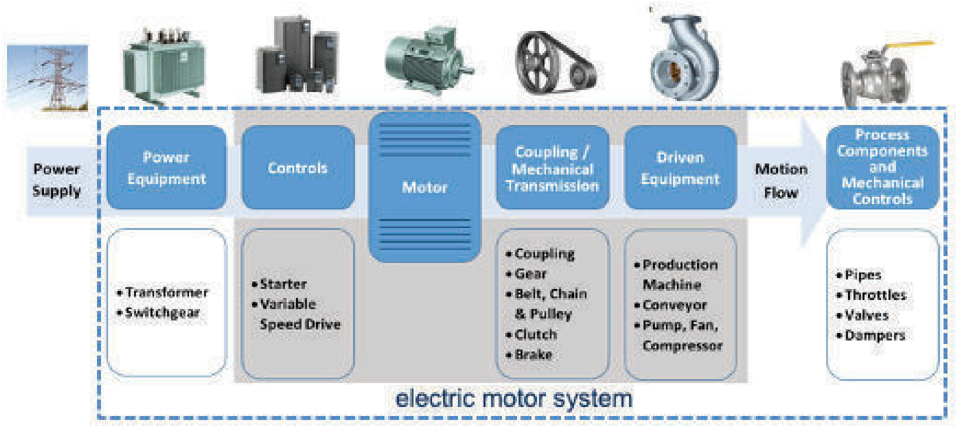


Figure 1: Components of an electric motor system[6]

Differentiated policy approaches are required for *new motor systems* entering the market and for the much larger stock of i*nstalled motor systems* respectively to realise this energy savings potential.

New motor systems

Mandatory Minimum Energy Performance Standards (MEPS) regulate the new equipment permitted to enter the market. MEPS may cover individual components or motor systems. In addition to MEPS, supporting policies such as 'Green Public Procurement'[7] create a demand for higher-energy-performance products and systems (HEPS).

It is to be noted that a part of the energy-saving potential in a motor system comes from improving the energy efficiency of the individual components, and another part comes from optimising the system's efficiency. For this reason, MEPS regulations have evolved towards a larger 'system border', including the motor, the VSD, and the driven equipment. However, a regulation that covers the efficiency of a complete system is more challenging, as the entire system is composed of more components e.g., piping and throttles, and is built at the end user's premises. As a result, the total savings potential of systems cannot be addressed by MEPS alone, and these need to be complemented by other supporting policies.

3 CLASP Net Zero Heroes, Nov 2023.
4 A doubling of efficiency would mean a 50 per cent reduction in the average energy consumption of new units.
5 To achieve the full replacement by the most efficient motors (IE5) by 2035.
6 Modified from the original figure created for the 2017 edition of the U4E Motors Policy Guide jointly with the Institute of Systems and Robotics, University of Coimbra.
7 Green Public Procurement can help to transform markets by leveraging the power of public purchases to drive markets towards sustainability, reducing governments' environmental footprint and contributing significantly to reductions in greenhouse gas emissions. Sustainable public procurement also allows governments to serve as an exemplary model and send strong market signals, fostering private sector and consumer behaviour change, enabling the overall transition to a green, sustainable economy.

Installed motor systems

MEPS and HEPS do not directly address the installed base of motor systems. With twenty years or more of average life expectancies, it would take decades for the old inefficient stock to be replaced with efficient new products.

Therefore, supporting policies are necessary to stimulate the accelerated turnover of the inefficient installed base and include programmes for communication and education, energy audits, improving motor repair practices, industry energy performance targets, energy management, and company motor management.

Over 56 countries representing 80 per cent of global electricity use in motor systems[8] have successfully steered their markets toward higher efficiency using approaches described in this Policy Guide. The risks of inaction are immense, particularly for developing and emerging economies. An absence of robust and well-enforced policies – when most of the world has them – may cause these economies to become the destination for inferior motor systems that are not acceptable elsewhere.

An Integrated Policy Approach to transform a market for energy-using products includes:

- **Standards and Regulations**[9] are essential for defining market eligibility and ensuring product quality and performance. They specify which equipment is blocked from the market for not meeting minimum energy performance standards (MEPS) and identify products that meet or exceed these requirements. They also mandate labelling to endorse performance and facilitate easy comparison between competing products. Additionally, they require green public procurement of the highest efficiency equipment that is economically justifiable over its lifecycle, establish testing protocols, and cover other critical aspects. These standards and regulations are crucial for the success of market transformation and form the cornerstone of the U4E Integrated Policy Approach. More precise recommendations on standards and regulations can be found in the U4E Model Regulation Guidelines for Motors.

- **Monitoring, Verification, and Enforcement (MVE)** are essential processes that track the equipment placed on the market, test it to ensure accurate performance claims, and prompt corrective actions for non-compliant products. Without effective MVE, incentives meant to promote efficient products may instead reward sub-standard alternatives, allowing non-compliant equipment to enter the market. This creates an uneven playing field, penalizing manufacturers who adhere to the requirements. Additionally, poor quality equipment falsely advertised as energy-efficient can disappoint consumers, potentially leading them to disregard performance considerations in the future.

- **Supporting Policies** aim to accelerate the sustainable renovation of inefficient motor systems, promote sustainable repair practices, mandate energy audits of motor systems and the implementation of audit recommendations, and enhance energy performance at the company and industry levels. Additionally, these policies focus on communication, education, and capacity building to ensure widespread understanding and adoption of energy-efficient practices.

8 Data by CLASP, IEA 4E EMSA, IEA.
9 "Standards" are technical requirements on equipment quality, safety, energy performance etc. set by standardisation bodies such as IEC/ISO and industry bodies such as NEMA. "Regulations" are specific rules or directives made and maintained by a governmental authority, typically enforceable by law. "Policies" are plans and actions a government adopts to achieve its objectives.

- **Financial Delivery Mechanisms** that address the barrier of higher upfront costs of efficient equipment through fiscal incentives such as grants, rebates, and tax relief, or by extending credit lines, partial risk guarantees, loans, bulk procurement opportunities, equipment leasing through financial intermediaries, and services through energy service companies.

- **Environmental Sustainability and Heal**th policies to promote, encourage, incentivise, and mandate the minimisation of the impact on human health and the environment over the life stages of the components of electric motor systems to ensure that equipment is kept in use for as long as possible, and waste and environmental impacts are reduced or eliminated through the circularity principles of durability, repairability, reuse, remanufacturing, and recycling.

The guidance is meant to be flexible, rather than prescriptive. Each country should consider and make decisions based on its specific priorities and circumstances. This process should involve all relevant authorities and stakeholders in jointly determining priorities and the most appropriate pathways to achieve them.

Key recommendations for policymakers:

- Use this U4E Electric Motor Systems Policy Guide, the Model Regulation Guidelines, and other resources available at united4efficiency.org to develop and implement a national strategy for efficient motor systems. Start with motors and extend in an appropriate timeline to efficient variable-speed drives, pumps, fans, and compressors.

- U4E recommends the following MEPS options, where an economic and environmental impact analysis will provide the principal basis for determining the scope and level of electric motor systems regulations. The U4E Model Regulation Guidelines provide ready templates to develop such regulations based on the market structure and practices in each individual country or region.

Motors

Adopt MEPS for motors at one of the following levels

- **Advanced Level (A), with the broadest coverage of motor types and sizes**
  Offers a regulatory framework designed to leapfrog directly to the best practice advanced level in line with current international best practice regulations. This is suitable for countries that either do not have a significant domestic motor manufacturing industry or already have MEPS for motors covering a narrower scope and/or at a lower efficiency level and are ready to adopt the advanced level:

    - IE4 efficiency class for a three-phase motors of 75 - 200 kW, which are not brake motors, Ex eb increased safety motors or other explosion-protected motors;

    - IE3 efficiency class for all other three-phase motors of 0.75 – 1,000 kW;

    - IE2 efficiency class for three-phase motors in the range of smaller 0.12 - 0.75 kW motors; single-phase motors rated above 0.12 kW; and an Ex eb motors for explosive atmospheres of 0.12 – 1,000 kW.

- **Bridging Starting Level (B), at IE3-level**
  Countries with a significant domestic motor manufacturing industry can choose to start at IE3-level "premium energy-efficiency" for a basic range of 0.75 – 1,000 kW for three-phase motors.

- **Bridging Starting Level (C), with limited time at IE2-level and transitioning to IE3-level**
  Countries that do have a significant domestic motor manufacturing industry can alternatively choose a more gradual transition by starting at IE2-level "high energy-efficiency", for a basic range of 0.75 – 1,000 kW for three -phase motors, to provide themselves with (limited) transitory time for upgrading technology with the objective of transitioning in steps to Level B and Level A eventually.

Variable Speed Drives

- Adopt MEPS for variable speed drives with an IE2 efficiency class for the entire range of 3-phase AC input i.e., 0.12– 1,000 kW.

Fans

Adopt MEPS for fans for five different fan types i.e., axial fans, centrifugal fans, cross flow fans, mixed flow fans and jet fans, with an electric input power between 125 W and 500 kW, at one of the following levels:

- **Advanced Level (A)**
  Offers a regulatory framework designed to leapfrog directly to the best practice advanced level in line with current international best practice regulations. Minimum fan energy efficiencies are defined by an efficiency grade N specific for each type. The efficiency grades N are at a 'premium level', ranging from N50 to N67, and include information requirements on partial load.

- **Bridging Starting Level (B)**
  The bridging level includes lower efficiency grades**, which provide domestic manufacturers with** a (limited) transitory time for upgrading technology. The efficiency grades N range from N45 to N65.

Pumps

Adopt MEPS for Rotodynamic pumps for clean water of the following types: end suction own bearing (ESOB), end suction close coupled (ESCC), end suction close coupled inline (ESCCi), vertical multistage (MS-V), horizontal multistage (MS-H), submersible multistage (MSS) and booster sets (BS), at one of the following levels:

- **Advanced Level (A)**
  Countries may start at the advanced level directly, the current international best practice level. The efficiency levels include

  - for water pumps a Minimum Efficiency Index of 0.4, and

  - for water pump units - for ESOB, ESCC and ESCCi end suction units up to 45 kW shaft power, an Energy Efficiency Index of not more than 0.62, and for booster sets an Energy Efficiency Index of not more than 0.5.

- **Bridging starting level (B)**
  The optional bridging level includes a lower Minimum Efficiency Index (MEI) for pumps only (the hydraulic efficiency) of MEI = 0.1, providing domestic manufacturers with a (limited) transitory time for upgrading technology. These exclude the booster sets.

Air Compressors

Adopt MEPS for rotary standard air compressor packages with a maximum volume flow rate of between 5 to 1,280 l/s when supplying air at discharge pressure(s) equal to or higher than 7 bar(a) and not exceeding 15 bar(a), at one of the following levels:

- **Advanced Level (A)**
  Current international good practice, defining a proportional loss factor value of d = -10 for rotary standard air compressor packages.

- **Bridging starting level (B)**
  Transitory bridging level, defining a proportional loss factor value of d = -15 for rotary standard air compressor packages, as an optional bridging level to provide domestic manufacturers a (limited) transitory time for upgrading technology.

General recommendations

- Collaborate with other countries in the region to harmonise standards according to international best practices and to share resources and lessons learned.

- Conduct targeted outreach and training to inform, educate, and gain the support of key stakeholders.

- Aim to implement an MVE regime within the national legal framework in time to coincide with the adoption of MEPS and ensure accurate and reliable measurement of the energy efficiency of motor system components as prescribed by the applicable IEC / ISO standards.

- Use voluntary supporting policies, namely communication campaigns to educate, inform, and build capacities; to improve energy management practices at the government, company, and industry level; to pull the market for new equipment above MEPS e.g. through Labelling and Green Public Procurement; to accelerate the renovation of inefficient motor systems in the installed base; and to improve repair practices. Encourage adoption of best practices (e.g., per ANSI/EASA AR100 or the specifications of the Consortium for Energy Efficiency) in shops to yield professional repairs so motors meet their original performance.

- Conduct market analysis to understand financial barriers so that applicable financial delivery mechanisms are in place to support voluntary actions (e.g., encourage the purchase of motors and motor systems with higher efficiency than MEPS, the early replacement of inefficient motors, the upgrade of installed motors systems).

- Establish circularity policies to promote, encourage, incentivise, and mandate the minimisation of the impact on human health and the environment over the life stages of the components of electric motor systems to ensure that equipment is kept in use for as long as possible. Waste and environmental impacts are reduced or eliminated through the principles of durability, repairability, reuse, remanufacturing, and recycling.

01 Introduction

1.1 Why Leapfrog to Energy-Efficient Electric Motor Systems?

Only a portion of the electrical energy that goes into a motor system is used for work, and the rest is lost. Techniques and technologies **exist** to reduce these energy losses significantly. For example, Figure 2 depicts a motor system in which only 31 per cent of the input power is converted to useful output power. With redesign, the improved system delivers 72 per cent (=31 input power /43 output power) of the input electrical energy for productive use, which is more than twice the original. In the redesigned system, the mechanical throttle has been replaced with a variable speed drive, and the motor, the pump, the coupling, and the pipes have been replaced with higher efficiency ones. In addition to these efficiency gains, energy use could be reduced further through the optimal matching of components with one another and then with the application's duty cycle. As can be seen from this example, the energy savings potential in motor systems is significant.

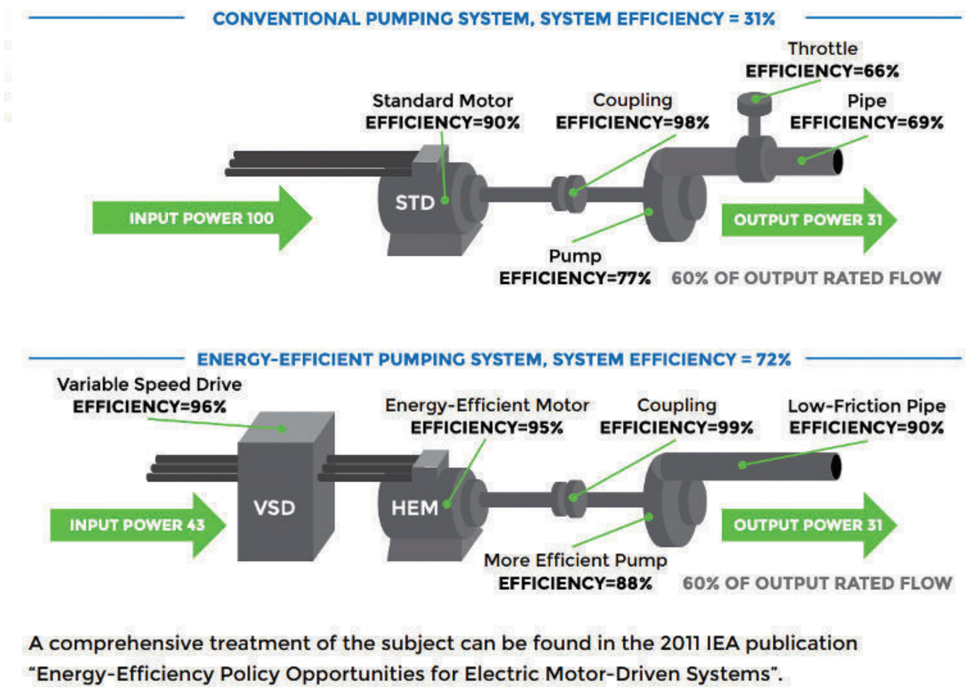


Figure 2: Energy savings potential of a typical motor system[10]

10 de Almeida, Anibal T., and others (2001) VSD's for Electric Motor Systems, SAVE

Extrapolating from IEA data, it is estimated that more than 50 per cent of all electrical energy i.e., 12,400 TWh (2021)[11], is used by electric motor systems globally mainly in the industrial and building sectors, giving rise to 6.5 Gt of carbon dioxide (CO2) emissions[12] (equivalent to the annual electricity generated by approximately 2,900 fossil fuel-fired power plants with a capacity of 1,000 MW).

IEA projects the global electricity demand to rise by 25 – 30 per cent by 2030 due to increased motor systems in industry and buildings, a shift to heat pumps, and an increased use of EVs and hydrogen (production). The most significant contribution to this demand growth i.e. 70 – 80 per cent, comes from the emerging economies and developing countries. According to modelling done by CLASP[13], policy actions to double the efficiency of new industrial motor systems and significantly accelerate the replacement of existing industrial motor systems stock by 2030 could mitigate 3.4 Gt CO_2 emissions by 2040 and 5.1 Gt by 2050.

Many countries are taking actions to address this opportunity. Argentina, Australia, Brazil, Canada, China, Chile, Colombia, Ecuador, Egypt, Ghana, India, Israel, Japan, Kazakhstan, Kenya, Mexico, New Zealand, Norway, Republic of Korea, Saudi Arabia, Singapore, South Africa, Switzerland, Türkiye, United States of America, Ukraine, Viet Nam and the European Union countries have worked to improve the energy performance of electric motor systems in their respective domains through policy actions.[14]

Yet, other developing and emerging economies are not taking such policy actions due to a combination of capacity challenges, financial barriers, and the prioritisation of different opportunities that are more familiar.

Since motor systems have long lifetimes, sometimes 20 years or more, the lack of policies locks in electricity waste for decades. Factories and businesses are less competitive as they spend more money than necessary to power their equipment while competing with energy-conscious companies elsewhere in the world. Utilities that struggle to meet electricity demand face unnecessary strains on the grid as additional inefficient motor systems enter the market.

Governments in developing and emerging economies can start by regulating motors, for which there is considerable international policy experience and best practices available for adaptation. Once knowledge has been gathered about regulating these motors, policies are typically expanded to cover additional motor sizes, types, and other parts of the motor system (which is more complex but offers considerably more significant energy savings potential).

This guide aims to support that policymaking process. It was designed with the participation of over 20 organizations, including intergovernmental organizations, environmental groups, international motor manufacturers, NGOs, and academic institutions.

Each country is encouraged to analyse its own market, consider the guidance in this document, and make policy decisions thereafter based on its specific priorities and circumstances.

11 IEA World Energy Outlook 2022, plus IEA World Energy Outlook 2016 and U4E analysis.
12 The global average CO2 intensity of electricity generation amounts 459 grammes of carbon dioxide per kilowatt-hour (g CO2 /kWh). This number varies widely today; in advanced economies the average number is between 210 - 450 (g CO2 /kWh) (i.e. European Union, United States of America, Japan, and Republic of Korea), in emerging market and developing economies the number is between 550 – 700 (g CO2 /kWh) (i.e. Africa, Middle East, China, Southeast Asia, India). The rapid growth of power systems in emerging markets and developing economies and higher use of unabated coal results in a 70 per cent higher average CO2 intensity of electricity generation than the average in advanced economies [IEA WEO 2022].
13 CLASP Net Zero Heroes, Nov 2023
14 Source: IEA 4E EMSA

1.2 The Integrated Policy Approach

A variety of barriers hamper the adoption of energy-efficient motors and motor systems, as noted in Table 1.

Table 1: Barriers to the adoption of energy-efficient motor systems

Barrier	Description	Manifestations
Financial	Higher first cost of more-efficient equipment relative to less-efficient equipment Cost of upgrading motor systems Cost of upgrading motor repair facilities	Investments in energy efficiency are considered a lower priority compared with core business investments. Emphasis on the lowest upfront costs (generally less than 2 per cent of lifecycle costs) rather than on the recurring costs of lost energy (usually more than 98 per cent of lifecycle costs) at the procurement stage, although there is generally a strong business case based on lifecycle costing for the incremental investment in terms of quick payback. Preference for repeated low-cost repairs of failed inefficient equipment rather than replacement with new efficient ones. There is an existing market for used equipment. Small and complex transactions and an inability to assess energy-efficiency investments deter financiers. Domestic manufacturers may not be able to produce higher-efficiency equipment.

Market	Market structures and constraints that prevent investments in energy-efficient motor systems	• Split incentives — Most motors are procured as a part of systems through equipment manufacturers who incur the higher costs of more efficient motors, while end-users reap the benefits. End users demand low system prices but not system energy performance, pressuring equipment-manufacturers to buy cheap motors, which are likely inefficient. • Split responsibilities for procurement and operations within companies, with independent budgets. • Operating plants are seldom disturbed for upgrades to higher-efficiency motor systems. The opportunity only arises when a motor fails. In such an event, the priority is often to get the plant up and running again as fast as possible by repairing the failed motor. • Distributors stock what sells in the local market, leading to limited availability and longer delivery times of high-efficiency motors until usage picks up, which in turn constrains usage growth. • Resistance from local motor manufacturers and distributors seeking protection by citing technology and financing constraints. • Users keep large stocks of unused motors for quick replacement, avoiding costly downtime, which significantly extends the lifetimes of old inefficient motors. Users consider it wasteful to scrap these. There is generally no rule on motors in user stocks built before the effective date of regulations.
Information and capacity	Lack of information and technical capacity for evaluating the potential savings from energy-efficient motor systems	• Lack of awareness/conviction of the energy savings potential of energy-efficient motor systems with users, partly due to missing technical capacity for evaluation and implementation of a motors efficiency programme. • Employees working with motor systems are inadequately trained to operate these optimally. • Equipment manufacturers and dealers are inadequately informed. • Motor systems are oversized and, therefore, inefficient due to layer upon layer of safety margins to cover unknowns and uncertainties, and equipment manufacturers' practices. • Lack of competent service providers for motor systems optimisation. • Motor repairers lack awareness of good practices.

Regulatory and Institutional	Structural characteristics of the political and legal system that make it difficult to promote efficient motors and systems	• Inadequately defined institutional roles and responsibilities for promoting energy efficiency. • Electricity subsidies distort the private business case for energy efficiency investments, causing a net public loss. • Nontariff barriers to imports of efficient equipment, like cumbersome registration processes or special requirements. Lack of harmonisation with trading partners. • Inadequate institutional capacities to deal with the large-scale imports of inefficient motors. • Inadequate monitoring, verification, and enforcement capacities.
Technical	Inadequate technology	• Inadequate access to technology for designing and manufacturing high-efficiency motors with local industry. • Inadequate equipment and technical facilities with motor repair shops. • Lack of adequate/accredited testing capacities. • Limited resources to monitor, verify, and enforce national regulations domestically and at customs.
Environ-mental risk perception	Environmental concerns over safe disposal of motors at end of life	Absence of specific policies for disposal of motors at the end of life, although individual policies may exist for its components—metals, plastics, rubber, hazardous wastes.

To address these issues and guarantee a sustainable transition to energy-efficient motors and motor systems, UNEP recommends an Integrated Policy Approach (see Figure 3).

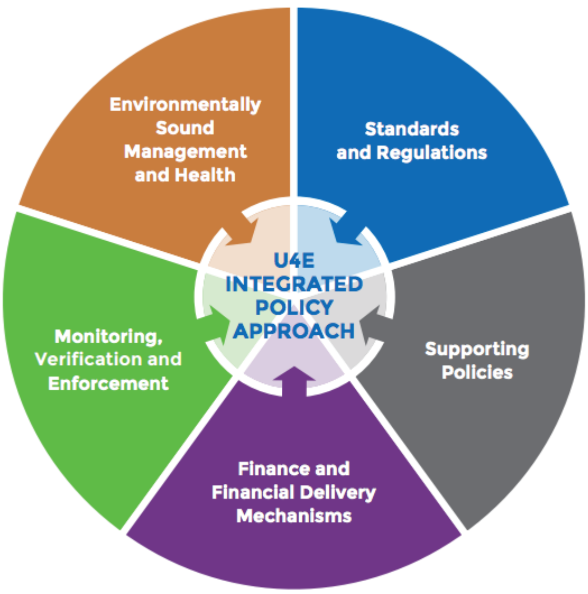


Figure 3: Integrated Policy Approach to transform the market for energy using products

An Integrated Policy Approach to transform a market for energy-using products includes:

- **Standards and Regulations**[15] that define which equipment is blocked from the market (those that do not meet minimum energy performance standards or MEPS); which equipment may be recognised for meeting performance and quality requirements; require labels that endorse the performance of the equipment or allow for easy comparison of performance between competing products; mandate green public procurement of the highest efficiency equipment that is economically justifiable over its lifecycle; how to test the equipment; and other aspects. Standards and regulations are essential to the success of market transformation and are the cornerstone of the U4E Integrated Policy Approach.

- **Monitoring, Verification, and Enforcement (MVE)** that tracks which equipment is placed on the market, tests the equipment to ensure that claims of performance are accurate, and prompts corrections by those that fail to comply. Otherwise, incentives for efficient products may reward sub-standard alternatives, and non-compliant equipment may enter the market. This results in an uneven playing field, penalising manufacturers who comply with the requirements. Moreover, poor quality equipment that is advertised as energy-efficient would disappoint consumers who may opt to avoid performance considerations in the future.**Supporting Policies** to accelerate the sustainable renovation of the installed base of inefficient motor systems; to encourage sustainable repair practices; to require energy audits of motor systems and implementation of audit recommendations; to support the improvement of company and industry level motor systems energy performance; to communicate, educate, and build capacities.

- **Financial Delivery Mechanisms** that address the barrier of higher upfront costs of efficient equipment through fiscal incentives such as grants, rebates, and tax-relief, or by extending credit lines, partial risk guarantees, loans, bulk procurement opportunities, equipment leasing through financial intermediaries, and services through energy service companies.

- **Environmental Sustainability and Health** policies to promote, encourage, incentivise, and mandate the minimisation of the impact on human health and the environment over the life stages of the components of electric motor systems to ensure that equipment is kept in use for as long as possible, and waste and environmental impacts are reduced or eliminated through the circularity principles of durability, repairability, reuse, remanufacturing, and recycling.

15 “Standards” are technical requirements on equipment quality, safety, energy performance etc. set by standardisation bodies such as IEC/ISO and industry bodies such as NEMA. “Regulations” are specific rules or directives made and maintained by a governmental authority, typically enforceable by law. “Policies” are plans and actions adopted by a government to achieve its objectives.

1.3 Differentiated Policy Approaches

Differentiated policy approaches are required to transform the market for new equipment and renovate the installed base of equipment, as shown in Figure 4.

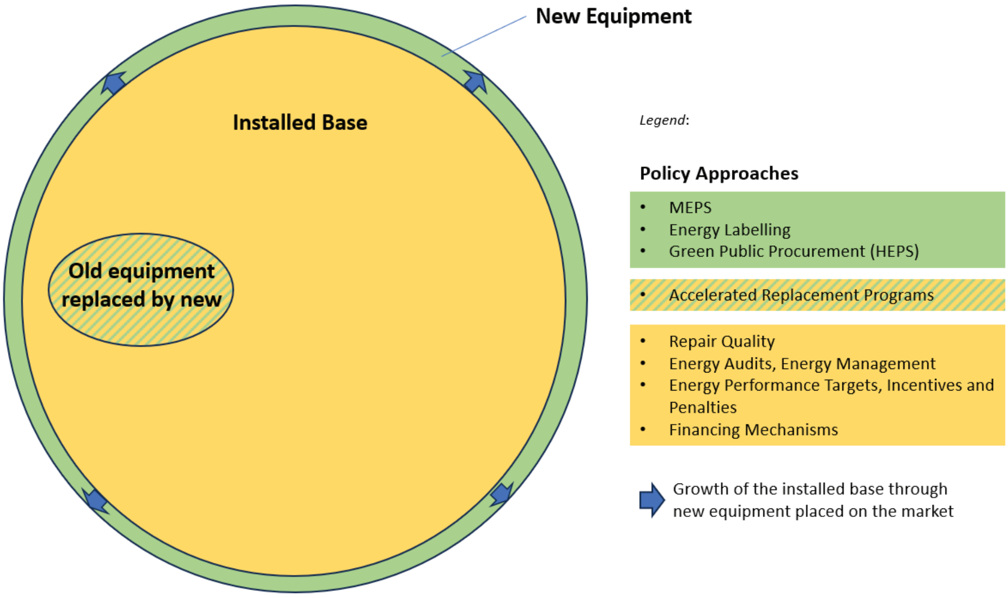


Figure 4: Differentiated policy approaches for new equipment and the installed base

A. Policies to Transform the New Equipment Market

02 Standards and MEPS Regulations

What?	An overview of the test standards and methods used to determine the energy performance of electric motors, variable speed drives, fans, pumps, and air compressors; a summary of minimum energy performance standards (MEPS) as a regulatory tool to transform motor system markets towards higher energy efficiency; an overview of the defined scope of U4E Model Regulation Guidelines; outline of a systematic approach to developing MEPS; the benefits of harmonisation regionally and with trading partners.
Why?	This section provides information on MEPS, the first part of UNEP's Integrated Policy Approach, which is the cornerstone of market transformation.
Next?	Some key questions to keep in mind: • What is the status of test standards in my country and neighbouring countries? • Are we affiliated with IEC or the International Organization for Standardization (ISO)? • What data is available on the motor systems market in my country? • What is the proportion of demand met by domestic manufacturing? How concentrated or fragmented is the industry? Who are the key players? How current is their level of technology? • Do we have domestic testing facilities? Can we collaborate with testing facilities in other countries? • What level of ambition would be appropriate? Should we adopt the technically achievable, economically justifiable efficiency level in one go or multiple steps?

2.1 MEPS – Minimum Energy Performance Standards

This chapter introduces MEPS as a key policy instrument to improve the energy performance of new electric motors and motor systems sold in a country. It offers practical guidance on the process and ways to harmonise standards and MEPS with trading partners and neighbouring countries.

A part of the energy-saving potential in a motor system comes from improving the energy efficiency of the individual components, and another part comes from optimising the system's efficiency. For this reason, MEPS regulations have evolved towards a larger 'system border', including the motor, the VSD, and the driven equipment. However, a regulation that covers the efficiency of a complete system is more challenging, as the full system is composed of more components e.g., piping and throttles, and is built at the end user's premises. As a result, the total savings potential of systems cannot be addressed by MEPS alone, and these need to be complemented by other supporting policies.

Test standards and efficiency metrics

The International Electrotechnical Commission (IEC) provides testing standards and standards for the energy performance metrics and classification of electric motors and variable speed drives, whereas the International Organization for Standardization (ISO) and some other industry organizations provide such standards for driven equipment such as pumps, fans, and air compressors.

MEPS

MEPS are a widely used policy instrument that work to improve the energy performance of new products of a given type sold in an economy by defining the minimum performance criteria that these must meet. While MEPS for electric motors go back to the mid-1990s (United States of America), these have evolved to define the minimum energy performance of electric motor systems, also termed as the 'extended product,' and the accompanying standards defining the metrics have evolved alongside.

Developing economies and emerging markets can profit from this international experience and 'jump start' to a suitably ambitious starting minimum energy performance threshold appropriate to their national/regional needs and the global marketplace.

Figure 5 provides an overview of IEC/ISO testing and efficiency classification standards, as well as efficiency metrics currently used in MEPS regulations for electric motors and systems in the three central economic regions of the world. The availability and use of these global standards and metrics benefit any country aiming to introduce MEPS regulations. Since the international marketplace is fairly accustomed to these standards, the availability of energy-efficient products and systems that comply with these standards and metrics is assured. Further, the prevailing MEPS regulations in these three regions can also serve as an international model.

Component	Scope	Testing Standard	Efficiency Classification Standard				Performance Requirement
				efficiency metric	P [I]	EP [I]	Mandatory MEPS [II]
Motor	3-phase induction motors (Low Voltage < 1'000 V)	IEC 60034-2-1 IEC 60034-2-3	IEC 60034-30-1 IEC TS 60034-30-2	IE, International Energy efficiency class	x		50+ countries (incl. EU)
Converter	Variable Frequency Converter (VFC, VSD)	IEC 61800-9-2	IEC 61800-9-2	IE, International Energy efficiency class	x		EU
Pump	Rotodynamic water pump	ISO 9906	EU: EN 16480 EU: EN17038-1,-2,-3,-4 US: p431, subpart Y *) CN: GB19762	MEI, Minimum Efficiency Index EEI, Energy Efficiency Index PEI, Pump Efficiency Index EI, Efficiency Index	x x	 x x 	EU **) EU **) USA China
Fans	Industrial	ISO 5801 ISO 13350	ISO 13349 ISO 12759-1, -2 ISO 12759-3 ISO 12759-4 ISO 12759-5 ISO 12759-6	*Vocabulary and definitions* *General information; standard losses* FEG, Fan Efficiency Grade FMEG, Fan Motor Efficiency Grade JFMEG, Jet Fan Motor Eff. Grade FEI, Fan Efficiency Index	 x 	 x x	 China EU **) EU **) USA ***)
Air compressor	Compressor package	ISO 1217, Am. 1:2016	CN: GB 19513 US: p431, subpart T *)	Compressor efficiency grade Isentropic efficiency		x x	China USA

I) P = product, EP = extended product (motor, control, transmission, pump/fan/compressor)
II) MEPS = Minimum Energy Performance Standard (set as requirement by regulators)

*) see eCFR.gov for definitions, test standard and efficiency requirements
**) MEPS under revision
***) MEPS under development

Source: EMSA 05.2024

EU = European Union
USA = United States of America

Figure 5: Testing standards, energy efficiency metrics and MEPS for electric motor systems

MEPS for electric motors have been implemented by fifty-six countries (see Figure 6). Additionally, countries like China, the European Union, the United States of America, Canada, Mexico, Republic of Korea, India, and Australia have MEPS in place covering (a selection of) fans, pumps, and/or air compressors. The experience of these countries shows that mandatory MEPS is the most effective instrument for transforming the market for new equipment to higher efficiencies. These policies prevent inefficient equipment (those that do not meet MEPS) from entering the marketplace, thus increasing average efficiency over time.

Process of setting MEPS

Each country will have national specific statutory criteria defining the process of developing and setting MEPS for energy-using products and equipment. The overarching main criterion will be to achieve the maximum possible improvement in energy efficiency that the responsible authority determines as technologically feasible and economically justified. The level of MEPS may also affect the local manufacturing industry if significant in size, and the protection of jobs and investments becomes important as well. Depending on the state of preparedness of the manufacturing industry, a gradual transition may be needed to allow for adaptation. The main applicable criteria for setting MEPS are:

- The economic impact on manufacturers, suppliers, and consumers;
- The savings in operating costs throughout the estimated average life of the covered products;
- The total projected energy savings;
- Any lessening of the utility or the performance of the covered products;
- Any lessening of competition likely to result from the MEPS;
- The need for national energy and water conservation;
- Any additional criterion as deemed relevant by government e.g., criteria for material resources and circularity and the like.

Section 2.3 describes the process of establishing regulatory requirements through MEPS in more detail.

This section elaborates on the recommended scope of coverage by MEPS for each component of a motor system, as further described in detail in the U4E Model Regulation Guidelines Part II.

Scope of MEPS

2.1.1 Scope - Electric Motors

Most of the 56 countries that currently have MEPS for electric motors cover the range of 0.75-375 kW at IE3-level. The 27 European Union countries and China cover an extended range of 0.12-1000 kW, and the United States of America has recently[16] enlarged the range to 0.18-559 kW (0.25-750 hp). Figure 7 gives an overview of the adaptation of MEPS for electric motors worldwide.

16 Compliance per due 1-6-2027.

The The 27 European Union countries, Norway, Switzerland, Türkiye, and the United Kingdom have adopted the higher IE4-level for the 75-200 kW range. From 1 June 2027, motors in the United States of America between 100-250 hp (75-186 kW) are required to meet IE4 as well. With these regulatory requirements, the European Union and the United States of America are the first jurisdictions in the world to require IE4 for certain electric motors in a similar power range.

Some countries have less stringent MEPS at the IE2-level, with India and Ghana covering an extended range of 0.12-1000 kW, Australia and New Zealand 0.73-185 kW, Ecuador 0.73-375 kW, and Chile 0.75-7.5 kW. A few have MEPS at IE1 defined by the state of preparedness of their respective domestic motor manufacturing industries. Figure 7 specifies the MEPS details per country/region.

An economic and environmental impact analysis provides the basis for determining the scope and level of electric motor regulations. It is important to remember that electric motors smaller than 0.75 kW are more numerous than those more significant than 375 kW. These smaller motors have lower efficiencies (compared with larger motors) and consume less electricity at an aggregate level. Small motors, especially single-phase motors, are often operated intermittently in domestic appliances such as washing machines. Medium-sized and large motors, on the other hand, are significant electricity user due to their size (kW) and higher average yearly operating hours. However, they are inherently more efficient, and the overall energy savings potential is enormous (in kWh/year). With these market characteristics, most countries have begun regulating the efficiency of medium-sized induction electric motors between 0.75 kW – and 375 kW, thus presenting an optimal economic balance to reduce overall electricity consumption.

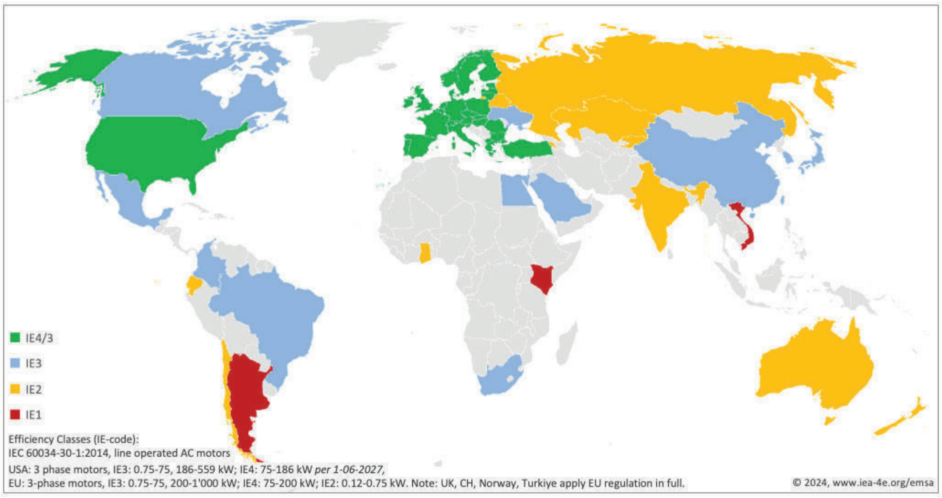


Figure 6: Overview of MEPS with IE-levels for electric motors worldwide

U4E recommends the following MEPS-level options depending on national circumstances. After evaluating all technical, environmental, and economic aspects and the availability of products in the market, Advanced Level (A) based on the best practices adopted by the European Union and the United States of America is recommended.

- **Advanced Level (A), with the broadest coverage of motor types and sizes**
  Offers a regulatory framework designed to leapfrog directly to the advanced best practice level in line with current international best practice regulations. This is suitable for countries that either do not have a significant domestic motor manufacturing industry or already have MEPS for motors covering a narrower scope and/or at a lower efficiency level and are ready to adopt the advanced level:

    - IE2 efficiency class for three-phase motors in the range of smaller 0.12 - 0.75 kW motors; single-phase motors rated above 0.12 kW; and an Ex eb motors for explosive atmospheres of 0.12 – 1,000 kW;

    - IE4 efficiency class for a three-phase motors of 75 - 200 kW, which are not brake motors, Ex eb increased safety motors, or other explosion-protected motors;

    - IE3 efficiency class for all other three-phase motors of 0.75 – 1,000 kW.

- **Bridging Starting Level (B), at IE3-level**
  Countries with a significant domestic motor manufacturing industry can choose to start at IE3-level "premium energy-efficiency", for a basic range of 0.75 – 1,000 kW17 for three-phase motors.

- **Bridging Starting Level (C), with limited time at IE2-level and transitioning to IE3-level**
  Countries that do have a significant domestic motor manufacturing industry can alternatively choose a more gradual transition by starting at IE2-level "high energy-efficiency", for a basic range of 0.75 – 1,000 kW for three -phase motors, to provide themselves with (limited) transitory time for upgrading technology with the objective of transitioning in steps to Level B and Level A eventually.

17 The recommended upper limit of the power range in the Bridging Starting Levels (B) and (C) is higher than that adopted by countries in the past (0.75-375 kW) as energy-efficient motors up to 1,000 kW are becoming increasingly available as a consequence of international best practise regulations.

Efficiency Levels 3-phase induction motors (Low Voltage < 1000 V)	Efficiency classification IEC 60034-30-1;2014 **IE efficiency class** [I]	Minimum Energy Performance Standard Mandatory MEPS [II] **Country / Region**	 Range [kW]	 Note	No. of phases 1	 3
Super Premium Efficiency	**IE4**	EU 27	75 - 200	b)		x
		UK, Switzerland, Norway, Turkye	75 - 200	b)		x
		USA, per 06.2027	75-186			x
Premium Efficiency	**IE3**	Brazil	0.12 - 370			x
		Canada	0.75 - 375			x
		China *)	0.12 - 1000			x
		Colombia *)	7.5 - 375			x
		EU 27 *)	0.75-75;200-1000			x
		UK, Switzerland, Norway, Turkye *)	0.75-75;200-1000			x
		Egypt	0.75 - 375			x
		Israel *)	7.5 - 375			x
		Japan	0.75 - 375			x
		Mexico	0.75 - 375			x
		Saudi Arabia	0.75 - 375			x
		Singapore	0.75 - 375			x
		South Africa	0.75 - 375			x
		South Korea	0.75 - 375			x
		Taiwan	0.75 - 200			x
		Ukraine *)	0.75 - 375			x
		USA *)	0.18/'0.75 - 375	a)	x	x
		USA, per 06.2027	0.75-75;186-559			
High Efficiency	**IE2**	Australia	0.73 - 185			x
		Chile	0.75 - 7.5			x
		Colombia	0.18 - 0.74			x
		Ecuador	0.75 - 375			x
		EU 27, UK, CH, NO, TR	0.12 - 0.75			x
		EU 27, UK, CH, NO, TR	0.12 - 1000		x	
		Ghana	0.12 - 1000			x
		India	0.12 - 1000			x
		Israel	0.75 - 5.5			x
		New Zealand	0.73 - 185			x
		Armenia, Belarus, Kazakhstan, Kyrgyzstan, Russia (EAEU)	0.75 - 375			x
		USA	0.18 - 2.2	a)	x	
Standard Efficiency	**IE1**	China	0.25 - 3.7		x	
		Vietnam	0.75 - 150			x
		Peru	0.75 - 375			x
		Argentina	0.75 - 30			x

I) Output power: 0.12 kW - 1000 kW, 50 and 60 Hz, line operated, 2-, 4-, 6- and 8-poles.
II) MEPS = Minimum Energy Performance Standard (set as requirement by regulators)
*) IE2 for some motor types
a) 0.18 - 2.2 kW, polyphase:
b) VSD: IE2 efficiency class, IEC

Figure 7: Scope of coverage and levels of MEPS for electric motors worldwide (IEA 4E EMSA)

The U4E Model Regulation Guidelines cover motors that:are single-speed, induction motors

- operate on a three-phase alternating current sinusoidal voltage supply [where Option A includes single-phase motors as well]
- have a 2-, 4-, 6-, or 8-pole configuration
- have a rated frequency of 50 Hz or 60 Hz; or 50/60
- have a rated voltage of 50 volts and above, up to and including 1,000 volts;
- are rated for continuous duty.

More comprehensive criteria for inclusion in the scope of coverage and for exclusion from the scope are specified in the Model Regulation Guidelines Part II.

Cost Effectiveness of U4e Recommendations

According to an analysis by CLASP, the Starting Level (A) is cost-effective on a lifecycle basis in most of the world, using US motor price and efficiency data and international electricity prices data. On the other hand, starting levels (B) and (C) are cost-effective in only a handful of countries with subsidised electricity prices and/or high interest rates. However, U4E recognises that cost-effectiveness cannot be the sole consideration when setting MEPS. Governments in emerging markets and developing countries with significant local manufacturing of motors should also consider local industry, employment, and investments, and a balance must be struck for a transitional period (see section 2.3 – processes to establish MEPS).

The same CLASP study also concludes that MEPS at IE5 is cost-effective in only a few island nations with extremely high electricity prices. This is one of the reasons U4E does not recommend MEPS for motors at IE5 at present.

Ref: Global Motors Life-cycle Cost (LCC) Analysis, CLASP 2024

Success of the European Union MEPS for Motors

The European Union market for motors has been pushed continuously by MEPS towards higher efficiency motors, as seen in the accompanying chart (Figure 8). According to market data from CEMEP, IE1, and IE2 motors have been gradually outpaced by IE3 motors between 2015 and 2022, and the trend is continuing.

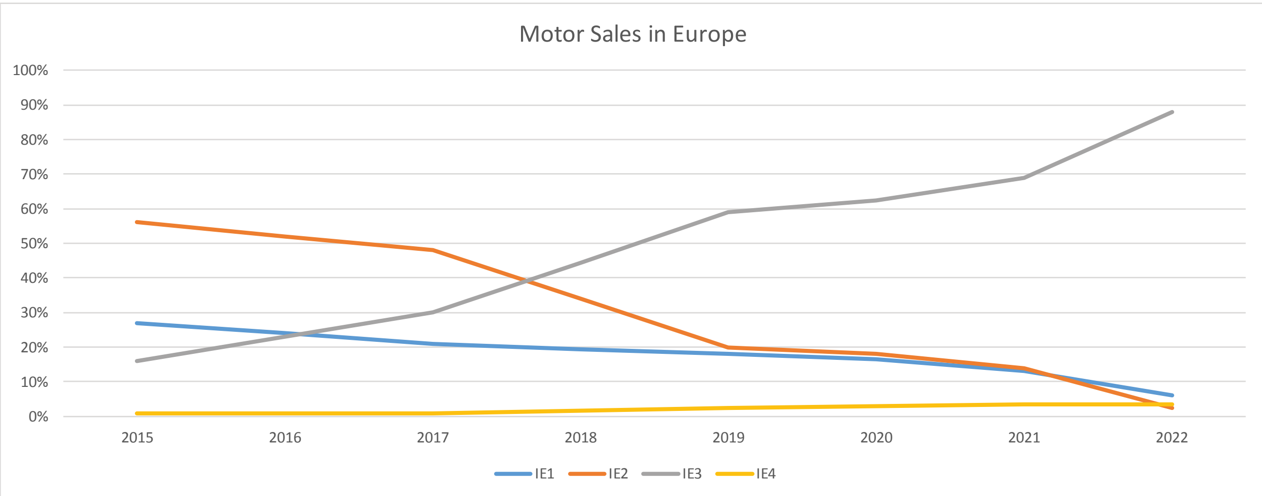


Figure 8: Example of European motor market transformation through regulations[18]

18 Source: CEMEP LV motors industry group, Oct 2023, for 3-phase motors, 0.75 – 375 kW, 2, 4 and 6 poles.

2.1.2 Scope - Variable Drives

Using a variable speed drive (VSD) can significantly enhance the energy performance of a motor system, particularly in applications that require variable outputs (e.g., variable rate of airflow), such as HVAC systems, industrial processes, and wastewater treatment. By eliminating inefficient mechanical components like throttles and dampers, a VSD can optimize system efficiency. Although a VSD introduces its energy losses and additional motor losses due to harmonics, it offers a new degree of freedom to the system design, which can lead to reduced energy consumption. For instance, if the motor operates at speeds below the rated operating point for specific periods, a VSD can improve the overall system energy performance by up to 40 per cent.

Even in constant load applications, VSDs can be beneficial due to factors such as motor oversizing, difference between design and actual load, potential process modifications over time, etc. Therefore, the decision to use a VSD should be made on a case-by-case basis, considering these factors.

Component regulations can only cover the energy performance of VSDs as a standalone component. However, in specific applications where a clear case exists, regulations could require a VSD. System regulations, which cover a set of components including a motor and a driven application, should set overall system requirements. In some cases, these requirements may only be met by incorporating a VSD. It is important to note that certain types of electric motors, such as Permanent Magnets and synchronous Reluctance, require a VSD to operate.

Energy Efficiency metrics for VSDs (IE codes) are defined in IEC 61800-9-2 (see section 11.2 of the Technical Annex). At present, the European Union is the only region to regulate the energy performance of VSDs at IE2 levels via its Ecodesign Regulation EC 2019/1781:

U4E recommends MEPS at IE2 levels for VSDs with a 3-phase AC input that:

1. are rated for operating a motor with a rated output between 0.12 kW-1 000 kW (equivalent VSD rating 0.278 kVA – 1209 kVA);
2. and have a rated input voltage between 100 V - 1 000 V AC;
3. and have only one AC voltage output.

2.1.3 Scope - Fans

The market for fans encompasses a wide variety of design, size, and application. As outlined below, the level of international harmonisation of product definitions, energy performance metrics, testing standards, and energy performance regulations for fans is more differentiated than in the case of electric motors and VSDs.[19]

- **China** regulates range hoods, household and ceiling fans (all residential use), as ID-fans for industrial steam boilers, IF- and ID- fans for power station boilers, and centrifugal blowers[20] (all for industrial use).

19 For a comprehensive coverage of the subject, refer EMSA publications “Policy Guidelines for Motor Driven Units”, parts I & II.
20 Industrial fans: China: GB 19761-2020, GB 28381-2012; EU: EC 327/2011;.

- The **United States of America** regulates large and residential ceiling fans and residential furnace fans and has established a mandatory test procedure for general fans and blowers with ≥890 W electrical power but <112 kW air power[21].

- The **European Union** regulates comfort fans below 125W, ventilation units (residential and non-residential), and 'fans driven by motors with an electrical input power between 125 W and 500 kW used in multiple sectors'[22].

- **Ghana and Iran** regulate industrial fans[23]

- *Ceiling fans* are regulated through MEPS in Brazil, China, Cuba, Ghana, India, Malaysia, Mexico, Sri Lanka, United States of America, and Viet Nam.

- *Other residential fan types* are regulated through MEPS in Egypt, Russian Federation, Mexico, Malaysia, Jordan, Ghana, Republic of Korea, Indonesia, Viet Nam.

Considering these diverse regulatory frameworks, the scope of coverage in MEPS regulations should be carefully evaluated based on the national market, economic and environmental impact, and the availability of established regulatory models and experiences in other countries.

The U4E Model Regulation Guidelines for electric motor systems (Supplement) cover small to large industrial fans that: are designed for use with or equipped with an electrical motor with an electric input power between 125 W and 500 kW.[24]

21 United States of America: the proposed Fans MEPS have been documented but negotiations are still ongoing, see: www.federalregister.gov/d/2023-28976/p-1

22 EU EC 327/2011

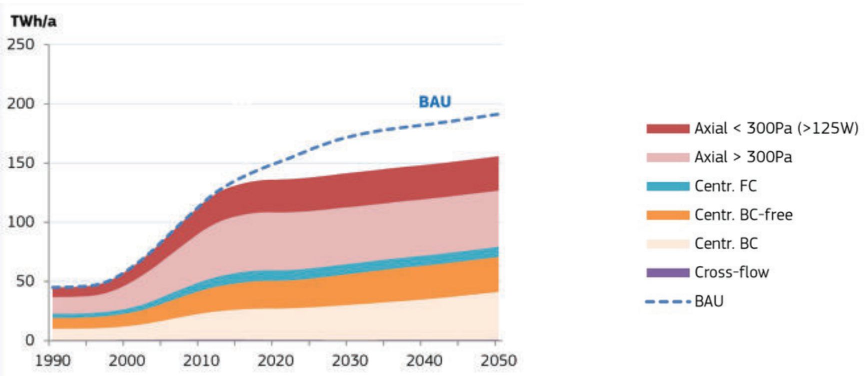
23 Ghana: LI 2444; Iran: ISIRI 10634

24 U4E regulation additionally covering ceiling fans are under preparation.

Energy savings by MEPS Fans Regulation 327/2011 in the European Union (estimation)

The European Union Ecodesign Impact Accounting Overview Report 2023 shows the following results for the MEPS for Fans in the European Union: in 2010, fans in the scope of the regulation consumed 230 TWh/a of electricity. Without measures, the consumption was expected to increase to 300 TWh/a in 2020 and 345 TWh/a in 2030. Due to the measures, it can be reduced to 272 TWh/a (-9 per cent) in 2020 and 284 TWh/a (-18 per cent) in 2030, link to report.

Almost half of the 2030 savings come from improvements on axial fans. Another 35 per cent comes from centrifugal backward curved fans, 11 per cent from centrifugal forward curved fans, and 4 per cent from cross-flow fans.



The MEPS define the 'target energy efficiency' at the fan's best efficiency point and includes efficiency grades (N) for five different fan types i.e.,

- axial fans,
- centrifugal fans,
- cross flow fans,
- mixed flow fans, and
- jet fans

between 125 W and 500 kW, see Figure 9. The overall efficiency of an industrial fan needs to be equal to or greater than the target energy efficiency value as specified for each fan type; see the Model Regulation Guidelines for the related specific formulas for the target efficiency, measurement category, and power range. The applied metric, the Fan Motor Efficiency Grade (FMEG), is described in detail in section 11.3 of the Technical Annex.

Fan type	Measurement category	Efficiency category (pressure)	Minimum efficiency grades (N) Tier 1	Minimum efficiency grades (N) Tier 2
Axial fans	A,C	static	40	50
	B, D	total	58	64
Forward curved <5 kW and backward inclined centrifugal fans	A, C	static	44	52
	B, D	total	49	57
Other centrifugal fans	A, C	static	61	64
	B, D	total	64	67
Mixed flow fans	A, C	static	50	57+7*(α-45)/25
	B, D	total	62	67
Jet fans	E	total	-	50

Figure 9: Minimum energy efficiency requirements for fans for different fan types

The Model Regulation Guidelines recommend two tier levels, with countries able to start directly at the current advanced level. The efficiency grades N range are at the 'premium level' and include information requirements on partial load. The bridging starting level offers a lower tier level to provide domestic manufacturers a (limited) transitory time for upgrading technology. The related minimum fan energy efficiencies are between 5 to 25 per cent lower than those on the advanced level (the exact percentage depends on the fan type and power).

2.1.4 Scope – Rotodynamic Pumps (Clean Water)

As in the case of fans, there is a wide range of pumps in the market in terms of design, size, and application, and the international alignment of product definitions, energy efficiency metrics, testing standards, and energy performance regulations for clean water pumps is more differentiated compared with electric motors. China, the United States of America, and the European Union regulate clean water pumps25; however, the scope varies. The United States of America MEPS applies to pumps sold bare or with a motor or with a motor and VSD; the European Union MEPS applies to the bare pump but will be extended to include requirements for the pump unit (i.e., pump, VSD and motor), while the Chinese MEPS apply to the bare pump only (early 2024). The energy performance metrics vary across regions as well.

The U4E Model Regulations for electric motor systems (II) cover rotodynamic water pumps of the following types:

1. End suction own bearing (ESOB),

b. End suction close coupled (ESCC),

c. End suction close coupled inline (ESCCi),

d. Vertical multistage (MS-V),

e. Horizontal Multistage (MS-H),

f. Submersible multistage (MSS),

g. Booster sets (BS).

25 China: GB 19762-2007; USA: 10 CFR 431, Subpart Y; EU: EC 547/2012

The metrics used in the U4E model regulations are the MEI (Minimum Efficiency Index) and the EEI (Energy Efficiency Index). The MEI is a dimensionless indicator for hydraulic performance and a measure of the quality of the pump's sizing in relation to performance. The higher the MEI value, the better the pump's sizing in relation to performance, and the lower the annual energy consumption due to the pump's use. The EEI is a dimensionless indicator of the average pump unit electric power input compared to a reference. The lower the EEI value, the better the pump unit's energy performance and the lower the annual energy consumption due to pump use.

The Model Regulation Guidelines define two tier levels, where countries can choose to directly start at the current advanced level, with MEI = 0.4 for water pumps, and an EEI =< 0.62 for ESOB, ESCC and ESCCi end suction water pump units up to 45 kW shaft power, and for booster sets an Energy Efficiency Index of not more than 0.5. The regulatory framework offers a lower tier level of MEI = 0.1, as an optional bridging level to provide domestic manufacturers a (limited) transitory time for upgrading technology. These requirements exclude the booster sets.

The benchmark value i.e., a pump considered to have the best possible pump design, is MEI = 0.7 (the metric is described in detail in section 11.4 of the Technical Annex).

2.1.5 Scope – Air Compressors

MEPS for air compressors are in place in the United States of America and China[26], whereas the European Union is not planning to adopt such a regulation in the foreseeable future[27]. Compressors used in refrigeration and air-conditioning are not covered as a standalone product but get covered indirectly through MEPS for 'fridges and freezers'[28] (European Union) and air-conditioners[29] (European Union) respectively.

The regulations cover the lubricated rotary air compressors as a main air compressor segment. The Chinese regulation is more comprehensive as it includes reciprocating piston air compressors, lubricated and oil-free models. Further differences exist in the specified operating pressure range, the nominal motor power range, and the flow rates. These MEPS covering air compressors are special in the sense that they cover a system: 'standard air compressor package' that consists of an electric motor, a compressor, a control, and other auxiliaries.

The scope in the U4E Model Regulation Guidelines for standard air compressor packages is rotary standard air compressor packages with a maximum volume flow rate of between 5 to 1280 l/s when supplying air at discharge pressure(s) equal to or higher than 7 bar(a) and not exceeding 15 bar(a).

The applied energy performance metric is 'Isentropic Efficiency', where the regulation specifies that the isentropic efficiency shall be equal to or exceed the corresponding calculated target efficiency. The calculation needs to be made based on the same maximum volume flow rate specified for that same discharge pressure and a proportional loss factor value of d. The recommended MEPS tier-level is expressed in the proportional loss factor d.

The Model Regulation Guidelines recommend two tier levels, where countries can choose to start directly at the current advanced level, i.e., with a proportional loss factor value of d = -10.

26 United States of America MEPS: 10 CFR 431, Subpart T; China MEPS: GB 19153-2019
27 In 2014/2019 two Ecodesign preparatory studies on 1) low pressure and oil-free compressor packages, and 2) lubricated/oil-injected ('standard air') compressor packages, have been carried out; two draft Ecodesign regulations (working documents) were elaborated.
28 EC 643/2009, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R2019
29 EC 206/2012, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0206&from=EN

The regulatory framework offers a lower tier level with a proportional loss factor value of d = -15 as an optional bridging level to provide domestic manufacturers with a (limited) transitory time to upgrade technology towards the next tier level.

2.1.6 Product Information

The regulations mandate additionally that manufacturers and importers display information about the energy performance of the motor system components in a prominent way on

a. the technical data sheet or user manual supplied with the product;

b. the technical documentation for conformity assessment;

c. free access to websites of the manufacturer, its authorised representative, or the importer; and

d. the technical data sheet is supplied with products for which the component is incorporated.

For example, in the case of an electric motor, the information about energy efficiency comprises 1) the energy efficiency class e.g., IE3 or IE4; 2) the rated efficiency at 100 per cent, 75 per cent and 50 per cent rated load and voltage; and 3) the power losses expressed in percentage (%) of the rated output power at seven additional operating points defined by speed versus torque e.g. (50 per cent speed; 25 per cent torque) (50 per cent speed; 50 per cent torque). Nameplate information requirements are specified as well.

Similar information on performance part load/speed operation may also be helpful for other motor system components such as VSDs, fans, water pumps, and air compressors.

The Model Regulations Guidelines provide further details for each product. This information helps motor system designers and operators optimise system design and operation to minimise energy usage.

2.1.7 Labelling Regulations

In defining labelling requirements, a clear distinction can be made between the technical information on the product itself i.e., marking the information on a nameplate like the rated efficiencies and efficiency level (in case of a motor), and the information to be displayed in marketing and communication materials and documentation.

For the latter purposes, special labelling schemes can be developed. The labels display information about products' energy efficiency so that purchasers can better distinguish between products, which helps pull more efficient products into the market.

Efficiency labels work differently for products purchased by consumers and by businesses. Consumer products are mainly purchased by lay people in physical or online stores. Simple, appealing, and visually communicative labels can influence their choices.

However, motor systems are typically purchased by technically adept businesses using procurement specifications via impersonal channels and often in bulk quantities. The emotional and visual elements of the labels are less important than the technical information. Driven by competitive pressures, industry practices, and regulatory requirements, manufacturers and importers generally provide information about the energy performance of their equipment on websites, in product datasheets and other documentation.

In the example of electric motors, most countries use the IEC efficiency level (IE-level) in their communications. However, some countries have designed a labelling scheme to accommodate national needs e.g., China, India, and Kenya, see Figure 10. Of the 56 countries having MEPS for motor systems in place a total of 13 countries has a labelling scheme for electric motors and some countries have it for air compressors and VSDs (China), and refrigerant compressors (Iran). The China Energy Label (CEL) requires registration and separate labelling for electric motors from Grade 3 (eq. IE3) up to Grade 1 (eq. IE5). Ghana has a star-rating scheme for motors in place; see the case study.

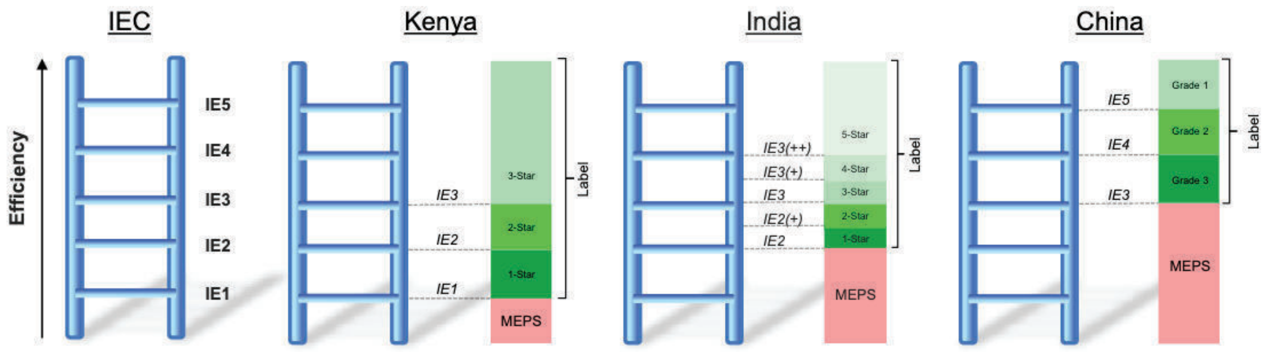


Figure 10: Example of labelling for electric motors in Kenya, India and China[30]

While comparing energy efficiency classes across countries, it should be noted that even though the numerical value of EE classes may be the same, the implementation and acceptance criteria need not to be different.

CASE STUDY: Motor Labelling – Ghana

Ghana has mandated that printed energy performance labels made of waterproof material in a prescribed format should be conspicuously placed in the terminal box and affixed to the packaging of electric motors manufactured, imported, or sold in the country. The labels may not be removed till the first retail purchase by an end-user. The labels show an energy rating from 1-Star to 5-star, within the International Efficiency (IE) classification levels, where 1-star = IE1, 2-star = IE1> ** <IE2, 3-star = IE2> *** <IE3, 4-star = IE3> **** <IE4 and 5-star = >IE4. The label should be placed on the back of the electric motor and on the packaging containing the electric motor.

See: Electric Motors regulations 2022.pdf (energycom.gov.gh)

30 Dr. Kevin Lane, IEA, 2021, Introduction to SEAD and the Product Efficiency Ladder Approach for Lighting and Cooling [Conference Proceedings, SEAD Regional Workshop for East Africa – Round table discussion focussed on Lighting and Cooling]

CASE STUDY: Energy Efficiency Labelling of Electric Motors in Brazil

The National Institute of Metrology, Quality and Technology (INMETRO) has mandated an energy efficiency labelling program for electric motors and centrifugal pumps. The program classifies electric motors from A (most efficient) to G (least efficient) and requires manufacturers and importers to display the energy efficiency label on the motor or its packaging. The label also informs the nominal power, voltage, frequency, efficiency, and annual energy consumption of the motor.

CASE STUDY: Motor Labelling – Pakistan

Pakistan introduced MEPS and labels for refurbished second hand motors in 2021. Starting as a voluntary programme, it will eventually transition to compulsory registration and IE3 minimum performance requirements in 2023.

[The Clean Energy Ministerial established the Super-Efficient Equipment and Appliance Deployment]

2.2 Green public procurement regulations

Green public procurement refers to integrating sustainable public procurement criteria and international regulatory, social, and environmental best practices in the day-to-day purchasing activities of Government and public sector organizations.

Green Public Procurement (GPP) can help to transform markets by leveraging the power of public purchases to drive markets towards sustainability, reducing governments 'environmental footprint and contributing significantly to reductions in greenhouse gas emissions.

Sustainable public procurement also allows governments to serve as an exemplary model and send strong market signals, fostering private sector and consumer behaviour change, and enabling the overall transition to a green, sustainable economy.

U4E provides a toolkit for economic and environmental analysis and overall recommendations for the tendering process for countries to develop their requirements for tendering processes to procure only higher energy efficiency products[31] e.g., for air conditioners, lighting, distribution transformers, refrigeration appliances (Note: electric motors are not covered yet).

2.3 Processes to establish regulatory requirements through meps

MEPS need to be developed methodically and transparently with the support and participation of representatives from the supply chain, end users, power utilities, public institutions, civil society, and the public. It is important that these key stakeholders are consulted and that their interests are addressed so that they understand and support the policy when it becomes effective.

31 The U4E Green Public Procurement Guidelines are a supplement to the U4E Model Regulation Guidelines and other already available international tools, standards, and reports from the U4E portfolio.

This is usually a multi-year to develop, review and finalize MEPS (incorporating data collection, analysis and stakeholder engagement). The selected MEPS and the pace of implementation must be fair to both manufacturers and users, not cause economic disruptions or distortions, and balance national objectives of energy and CO2 savings with net economic benefits. A systematic approach is outlined below:

1. Establish a legal and institutional framework for mandatory MEPS (see the example of the European Union MEErp methodology).

2. Survey the technical standards being followed by manufacturers and importers, particularly for efficiency testing and classification. If national or regional standards are followed, are these harmonised with the international standards described in Section 2.1? If diverse standards are being followed, encourage alignment with international standards and ensure that the interpretation and implementation of the standard is correct.

3. Collate country-specific market baseline data (e.g., on equipment sales, trends, prices, origin of the products, performance) with the help of industry associations and trade data, or through independent research organizations. For example:

    a. Annual sales by type and average price

    b. Which of these are manufactured in-country, and which are imported?

    c. How many are imported as a part of motor systems?

    d. Who are the main manufacturers and import sources?

    e. How many are purchased by end users and equipment manufacturers, respectively?

    f. What are the historical market trends?

4. With the help of leading manufacturers, industry associations, consumer groups, and NGOs, determine the reasonable cost levels of products of different efficiency levels by type and size range.

5. Collate information on the electricity tariff(s) and carbon emission factor(s), current, historical, and projected. Some sources of information are the electricity regulator, power utilities, IEA (www.iea.org), and Enerdata (www.enerdata.net).

6. Establish a baseline - it is also important to collect data on how the product is being used. For example, in the case of motors, the information to be collected should include average load factor, operating hours, lifetime, and efficiency. When possible, this information should be collected for different power ranges and sectors.

7. Once the baseline is established, scenarios should be developed for the energy, economic, and environmental impact if MEPS are set at various levels. The scenarios should address questions such as:

    a. How much energy and CO_2 emissions would be saved at the national level and what would be the overall environmental impact?

b. What incremental upfront costs would users have to bear for higher efficiency?

c. How much would the users save in energy costs each year?

d. How many years would it take for the upfront investment to be paid back? This will provide the economically justified level of MEPS.

e. What are the other benefits for the wider society (environmental benefits, jobs created).

8. Consult with manufacturers on the implications of MEPS at each of these levels. Consider how to address (and advocate eliminating) the market-distorting effects of energy subsidies or taxation on higher-efficiency equipment, if any. Be prepared for various responses, as some will resist any regulation while others see an opportunity for brand building and gaining a competitive advantage. Inadequate access to technology and finance are legitimate constraints that may be considered as well. The regulation should uphold the competitiveness of domestic industry, reduce employment potential, favour one manufacturer over another, or drive anyone out of business without having been given adequate but limited time and support for adjustment. Through these consultations, it should be determined how much time and investment would be required by the domestic manufacturing industry to adjust to a given MEPS level.

9. Gather perspectives from the other key stakeholders. Policymakers have the difficult but critical task of making well-informed decisions that account for competitiveness, employment, environmental impact, energy security, energy bills, timeframe (e.g., keep in mind institutional and supply chain constraints), and other concerns.

10. Set an appropriate MEPS level. As an orientation, the MEPS level should correspond to the "Least Life Cycle Cost" (LLCC) level. Levels set will vary amongst countries based on local circumstances. The U4E Model Regulation Guidelines provide a template to benchmark with policies in place in other countries.

11. Build Monitoring, Verification and Enforcement (MVE) capacity to ensure the success of MEPS. It may be better to delay MEPS rather than promulgate it without strong effective MVE capabilities in place – see next chapter 3 on MVE.

12. Limit the scope of exempted products so that the MEPS coverage is as comprehensive as possible and the maximum energy savings are achieved.

13. Consider whether test reports by manufacturers own certified test laboratories are acceptable. In the case of large global manufacturers, the laboratories are often capable of testing products e.g., motors for the entire power range whereas there are not many external test laboratories with similar capabilities globally.

14. Minimise the burden registration requirements place on manufacturers and importers.

Based on the above, the technically feasible and economically justifiable MEPS level and the timeframe for adoption should be possible to conclude. The U4E model regulation guidelines provide ready templates. Once established, MEPS programmes should be monitored, evaluated, updated, and revised every few years to ensure they remain appropriate and relevant.

Example: European Union Methodology for ecodesign of energy-related products

The Methodology for Ecodesign of Energy-related Products (MEErP, part of the framework of the Ecodesign Directive (2009/125/EC) is used to identify policy options for reducing the environmental impacts of Energy-related Products (ErP) in Europe. The MEErP was published in 2005, is reviewed in 2011, and again in 2020-2022, and has been used in more than 40 preparatory studies for Ecodesign of ErP. The objective of this methodology is to support the implementation of any ecodesign requirements. The most important part of the analysis takes place within the techno-economic assessment, at the point when the life cycle cost curve is determined, and the Least Life Cycle Cost (LLCC henceforth) is defined.
Link: Methodology for ecodesign of energy-related products (MEErP 2011) - Publications Office of the European Union)

Example: Development of MEPS for electric motors in Egypt

Egypt has adopted Motor MEPS at IE3 from May 2022 (Decree 463 of 2020) after a five-year developmental effort that involved the following steps:

- establishing political and organizational leadership through institutional analysis and engagement.
- establishing national technical standards harmonised with international standards.
- devising an implementation timeline that was acceptable to stakeholders.
- consulting with the private sector, understanding needs, perceptions (or misperceptions), raising awareness and building consensus.
- planning for effective market surveillance including a new test lab and building capacity of market inspection authorities.
- helping upgrade equipment supply chains to deliver and assimilate better motors.

The Ministry of Trade and Industry has received support from the International Finance Corporation who has partnered with local and international technical experts i.e., US based consultancy E3 International, Cairo University's Energy Research Centre (ERC), the Lawrence Berkeley National Laboratory (LBNL), Ecofys, Chemonics Egypt and Waide Strategic Efficiency Ltd to develop the MEPS.

Projected savings in Egypt are US$560 million NPV from the 2016 base to 2031, 3 TWh saved annually, with avoided investment in 1,100 MW of new power generating capacity.

[Tait, J. et.al. Egypt Mandates IE3 Energy Efficiency Standards for Electric Motors, see link to storymap

The benefits of well-implemented MEPS vary by stakeholder, but generally include:

- Efficiency levels are technically achievable and cost-effective for consumers;
- The mandatory nature (coupled with robust monitoring, verification, and enforcement) provides a high degree of certainty that energy savings are achievable and sustainable;
- There is a minimal impact on governmental finances (unlike equipment incentives and subsidies that are intended to lower the burden of procurement costs on their constituents;)
- Manufacturers (motors, VSDs, pumps, fans, compressors), end-users, and retailers of market demand receive clear signs for efficient products;
- Manufacturers and sellers of quality products have an opportunity to gain market share;
- Incentives for product innovation;
- The average performance of products available for sale is improved;
- Manufacturers gain access to additional markets where equivalent MEPS are in place;
- MEPS can be easily adjusted iteratively as the market and electric motors technology evolve;
- MEPS maximises consumer benefits at minimum per unit transaction costs.

In general, the evolution of the market for new equipment after the introduction of MEPS is rather gradual and the average efficiency of the installed stock increases progressively over time.

2.4 Harmonisation of standards and regulations

If MEPS are to be adopted in a country or regional market, stakeholders should consider whether to harmonise with existing motor MEPS regulations in their region[32] or with those of a large trading partner. If one country in a trading region chooses to adopt MEPS that are incompatible with its neighbouring markets, this decision could be disruptive to the supply chain. It may increase the cost of energy-efficient electric motors for all parties. This could occur due to the added expenses of manufacturers needing to perform different or additional tests, create unique labels and catalogue numbers for each market, and track, keep inventory, and ship country-specific motor products.

32 Regional harmonisation would mean that the policy documents are harmonised and preferably have the same MEPS levels. However, if needed, the time required to reach the common level could be different, as national circumstances in a trading block vary considerably e.g., Philippines and Singapore in ASEAN.

Harmonisation of MEPS offers many benefits, including avoiding the costs of duplicating testing and non-comparable performance information and requirements for countries, the private sector, and consumers. Thus, stakeholders benefit from the removal of this administrative trade barrier and can leverage the better prices and choice of goods associated with the larger economies to which these are harmonised.

If countries have different requirements, it is difficult, costly, and time-consuming for a manufacturer to create and maintain different electrical designs, and to carry out the necessary tests for each specific country. Thus, harmonisation enables multiple national markets to be accessible for the cost of only one test.

Working within a region and with different organizations (e.g., government, private sector, civil society) can result in more effective outcomes. Regional cooperation can achieve positive results by sharing resources for energy-efficient motor policies and programmes. Many energy-efficient motor programmes are initiated yearly at local, national, and regional levels, which can inadvertently duplicate effort, conflict, or cause confusion. A regional cooperation initiative helps to coordinate such programmes so that they do not conflict, and they cost-effectively achieve their results.

For a successful regional cooperation initiative, consensus among the stakeholders is important. The following are some suggestions for promoting regional cooperation:

- Conduct regional and national technical committee meetings to build consensus on activities to reach agreement about issues, policies, guidelines, standards, and related subjects;
- Identify liaisons in each country to be the point of contact and lead on local activities;
- Establish bilateral or cross-border activities with another country in the region;
- Establish regional collaboration between two regions working on related topics;
- Conduct in-person and online events to share experiences and information;
- Develop infrastructure for communication between stakeholders.

Regional cooperation can include:

- Developing a regional efficient electric motors roadmap to identify areas of cooperation and ways to share resources and build regional markets for efficient electric motors;
- Developing regional market assessments to establish the baseline and possible areas of intervention for efficient electric motors;
- Establishing regionally harmonised standards that prescribe minimum energy performance requirements;
- Coordinating monitoring, verification, and enforcement activities (e.g., verification of labels, mutual recognition of test results, sampling and checking MEPS compliance);
- Expanding motor test facilities to reduce costs and build a network of professionals, with some countries potentially specialising in certain aspects of testing;

- Pooling resources and using of the available structures and capacities within regions to improve the effectiveness, mutual reinforcement, and synergy between the various country programmes, making them more cost-effective and impactful.

Regional coordination and planning are also crucial for the success of large, complex projects with cross-border and trade implications or important projects for more than one government to address. Although specific requirements may vary from country to country (e.g., scope of products, power range covered, specific exclusions), motor MEPS have gradually been harmonising primarily due to the global alignment of both test and classification standards.

Given the benefits of regional harmonisation, which can reduce the costs and complexity of developing and administering policies, such opportunities should be thoroughly investigated before developing country-specific standards and programmes.

03 Market Monitoring, Verification and Enforcement

What?	Describes the processes for establishing and maintaining a robust Monitoring, Verification and Enforcement (MVE) regime, which is critical to the success of energy efficiency standards and labelling.
Why?	A robust MVE regime safeguards the credibility of the programme, raises user confidence, and provides a level playing field for the supply chain. Suppliers get discouraged from noncompliance by the certainty of exposure and adverse consequences and get encouraged to bring products that are more efficient to the market. Users have the confidence that product efficiency is indeed as it is claimed to be. Policymakers get the reassurance that the intended benefits from the programme to the economy and the environment are secure.
Key Questions	Some key questions to keep in mind: • Do we have the legal framework to structure a complete MVE scheme? • Which government bodies oversee product safety? Could their function be expanded to include energy efficiency as well? • What public resources are available to staff and finance a MVE regime?

MVE revolves around monitoring markets, verifying compliance, and enforcing the regulation on companies that fail to meet them. Figure 11 highlights the fundamental aspects of MVE.[33]

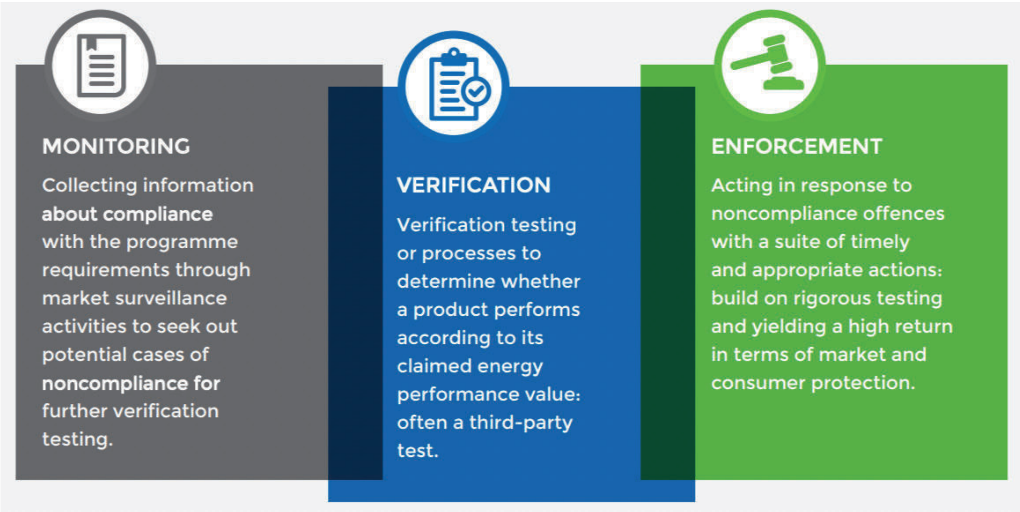


Figure 11: The market monitoring, verification, and enforcement process

33 Mark Ellis & Associates: Compliance Counts - A Practitioner's Guidebook on Best Practice Monitoring, Verification, and Enforcement for Appliance Standards & Label-ing, CLASP, (2010).

The goal of MVE is to ensure the integrity of market-transformation programmes by minimising, if not eliminating, the sale of noncompliant products after the effective date of a regulation.

A robust MVE regime benefits all the three main stakeholders involved: the supply chain, purchasers, and policymakers, as depicted in Figure 12.

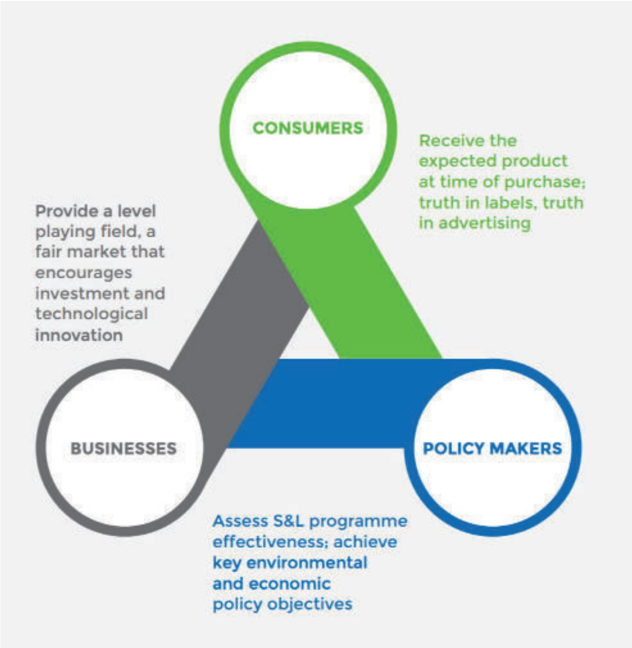


Figure 12: MVE benefits to key stakeholders[34]

On the other hand, a weak MVE regime leads to the eventual failure of the policy. The two "compliance circles" in Figure 13 illustrate the self-reinforcing nature of robust and weak MVE regimes, which lead to high and low compliance rates respectively:

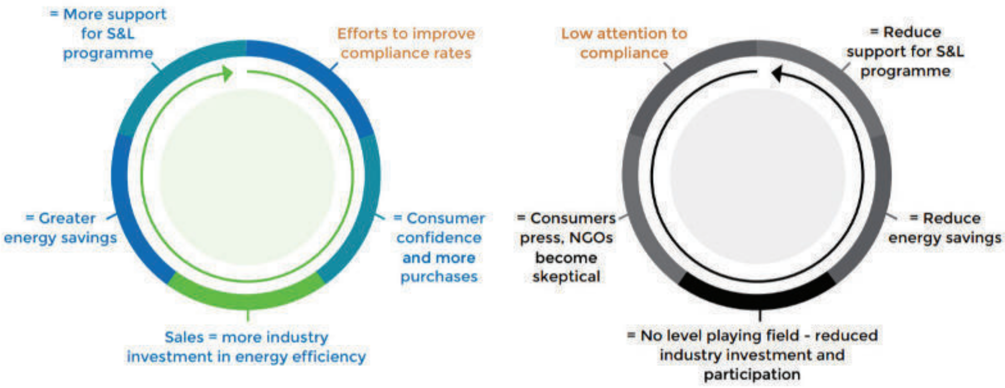


Figure 13: The compliance circles[35]

Regional Harmonization supports a successful compliance - implementation and enforcement of the energy efficiency policy – and helps to safeguard policy benefits by ensuring that substandard and inefficient products are not allowed into or are removed from the national markets.

34 Mark Ellis & Associates : Compliance Counts - A Practitioner's Guidebook on Best Practice Monitoring, Verification, and Enforcement for Appliance Standards & Label-ing, CLASP, (2010).
35 Ibid.

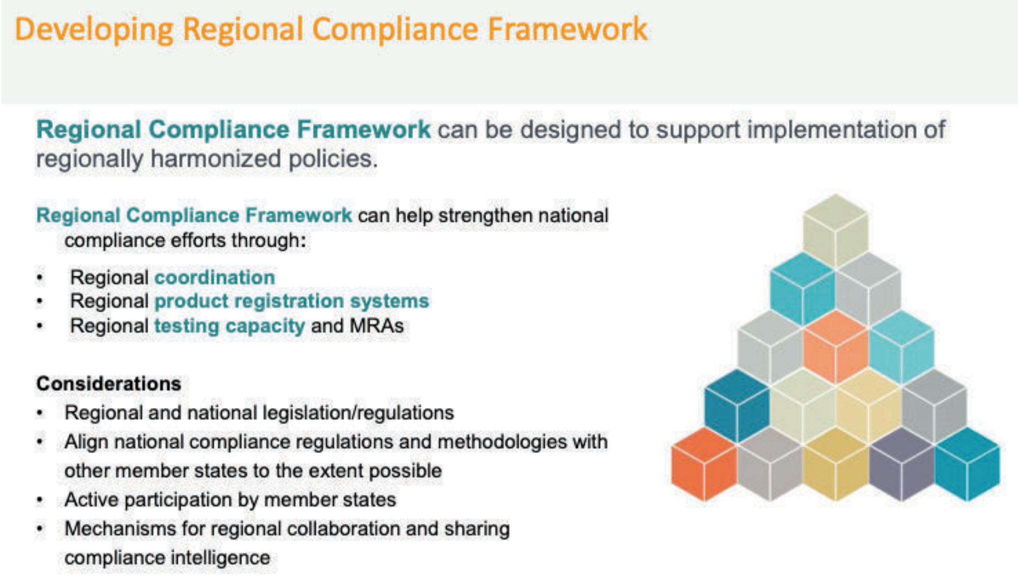


Figure 14 : Developing a Regional Compliance Framework [36]

3.1 Legal and administrative framework

A strong foundation within the national legal framework is crucial for an MVE scheme. This foundation should encompass legal authority, enforcement powers, and penalties. The legal framework for an energy efficiency enforcement regime will depend on the national governance structure, existing legislation, and the infrastructure and design of the MVE process.

Legal frameworks must delineate responsibilities between the different government agencies implementing MVE nationally, including the agency responsible for coordinating the MVE scheme and other agencies such as customs, standards and metrology that will have central roles. The framework could bestow the authority for an agency to issue fines and block the sale of non-compliant products from entering the market.

The operational framework within which the enforcement authority operates should be transparent. Clear communication and understanding of the MVE scheme improve compliance rates.

3.2 Financing monitoring, verification, and enforcement schemes

The costs of a national MVE scheme will vary with the scope of the programme as well as local or regional factors, such as labour and services costs. When planning how to allocate funding for an MVE scheme, the managing agency typically considers the relative scale of the harm caused (i.e., cost of wasted energy, loss of consumer confidence, and frequency of noncompliance).

In general, more resources are allocated toward addressing cases of noncompliance that have the greatest impact and occur frequently. Budget allocation should be an evidence-driven, risk-based process that is transparent and defensible.

The areas of an MVE scheme which incur costs are listed below:

36 Lina, Kelpsaite, CLASP: Regional Approach to Policy Compliance, In: IEA (ed.), SEAD REGIONAL WORKSHOP FOR EAST AFRICA ROUNDTABLE DISCUSSION FOCUSSED ON LIGHTING AND COOLING, IEA, (2021).

- **Establishment costs**—setting up a main office and possibly field offices.

- **Staff costs**—hiring and training/capacity building the staff, covering the key areas of administration, investigation, and management, as well as specialist areas such as customs officials and test labs.

- **Communications**—informing the market about the regulations, the MVE scheme and enforcement proceedings, as deterrence is highly cost-effective; and

- **Legal and enforcement action**—the MVE agency needs to have (and be seen to have) sufficient funding to use its full range of legal powers.

The most common funding source is the government's general operating budget; however, there can be other funding sources. Cost recovery from suppliers can also be another funding source, with many programmes worldwide introducing cost-recovery elements to their schemes. Cost recovery can be partial or complete and can be achieved through registration fees, verification testing fees, enforcement fines, etc.

Many programmes require suppliers and products to register before they are placed on the market. Fees from suppliers can be collected during registration. This may take the form of an annual payment, a one-off payment for a specified period, or a higher initial fee followed by a smaller annual payment. Registration fees are generally levied on product groups rather than brands or suppliers, as this best reflects the costs involved.

An increasing number of programmes require that products have third-party certification from an independent body as a condition of entry. While this is not cost recovery per se, it can reduce the programme's costs because the system administrator is, in effect, delegating some of the responsibility for ensuring products meet the necessary requirements to third parties paid by the product suppliers. However, this does not fully eliminate the need for effective MVE.

An increasing number of programmes require that products have third-party certification from an independent body as a condition of entry to the programme. While this is not cost recovery per se, it can reduce the costs of the programme because the system administrator is in effect delegating some of the responsibility for ensuring products meet the necessary requirements to third parties paid by the product suppliers. However, this does not fully eliminate the need for effective MVE.

Finally, support for MVE schemes can also be derived from stakeholders in the market. Collaboration and cooperation with industry or civil society may provide additional resources. For example, by providing expertise, supporting data collection, and sharing, or even providing testing facilities.

Prior to engaging in this form of collaboration, the goals of cooperating need to be established, as some contributions may not be admissible as a foundation for legal action (e.g., there may be a conflict of interest in using industry funding to legally prove competitors' noncompliance in the market).

All compliance regime designs that deliver similar compliance rates will likely have similar overall costs. However, the costs may be distributed differently among governments, industry, and consumers.

Table 2 lists the three most common processes for the provision of information on product performance, which plays a substantial role in monitoring and enforcing the programme.

In the first model, the supplier's self-certification of energy performance is an acceptable entry condition. In the second model, the supplier's declaration of energy performance is based on a test report from an independent laboratory, which need not be accredited. In the third model, a verification authority administers the testing and certification (see 6.4 below) of equipment by an accredited laboratory prior to market entry. The verification authority may be a private, public or industry organization.

Table 2: Most common models of cost distribution among stakeholders

ENTRY CONDITION	DISTRIBUTION OF COSTS		
	GOVERNMENT/ PROGRAMME	MANUFACTURERS/ SUPPLY CHAIN	USERS
In-house testing, calculation or self-declaration allowed	High cost in market surveillance and verification testing	Low compliance costs	None
Independent tests required	Medium cost in market surveillance and verification testing	Medium initial compliance costs	May fund compliance costs in price of equipment
Third-party verification and/or certification required	Low-cost in market surveillance and verification testing	High initial compliance costs	May fund compliance costs in price of equipment

Since each of these models allocates costs to stakeholders differently, a key factor in the choice of system is the consideration of which is most equitable and feasible. Assess the pros and cons of each entry condition within context since there is no one-size-fits-all solution.[37]

For each model, the programme must specify what type of evidence the supplier must provide for compliance to be checked by the competent authorities. For instance, in the case of self-declaration, suppliers may be required to provide test reports (whether from an in-house lab or a third party) supporting their declaration. It is also important to specify which test methods are accepted (e.g., with reference to relevant international standards).

3.3 Proactive communications

Communication is a critical element of any successful MVE scheme. Manufacturers are kept aware of their legal obligations and the consequences of noncompliance, thus gaining their respect and improving compliance rates. Consumers are given confidence that component efficiencies (motor, pump, fan, compressor) are accurate as these are claimed to be by manufacturers. Highlighting specific examples of enforcement actions responding to noncompliance can also be a powerful deterrent to others.

Governments should develop a dedicated module for MVE within the broader communications plan that is fine-tuned for all main stakeholders in the supply chain. It should address compliance requirements, the risk of detection and sanctions, any corrective action taken, and so on. Governments may list the number and frequency of inspections and tests, identify plans for future compliance work and publish information about their work. Governments may also consider publicising ("naming and shaming") non-compliant products and brands.

37 Ellis & Associates, 2010. Compliance Counts: A Practitioner's Guidebook on Best Practice Monitoring, Verification and Enforcement for Appliance Standards & Labelling, www.clasp.ngo

Training and guidance can also help improve compliance. For example, governments can offer courses that explain the regulatory requirements, maintain a regulatory hotline or email service to answer questions, and post frequently asked questions and on a website. These approaches help to minimise the costs of compliance and thereby help with overall success. It is important to consider gender balance in all the activities promoted, both among the presenters and professionals in charge of providing training and among the audience.

3.4 Product registry systems

Product registry systems offer an initial compliance gateway whereby suppliers register compliant products with the regulatory authority. They provide a simple, practical tool for verification by persons who are not subject matter experts, such as customs officers. The registration process usually requires manufacturers to submit those test results on the products and certify that the product performance meets the meps and/or any labelling requirements before the product can be placed on the market.

The data fields typically recorded in these databases for products i.e., motor, VSD, pump, fan, or compressor, are as per regulatory requirements (see the accompanying U4E model regulations). Constructional (e.g. foot or flange mounting for a motor) or electrical (e.g. a motor with 400/415/440/690 V options) variants of thermally equivalent motors should appear at most once. The number of variations should be kept low as each additional variation incurs registration and testing costs, ultimately borne by the market but not so low that there is inadequate differentiation. Regulation is usually worded rather tightly, to be specific, but if the wording is too narrow, a minor tweak to the component specifications can take it beyond the regulatory scope. For example (for a motor), the regulation might specify a temperature range of -10 to +400C; however, to escape coverage, a motor nameplate could say -11 to +400C, although there may be no difference in design or construction between the two. The current Department of Energy (DOE) - United States of America template (available at https://www.regulations.doe.gov/ccms/help/instructions-for-ccms-reporting-certification-and-template-v5-electric-motors) can be used as an example. Registration fees should be kept at a reasonable level.

When governments set up product registration systems, they must do so via legislative and/or regulatory authority. Mandatory registration systems are in place for products with MEPS or energy labelling in Australia, Canada, China, India, New Zealand, Singapore, and the United States of America. These registration systems include energy performance data, technical product specifications, sales figures, and product prices[1]. The registration systems are generally designed to meet the needs of many different stakeholder groups, as shown in Table 3.

In the United States of America, each manufacturer must request a Compliance Certification number from the DOE and the product should be pre-validated before they can be introduced into the market. The manufacturers must either have the product tested at a certified independent laboratory or calculate the product's efficiency using a tool that has been qualified as an Alternative Efficiency Determination Method or AEDM[38].

38 An AEDM is an analytical calculation tool for determining energy efficiency and, therefore, it is cheaper and less time-consuming than physical testing of the product in a laboratory. AEDMs are developed by individual manufacturers (as manufacturing processes vary) and are rigorously vetted through a series of laboratory tests before these are allowed by the Department of Energy (DOE) - United States of America. For more information see http://energy.gov/eere/buildings/appliance-and-equipment-standards-program

By contrast, in Europe, manufacturers place their products on the market through a self-declaration process. In this system, the manufacturer declares that the product complies with European Union directives by placing the CE mark on the product. There is no requirement for advance registration or a qualification process for products at present, although other products covered by energy labelling must be registered.[39]

Although product registration into a database is a valuable tool, the process should be simple. A cumbersome process can discourage some manufacturers and importers, particularly from small national markets, and burden market surveillance authorities. The authorities in small national markets should consider using Mutual Recognition Agreements (MRA) with their trading partners instead. A MRA is a clause within trade agreements that enables a country to recognise and accept the standards, regulations, and conformity assessment procedures for the products of its trading partners on a reciprocal basis. A product approved for sale in these countries could be imported and sold in the national market without further testing or certification.

Table 3: Product registry system users and their potential needs

Table 3: Product registry system users and their potential needs	Potential User Needs
Table 3: Product registry system users and their potential needs	Provides a record of baseline data to support policymaking; expands the evidence database for market surveillance; serves as a storehouse of ancillary information and data about products on the market
Table 3: Product registry system users and their potential needs	Facilitates declaration of conformity with regulatory/voluntary requirements; provides information about innovation in product design (fostering competition and innovation); strengthens brand credibility; helps to ensure a level playing field
Table 3: Product registry system users and their potential needs	A database of product-specific information in the public domain; opportunity for advanced features through apps or other tools, doing product searches; enhances transparency of communication about product performance
Table 3: Product registry system users and their potential needs	Retailers can verify products being supplied are registered and compliant with local laws
Table 3: Product registry system users and their potential needs	Registry information can be used to determine product performance for market pull programmes incorporating financial incentives, subsidies, and prizes.

39 As of 1 January 2019, suppliers (manufacturers, importers, or authorised representatives) need to register their appliances, which require an energy label in the European Product Database for Energy Labelling (EPREL), before selling them on the European market.

U4E has developed a prototype product registration system that can be implemented by countries. The prototype is for free (open source) and was developed based on best practices together with several technical experts. The software, which can be accessed here, has all of the functionalities of a product registration system and can be readily taken over by countries. In addition, U4E developed also a regional database together with the ASEAN Centre for Energy (ACE) and the ASEAN countries which aims to collect data from national product registration systems to be displayed at the regional level. Interested regions can reach out to U4E to discuss a potential implementation. Further information through guidance notes and webinars is also available through this link.

3.5 Self – Declaration, AEDM & Certification

It is to be ensured that a product meets the claimed energy performance before it is placed on the market in one of three ways:

- **Self-declaration:** By testing in the manufacturer's own test laboratory.
- **Calculation** by an Alternative Energy Determination Method (AEDM) tool.
- **Third-party certification**: By testing in an independent test laboratory.

These processes vary widely across the world as can be seen in Table 4. Given the widespread cross-border trade in products either by themselves or as part of systems, the differences in requirements beyond efficiency (e.g., marking, certification, registration) and the high associated costs in small individual national markets, it makes great sense to share test results with trading partners or in a region. Examples of such co-operation agreements exist around the world with varying levels of formality[40].

40 Denmark, Sweden, and United Kingdom of Great Britain and Northern Ireland formally share costs of testing through the pilot Ecopliant initiative. The European Commission has created a platform for the sharing of information between European Member State Market Surveillance authorities – the ICSMS (Information and Communication System on Market Surveillance) database.
• Australia formally shares results with New Zealand, and sometimes informally with other IEC members.
• The United States of America informally shares results with Australia, European Union, Canada, Japan, Republic of Korea, and Thailand.

Table 4: Processes to obtain approval before placing on the market in different countries[41]

MEPS	PROCESS TO OBTAIN APPROVAL TO START SALES	TESTING	QUALITY ASSURANCE
AUSTRALIA	Registration with type test report to government web pages	Manufacturer lab	Manufacturer's quality system
BRAZIL	Manufacturer test lab approval, registration including technical documentation	Manufacturer lab once approved by INMETRO	Yearly follow up testing of manufacturer products
CANADA	Third party approval for test laboratory	Certified lab (manufacturer or a third party)	Quarterly audits of production units by a third party, yearly audit of manufacturer test lab
CHINA	Registration including test reports and technical documentation	Manufacturer lab	Audit by authorities every five years
EU	Self-certification, CE mark	Manufacturer lab	Manufacturer's quality system
JAPAN	Self-certification	Manufacturer lab	Annual reporting, Manufacturer's quality system
REPUBLIC OF KOREA	Registration incl. Type test reports	Korea Testing lab	Annual reporting, manufacturer's quality system
SAUDI ARABIA	Registration to Saudi Standards, Quality and Metrology Organization (SASO) web pages and third party certification of conformity	Manufacturer lab approved by SASO	Validity of registration up to 12 months
US	Third party approval for test laboratory, AEDM	Certified lab (manufacturer or a third party)	Manufacturer's quality system

3.6 Monitoring

one of the most critical functions of a government market surveillance authority is to conduct regular, ongoing monitoring of the market to ensure that the products being supplied are compliant with regulations. The aim is to identify potential cases of noncompliance for verification testing and use the monitoring results as a first step in engaging with the industry to reach compliance.

Market monitoring can be carried out in different ways:

- By checking documentation furnished to registry systems;
- By customs authorities confirming all required documentation is provided;
- By checking in dealerships whether product nameplates meet the IEC, ISO or other specified norms;

41 Malinowski, J. and Korkeakoski, J. (2016) CEMEP/NEMA presentation to the Motor Summit 2016.

- By scanning manufacturers' websites for energy efficiency information;
- By providing a hotline for user and competitor complaints;
- By monitoring results shared by other economies.

A market baseline provides a snapshot of the products available in a market at a given point in time. It provides a sound technical foundation for developing new or revised policies for efficient equipment. Market baselines enable policymakers to thoroughly understand product availability, performance, pricing, and other important factors influencing policy development. In practice, obtaining reliable data for the baseline is a challenge.

Market baselines are refreshed over time so policymakers can understand market trends and responses to policies and programmes. This information facilitates the development of more effective regulations.

3.7 Verification testing

Verification testing is the process of checking products already in the market against their claimed energy performance. Such testing can be carried out as a random check on representative samples (check testing) or in response to market intelligence on possible noncompliance, usually from competing manufacturers (challenge testing).

The verification testing of products faces a few challenges:

- The choice of sample products for verification testing needs to be exercised carefully, as testing is expensive, and the budget is limited. Different screening criteria are used: Is a test report available? Have the tests been performed according to the state of the art. Are the values plausible? Is there market intelligence about likely compliance issues? Has there been a past record of failures? Do the products have a high market share? Is the manufacturer a new entrant? Is the overall impact on energy consumption high (e.g. smaller motors are sold in higher volumes than larger motors)? Would the deterrence impact be higher for a given testing effort? Care must be taken that manufacturers are treated equitably.
- Unlike consumer products, industrial products cannot be purchased anonymously from the retail market. While small commonly used products can be procured through dealers and stockists, the larger and less common ones need to be procured directly from the manufacturer or importer with a delivery lead-time in weeks. Invariably the purpose of procurement can be inferred, and this gives rise to the possibility that the product offered for testing may be a specially designed one.
- The decision on whether to test at an independent test laboratory or at the manufacturer's test laboratory is important, as two-way transportation can be a major component of testing costs.
- Ensuring the compliance of products imported as a part of systems is a serious but important challenge to address; in the example of motors, 70 per cent of the motors are purchased as a part of a system. Firstly, the entire system would have to be purchased and the motor removed from it for testing, which would involve higher costs and logistics. Secondly, the motor may be fitted to the system and be difficult to separate. The motor may require special cooling to achieve the claimed performance. The motor may also carry the system manufacturer's nameplate, and not that of the motor manufacturer, making it

difficult to correlate with test documents. Finally, it may be sourced from a country with less stringent standards.

- Testing based on information provided by competitors requires sensitive handling. On the one hand, such market intelligence is needed, but on the other hand, the compliance regime should not be allowed to be misused by manufacturers to hurt a competitor unfairly.

3.7.1 Test laboratories

The accurate and reliable measurement of the energy efficiency of motors provides the foundation for a robust MVE system and the effective implementation of MEPS and labels. These measurements need to be carried out in laboratories that can be relied upon to deliver very high accuracy results consistently. The referenced testing standards for motors as prescribed by IEC Standard 60034-2-1:2024, method 1-B; for VSDs by IEC 61800-9-2:2023; for fans by ISO 5801:2017; for pumps by ISO 9906:2012; and for air compressors by ISO 1217:2009/Am. 1:2016, see Technical Annex for further details.

The accreditation of test laboratories is carried out according to ISO/IEC 17025: 2017 "General requirements for the competence of testing and calibration laboratories". The standard requires an accredited laboratory to fulfil stringent requirements covering all aspects of the organization of the laboratory including:

- Impartiality and confidentiality
- Resource requirements
- Process requirements
- Management systems

Accreditation is carried out by designated organizations such as the National Institute of Standards and Technology in the United States of America, which operates the National Voluntary Laboratory Accreditation Program (NVLAP).

Only a limited number of test laboratories can fulfil these requirements on a continuing basis. A less stringent alternative for a motor manufacturer's test laboratory would be the certification by a reputed third party such as UL or CSA that its testing methods are in accordance with IEC Standard 60034-2-1-1B:2024, method 1-B.

Although having a national laboratory can be a prestigious asset, these are expensive facilities to establish, commission, earn accreditation for, and maintain. There needs to be a certain minimum level of paid tests each year for a laboratory to be financially viable to retain experienced, qualified staff and maintain quality standards.

Unless manufacturers and testing agencies can utilise the laboratory capacity optimally, the facilities will fall into disuse. Thus, for countries with smaller motor, pump, fan, compressor markets, it may make sense to look at outsourcing their laboratory test needs to neighbouring countries or other entities until their market grows, and they are able to justify direct investment in a domestic facility. For example, the 27 member states of the European Union are individually responsible for MVE, but the verification testing is done in only a handful of laboratories and shared. Such shared testing can form part of a harmonised MEPS for products within geographic regions, which reduces the cost of MEPS implementation, verification, and enforcement.

3.8 Enforcement

Enforcement should be visible, and sanctions should be certain to deter non-compliance. When addressing cases of non-compliance, it is recommended that enforcement authorities carefully consider the degree of non-compliance to respond with a proportionate enforcement action. The available enforcement actions should be flexible. The penalties and powers of the enforcement authority should be set out in law. The powers and actions should be further outlined in administrative procedures or operational guidelines.

Many enforcement authorities develop an "Enforcement Pyramid" to inform and manage their enforcement response strategies (see Figure 15). A pyramid of sanctions ensures speed and proportionality and keeps costs low. The pyramid can be populated to be most effective for the national enforcement strategy, in accordance with the legal requirements and resources available to the enforcement authority, and the characteristics of the programme and its participants and stakeholders.

The bottom of the pyramid typically features more informal actions. In contrast, the top should reflect the most severe enforcement response to non-compliance, e.g., notices, fines, delisting, and naming and shaming. Legal enforcement can be expensive and should be a last resort. The guiding criterion should be that the cost of sanctions outweigh the potential benefits of non-compliance to the manufacturer.

In practice, manufacturers prefer a quiet, speedy resolution. They respond constructively as they fear the loss of reputation the most, followed by the loss of market share that would follow the withdrawal of a group of products from the market. A proactive communication strategy is critical to the success of an enforcement regime.

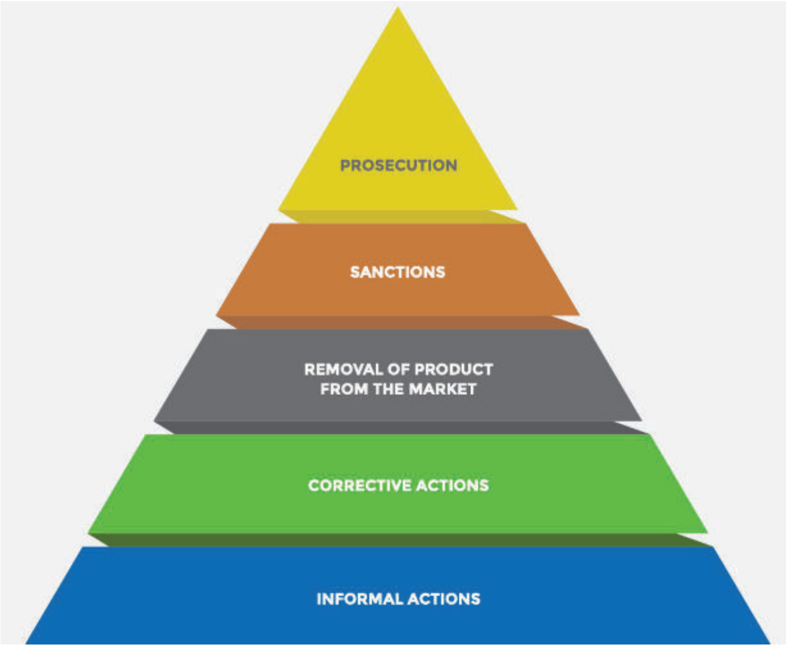


Figure 15: Pyramid of escalating enforcement[42]

42 Ayes and Braithwaite : Responsive Regulation - Transcending the Deregulation Debate, Oxford University Press, New York (1992)

In the example of electric motors, variations are possible in the measured efficiency levels of identical motors due to slight variations in the manufacturing process, materials, and testing uncertainties. Therefore, IEC 60034-1:2022 allows a 15 per cent tolerance on the measured motor losses, and the United States of America Rule allows 20 per cent. In practise, it is statistically possible for a single motor to exceed this tolerance even if the manufactured lot is within the range. As a result, retesting of motors on a sample of three to five motors is allowed in different enforcement regimes, with the manufacturer being asked to bear the cost.

For more information on effective enforcement schemes, please see a UNEP report[43] that is a practical resource for policymakers on the steps to follow when implementing a national enforcement programme. This report covers (a) legal and administrative foundation for enforcement; (b) enforcement budget and activity planning; (c) identifying types of noncompliance; and (d) communicating to stakeholders.

43 UNEP (2016) Enforcing Efficient Lighting Regulations, Guidance Note. Available at http://www.enlighten-initiative.org/portals/0/documents/Resources/publications/Enforcing%20Efficient%20Lighting%20Regulations_February%202016.pdf

B. Supporting Policies

What?	A review of supporting policies that could supplement standards and regulations in transforming the markets for new equipment to higher energy efficiency as well as to accelerate the renovation of the installed base of inefficient equipment.
Why?	Provides information on supporting policies, the second part of UNEP's Integrated Policy Approach, which is critical for securing public support and accelerating the transformation of energy-efficient motor systems markets.
Key Questions	Some key questions to keep in mind: • Has our country convened an energy efficiency communications campaign in the past? If so, what worked and what did not work? Are there lessons to be learned from other communications campaigns (e.g., on safety) that could help? • Who would lead a national campaign in our country promoting energy-efficient motor systems? Which partners would be needed? What impact could it have? • What policies does our country have to improve the performance of the industry sector?

04 Supporting Policies That Address the Installed Base of motor Systems

4.1 Accelerated Renovation Programmes

MEPS apply to new motor systems entering the market – as well as to the replacement of system components for maintenance purposes, but these do not apply to the much larger installed base of existing equipment. Separate policy initiatives are necessary to initiate efficiency improvements of the installed base:

1. Initiatives to inform, educate and build capacity.

- Users are unaware of the potential for energy and cost savings of energy-efficient motor systems within their plants. In many fan and pump applications, the simple act of replacing an old IE1 fixed-speed motor and downstream mechanical throttles and dampers with a variable-speed drive and IE4 motor could have an attractive payback period;
  Research on savings by accelerated motor replacements.
  Communication campaigns can inform such users.

- Users lack the tools to be able to estimate the savings reliably and create a business case for investment.
  Capacity building initiatives can equip such users.
  Measurement and Verification (M&V) training can ensure the reliability of the projected energy savings.

2. Initiatives to address user practices

- Users get motors repaired repeatedly rather than replacing them. Even when a motor reaches the end of its life, users replace it with an equally inefficient spare motor. *Scrappage policies could incentivise accelerated replacement.*

- Large industrial users should be mandated and/or incentivised to adopt motor management programs and conduct energy audits of motor systems.
  Mandatory motor system audit programme as part of a regular industrial energy audit [see Case Netherlands] in combination with an Energy savings Duty.

3. Mechanisms to address financial barriers

- Individual investments in energy-efficient motor systems involve small and complex transactions.

- When it comes to investible funds, energy savings projects have a lower priority compared with the user's core business.

- Potential creditors are often unable to reliably assess and securitise the returns from future energy savings. Thus, the availability of finance for energy efficiency investments becomes dependent upon the overall creditworthiness of the energy user, which is particularly challenging for SMEs.

Therefore, innovative financial delivery mechanisms including but not limited to incentives, grants, tax rebates, green credit lines, credit risk insurance, leasing, vendor financing, demand aggregation and bulk procurement, and energy performance contracting can address these barriers (see Chapter 4).

CASE STUDY: National Motor Replacement Program (NMRP) Indias

India adopted Motor MEPS at the IE2 level in 2018. However, MEPS apply to new motors being placed on the market rather than to the estimated 25 million motors in the installed base, of which more than 90 per cent may be at or below IE1 efficiency levels. NMRP's objective is to accelerate the voluntary replacement of these inefficient motors to IE3 levels. The increased use of IE3 motors for replacements is expected to also pull up the market for new motors to IE3.

The publicly owned Energy Efficiency Services Ltd. (EESL) procures the IE3 motors (0.75 – 75 kW) in bulk, which enables it to negotiate price discounts of up to 25 per cent. It also gets fixed delivery schedules, a 3-year extended warranty, and enhanced after-sales support from vendors. It also offers an instalment payment option of up to 3 years and walkthrough audit services. Users find this suite attractive.

EESL offers two service models. In the first model, EESL's services comprise Project Management Consultancy (PMC), beginning with identifying the motors to be replaced, estimating the potential energy savings and investment required, writing specifications of the motors to be procured, and coordinating procurement and supply. The entire investment cost is borne by the user upfront.

The second is an Energy Services Company (ESCO) model. In this model, EESL provides the PMC activities of the first model and incurs the entire investment cost. EESL recovers these costs and overheads from the user in equated quarterly instalments over a maximum of three years. It is observed that the instalments are about 50-70 per cent of the monetized energy savings, thus providing a net surplus of 30-50 per cent to the end-user over the repayment period, and 100 per cent thereafter for the lifetime of the new motor.

The program was designed in consultation with diverse stakeholders including motor manufacturers, end users, industry bodies, inter-governmental and non-governmental organizations with the International Copper Association India as the knowledge and outreach partner. A deemed energy savings model has also been used.

As of 2023, the accrued energy savings due to NMRP as a market enabler are estimated at around 32.42 TWh, resulting in a GHG reduction of 2.4 MTCo2e.

For more information: NMRP – Energy Efficiency Services Limited (eeslindia.org)

CASE STUDY: European Motor Renovation Initiative (EU-MORE)

In the European Union, industrial and service electric motors used approximately 900 TWh p.a. in 2020. The EU-MORE project seeks to develop new policies, tools, and financing mechanisms to accelerate the replacement of inefficient motors by applying a systems approach. EU-MORE also aims to equip local stakeholders with the necessary knowledge and skills on best practices for motor system renovation, such as proper motor sizing, speed variation and digital technologies.

For more information: EU-MORE – To accelerate the early replacement of old inefficient electric motors in industry & tertiary sector

4.2 Improving Motor Repair Practices

Motors fail in service for various reasons. The most common cause is bearing failure due to mechanical vibrations or shocks from shaft misalignment or improper assembly. Bearings also fail due to under- or over-lubrication or contamination of the lubricant.

The second most common cause is the failure of the coil insulation due to overheating caused by overloads, poor ventilation, contamination, or power quality issues such as unbalanced voltages and currents. This could also happen if the motor has previously been repaired poorly. There are other causes of motor failures as well, such as mechanical damage and a mismatch between the motor's characteristics and the starting torque requirements of the load.[44]

If a spare motor is readily available, the failed motor may be replaced, and the driven equipment can return to operation. The maintenance department must decide whether to repair or replace the motor based on the extent of damage, the motor's previous repair history, and the relative costs of repair versus replacement.

Professional maintenance strategies include a motor management programme to enable informed decisions[45]. If a spare motor is not available and a critical system is at a standstill, there is no option but to carry out prompt emergency repairs on the failed motor.

In practice, motors above a certain size (which depends on local labour and material costs) are typically more economical to repair than replace. In developing countries, lower labour and material costs mean that even small motors get repeatedly repaired rather than replaced. Even if repairs are carried out very professionally, outdated motors remain in operation for decades, and opportunities to improve performance significantly are missed.

If, on the other hand, no exact spare motor is available and the driven system is at a standstill or has been made operational through a temporary makeshift arrangement, there is no option but to carry out emergency repairs on the failed motor to take it back into operation at the earliest. In such an event, the pressure from the business owner who is confronted with a plant that is underperforming or at a standstill is on the speed of repair, not its quality.

44 ECONOLER (2014) Motor Repairs: Potential for Energy Efficiency Improvement, Study for Super-Efficient Appliances Deployment/Clean Energy Ministerial
45 Guidelines for an effective motor management programme are available at https://www.copper.org/environment/sustainable-energy/electric-motors/case-studies/a6141.html#a5

Professional shops that follow industry best practices, such as the Electrical Apparatus Service Association[46] specification ANSI/EASA AR100 or the repair specifications of the Consortium for Energy Efficiency[47], can make repairs that yield performance that is as energy efficient as the original condition. Even with the best repairs, a technologically obsolete motor would never become as energy efficient as current designs. Replacement rather than repair becomes more cost-effective at some point during a motor's lifetime due to the extra energy savings.

Anecdotal evidence suggests that in many countries motor repairs are often carried out in shops with inadequate equipment, processes, expertise, and quality. A survey of 45 service centres across Japan, China, New Zealand, United States of America, and Viet Nam showed an increase in losses up to 6 per cent after motors were repaired.[48] See Table 5 for examples of a reduction in motor efficiency after repairs. Since a motor may be repaired several times during its life, these cumulative losses can become significant.

Table 5: Typical reasons for a reduction in motor efficiency after repairs

Loss Component	Cause of Efficiency Reduction
Stator copper	Reducing conductor cross-sectional area and/or increasing its length.
Rotor copper	Damaged rotor cage, poor connections between bars and end rings and wrong or improperly installed bars.
Core	Winding removal operation by: (1) applying improper burnout temperature, (2) overusing abrasive blasting with sand or a similar material; and (3) hammering the core.
Friction and windage	Motor reassembly by damaging or improperly installing the bearings, applying excess greasing to the bearings and by using poor quality grease and the wrong size or type of fan.
Stray	Use of poor repair techniques for motor dismantling, winding removal, core cleaning and motor rewinding.

Improving Motor Repair Practices

Considerable energy can be saved through up-grading motor repair practices. Electric motor losses can increase after repairs if carried out unprofessionally, which can happen up to three times over a motor's lifetime. When carried out in accordance with industry best practices, the repaired motor should perform at least as well as the original one[49].

46 The Electrical Apparatus Service Association (EASA) is an international trade organization of more than 1,700 electromechanical sales and service firms in 70 countries. Available at www.easa.com/accreditation
47 Available online at www.cee1.org
48 ECONOLER (2014) Motor Repairs: Potential for Energy Efficiency Improvement, Study for Super-Efficient Appliances Deployment / Clean Energy Ministerial
49 ANSI/EASA AR 100-2015 (2015) Recommended Practice for the Repair of Rotating Electrical Apparatus. Available at www.easa.com, Tools and information for electric motor end-users are also available at Electromechanical Resource Center (easa.com)

Typical poor repair practices relate to inadequate equipment, processes and knowhow and missing quality standards, more so in developing countries. Policy interventions could cover the following:

- Awareness campaigns
- Training materials and facilities
- Financing schemes for equipment up-gradation in repair shops
- Developing repair quality standards and certification/accreditation programmes[50]
- Repair quality labels.

These recommendations are elaborated in a study commissioned by the Clean Energy Ministerial SEAD programme[51].

Case study: India Motor Rewinder Certification System (MRCS)

The Motor Rewinder Certification System (MRCS) is a voluntary mechanism and framework developed by the International Copper Association India and the Confederation of Indian Industry (CII) to assess and certify motor repair centers in India. The MRCS certification process involves a comprehensive evaluation of the quality of the rewinding process, the use of energy-efficient practices and the adherence to safety standards. Overall, the MRCS aims to enhance the skills of rewinding professionals, promote the adoption of best practices and guide motor repair centers toward becoming nationally and globally recognized entities. The five-point certification levels awarded to the repair centers are based on their assessment scores.

CII - Centre of Excellence for Competitiveness for SMEs (cii-competitiveness.in)

50 The EASA Accreditation Program on Energy Efficiency and Reliability has accredited 160 workshops in 5 continents (America, Europe, Asia, Africa, Oceania). Outside of Europe and North America, service centres have been accredited by EASA in Azerbaijan, Australia, Chile, Morocco, Philippines, Thailand, Trinidad and Tobago, and United Arab Emirates. https://easa.com/accreditation
Available at www.easa.com

51 ECONOLER (2014) Motor Repairs: Potential for Energy Efficiency Improvement. SEAD programme and Asia-Pacific Economic Cooperation/Collaborative Assessment of Standards and Testing. Available at https://www.cleanenergyministerial.org/

4.3 Company motor management programmes

A company motor (energy efficiency) policy[52] enables a company to systematically transition to higher-efficiency motors and systems over time. It is usually a component of a broader government policy such as an Industry Sector Energy Policy or an Energy Management Programme, although it could be a standalone policy as well. Such a policy typically lays down

- A consideration of energy efficiency and lifetime costs, while procuring motors and drive systems
- Rules for repair/replace decisions when motors fail, incorporating energy savings considerations
- Requirements to prevent loss of efficiency due to improper installation
- Guidelines for ensuring professional motor repairs with no loss of efficiency.

A broader company motor management[53] programme would additionally include elements such as:

- Motor data management and analysis
- Motor surveys and tagging
- Motor inventory analysis
- A spares stocking policy
- Preventive and predictive maintenance.

52 For more information see: IEA 4E "Policy Guidelines for Motor Systems, Part 2", 2014, section 6.6. available at https://www.iea-4e.org/emsa/ . Further company case studies are available at https://www.unido.org/sites/default/files/unido-publications/2023-11/Egyptian%20Program%20for%20Promoting%20Industrial%20Motor%20Efficiency.pdf
53 https://www.energy.gov/eere/iedo/motor-systems

CASE STUDY : Example of Regulations on Company Electric Motor Systems Policies, Netherlands

Regulations require companies to define policies for electric motor systems.

The statement includes that:

- The data of the most important energy-using electric motor systems is updated periodically.
- The options for improving the efficiency and energy use of motor systems are periodically investigated and reported, considering in any case:
  - replacement of the motor and/or application after its economic life cycle with high efficiency units;
  - correct control of the systems so that motors, pumps, fans, compressors and machines that are unnecessarily in use are switched off and that unnecessary bypasses are removed;
  - power, frequency, flow and control are adequately adjusted to the demand; and
  - adjustments to systems with multiple pumps, fans, and compressors through better control and/or system adjustments for optimal energy use.
- there is a maintenance and replacement strategy, which includes:
  - specification of the replacement policy at a natural moment (i.e. a planned or unplanned investment moment);
  - definition of the natural moment regarding the end of the economic lifespan/ depreciation;
  - how the system optimization aspect is secured;
  - that measures that have an autonomous payback time within five years or less are carried out.

05 Overarching Supporting Policies

This chapter describes a choice of overarching supporting policies that address the new equipment market as well as the installed base of motor systems.

5.1 Communication and education

Designing a Communications Campaign

An effective communication and education campaign informs, educates, and gains the active support of key stakeholders. There are seven steps involved in designing such a campaign, as shown in Figure 16.[54]

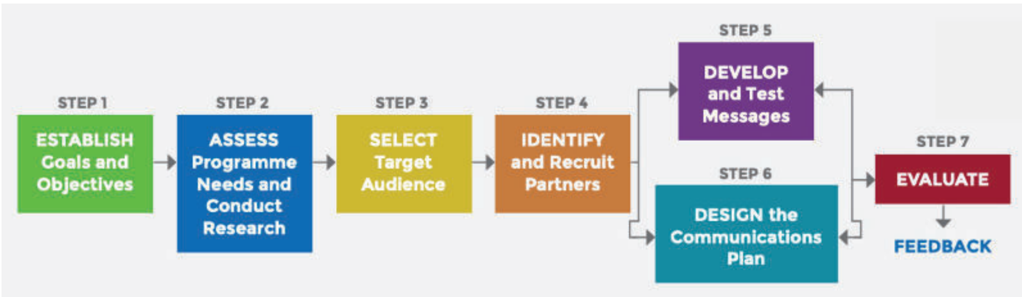


Figure 16: Major steps in creating a communications campaign[55]

Identifying and Engaging Stakeholders

Table 6 depicts the target audiences of an energy-efficient motors communication and education campaign, examples of the stakeholders in these groups, and their primary interests and potential areas for involvement.

54 A detailed coverage of how communication campaigns for Appliance Energy Efficiency Standards and Labelling Programs are designed is provided in Chapter 7 of www.clasp.ngo/en/Resources/Resources/PublicationLibrary/2005/SL-Guidebook-English

55 CLASP (2005) Standards and Labelling Guidebook

Table 6: Motors communication campaign stakeholders and areas of interest/involvement

Target Audience	Primary interests	Areas of involvement
Public Institutions • Political executive and legislature • Regulatory bodies, particularly electricity regulators • Standards bodies • Accreditation bodies • Enforcement officials • Customs authorities.	• Reduce the need for new power plants, reduce GHG emissions, while improving the national economy • Protect domestic industry and jobs while respecting trade obligations and without limiting trade opportunities • Ensure market transformation to energy-efficient products	• Policy formulation, legislation, funding, and human resource support for energy efficiency market transformation programme • Support to regulatory initiatives and policy implementation • Evaluation and monitoring of programme against established targets • Public procurement policy • Standards and Regulations • Incentives and subsidies • Testing lab accreditation • Product registration • Compliance • Communication campaign.
Power Utilities	• Reduce peak demand • Increase energy access	• Demand-side management programmes • Incentive and subsidy programmes for efficient motors and motor systems

Supply Chain • Equipment manufacturers • Motor repair shops • Equipment industry associations • Dealers • System integrators	• Seek competitive advantage, improved market share • Protect against business disruptions • Minimise costs, seek return on new investments • Be seen as an environmentally sensitive, responsible corporate citizen • Gain public recognition	• Assist regulators in determining level of ambition and timeline • Upgrade capacities for design, manufacture, testing and marketing of energy-efficient motors and systems • Ensure accurate energy labelling • Act as change agents • Facilitate direct and indirect end-user communication
End Users • Company management • Energy managers • Maintenance managers • Purchase managers • Facility managers • Energy auditors • ESCOs • Energy consultants	• Create sustainable corporate performance—financial, environmental • Save costs, improve productivity • Maintain plant uptime	• Develop company energy policy, motor-management policy, procurement policy • Acquire information and develop capacity to make informed decisions about the savings associated with a switch to efficient motors • Conduct energy audits • Provide data on procurement practices
Others • Civil society • Environmental organizations • Educational institutions • Research and training institutes • Media and general population	• Sustainable development, environmental protection • Education and training	• Assist public institutions with the development and implementation of sustainable appliance policies • Identify best practices and policies • Publish formal and informal education and training materials • Increase awareness and develop knowledge about energy-efficient motor systems among professionals and users • Support for sustainable appliance policies among general population

Education and training programmes should be carried out for motor, drive, pump, fan and compressor manufacturers, repairers, and end users, while promoting equal participation of women and men. Many end users lack the tools and knowhow to reliably assess the energy-savings potential of individual motor system applications within their plants, or how to optimise motor systems and create a bankable business case for investment.

Many professional energy auditors are better equipped to assess the savings potential from improvements in other plant areas such as process energy, thermal leakages, air, and water leakages, rather than from motors and motor systems. Therefore, training content in the form of practical tools, guides, reports, and manuals should be leveraged to bridge these gaps of knowledge and ability. As a rule, these should be held at neutral venues, but some could be conducted onsite for large companies.

Please see the IEA 4E "Policy Guidelines for Electric Motor Systems, Part 2", 2014, sections 6.8.4 to 6.8.9 for best practice examples of motor communication campaigns, awards, guides, training programs, energy-savings tools, and lifecycle costing calculations [56].

5.2 Energy Audit Programmes

An energy audit systematically identifies opportunities for cost-effective energy savings in a company, including in motor systems, by an internal or external energy auditor; the related ISO standard is ISO 50002. The energy audit report contains a list of savings measures, usually accompanied by an implementation plan for the most cost-effective energy savings measures.

An energy audit Programme is a government-led initiative encouraging and supporting companies to conduct periodic energy audits, sometimes mandatorily, and provides methodologies, tools, training, and certification for energy auditors. This is usually a component of a broader policy such as an industry sector energy policy, an energy management programme, or a financial assistance programme. However, it could be a standalone policy as well. From the perspective of electric motor systems, energy audit programmes should support energy auditors with motor system-specific methodologies, tools, and training; for this, particular publications are available[57].

Case study: Netherlands Energy Savings Obligation - Mandatory motor system analysis

In the Netherlands, by mid-2023, large energy-consuming industries must comply with the Energy Savings Obligation, which includes an analysis of electric motor systems as part of a full energy audit. The analysis targets all motor systems >15kW and needs to address all savings measures like replacement of inefficient motors, better component sizing, better systems control and highly efficient driven applications. All identified measures with a payback period below five years need to be scheduled for implementation within four years. This audit obligation is mandatory for companies with >10 GWh of electricity use or 50.000 m3 gas per year.

For more information: Energy Saving Obligation (rvo.nl)

56 For more information see: www.motorsystems.org
57 For more information see: IEA 4E EMSA "Energy Audit Guide for Motor Driven Systems", 2018, available at www.iea-4e.org/emsa/

5.3 Measurement & Verification

Anyone making an investment decision must be convinced that the estimated savings in energy efficiency projects will be achieved. Calculating energy savings in energy efficiency projects is unique in that they come from the absence of energy use and thus cannot be measured like kilowatt hours generated from traditional power or renewable energy supply-side projects. Savings are determined by analysing measured energy use after implementing an energy efficiency project versus the 'Energy Baseline' before its implementation.

M&V guidelines have been developed in the globally recognised International Performance Measurement and Verification Protocol (IPMVP), which is a document containing the accepted principles for the measurement, verification and calculation of the energy savings of energy efficiency projects. These principles are contained in the "IPMVP Core Concepts" document owned and managed by the non-profit, Efficiency Valuation Organization (EVO), and can be downloaded at no cost from EVO's website at: http://www.evo-world.org/.

CASE STUDY: Deemed Savings Approach, NMRP, India

In the Netherlands, by mid-2023, large energy-consuming industries must comply with the Energy Savings The NMRP (see above) uses a deemed savings approach to estimate the energy savings from replacing old and inefficient motors with new IE3 motors. The deemed savings are calculated based on the difference in efficiency between the old and new motors, the rated power, the operating hours, and a load factor. The deemed savings approach simplifies the measurement and verification process and reduces the transaction costs for the participants.

For more information: NMRP – Energy Efficiency Services Limited (eeslindia.org)

5.4 Industry Energy Performance Targets

Countries with energy-intensive industries like mining, cement, or textiles can consider special policies focused on reducing the specific energy consumption (SEC = units of energy required per unit of production) of individual companies in these sectors and the sector as a whole[58]. These companies will also usually be among the top 10 per cent in size and consume 70 to 80 per cent of the electricity used by industry.

Policymakers can benchmark[59] the SEC of domestic industry internationally or compare individual companies with the least energy intensive domestic producer, or even of a company vis-à-vis its own past performance, to arrive at the energy-savings potential. These benchmarks can then be used to set improvement targets, that could be supported (e.g., by enabling access to superior technology, knowhow), incentivised (e.g., through public recognition, trade-able certificates, subsidies, tax rebates) and mandated (e.g., under threat of penalties).

SEC can be reduced in many ways, including by eliminating water/steam leakages, improving technology, and restructuring industrial processes. To ensure that the upgradation of motor systems is prioritised, specific motor efficiency elements or a sub-target for reduced electricity consumption should be included within the overall target for an energy mix, which usually includes oil, gas, and coal.

58 IIP has developed a database and research report to support countries developing policy packages for industrial efficiency improvement http://iepd.iipnetwork.org/content/policy-pyramid
59 For a more detailed coverage of benchmarking, policy references and further case studies, see IEA 4E "Policy Guidelines for Motor Systems, Part 2", 2014, sections 6.8.10 and 6.3 respectively. Available at www.motorsystems.org

CASE STUDY: Perform Achieve and Trade, India

Perform, Achieve, and Trade is a mandatory programme introduced by the Indian government in 2013 covering eight energy-intensive industry sectors. An annual SEC improvement target is set for each individual industrial unit based on its past SEC, benchmarked on the industrial unit with the lowest SEC. Thus, less-efficient units have higher SEC improvement targets than already efficient ones.

If an industrial unit can exceed its SEC reduction target, it earns a certificate from the government in units of one tonne of oil equivalent. These certificates are tradable on an exchange. On the other hand, if an industrial unit cannot meet its SEC reduction target, it must make up the shortfall by buying certificates from the market. The merits of this programme are that there is a transparent incentive-penalty mechanism at a low cost to the government, essentially for ensuring compliance.

As a prelude to this programme, the Indian government separately mandated that all industrial units within these eight sectors above a certain energy use level must employ a certified energy manager, conduct energy audits, and conduct energy-saving programmes.

For more information: Perform, Achieve and Trade (PAT) | BUREAU OF ENERGY EFFICIENCY, Government of India, Ministry of Power (beeindia.gov.in)

5.5 Energy Management Programmes

Energy Management Programmes are government-led initiatives encouraging individual companies to adopt management systems to improve their energy performance systematically. These complement the top-down approaches of the previous section by equipping companies with a framework and tools to identify energy-saving opportunities, implement savings measures, and evaluate outcomes. The IEA has developed a guide[60] to assist policymakers in developing such programmes.

By participating in such a programme, companies benefit directly through lower costs, reduced exposure to energy price fluctuations, and improved competitiveness, in addition to contributing to national energy and carbon emissions savings.

The international standard ISO 50001:2018, Energy Management Systems (EnMS) – Requirements with guidance for use, requires companies to develop such systems to continuously improve energy performance through a Plan-Do-Check-Act (PDCA) cycle. This is the same PDCA cycle as other well-known standards like ISO 9001, Quality Management Systems and ISO 14001, Environmental Management Systems; it is easier for companies to adopt and implement ISO 50001-EnMS if they are familiar with these standards.

60 IEA, Institute for Industrial Productivity (2012) Policy Pathway Series: Energy Management Programs for industry. Available at www.iea.org/publications/freepublications/publication/policypathwaysindustry.pdf

The adoption of an Energy Management System usually moves companies to create policies and practices for regular energy performance assessments, including on energy-efficient motors and motor systems, although these could be standalone policies as well[61]. The United Nations Industrial Development Organization (UNIDO) Industrial Energy Efficiency Programme[62] focuses on promoting and supporting industrial Energy Systems Optimisation (ESO) as a complementary approach to EnMS implementation.

ESO emphasizes systems design as well as operation and maintenance practices. UNIDO assists developing country governments with policymaking technical assistance, institutional capacity building, and market transformation support for the adoption, implementation, and dissemination of EnMS and ESO, including motor systems.

UNIDO international trainers collaborate with national partners to create awareness and provide user and expert training over six to nine months. Working with governments, companies, and local energy efficiency service providers, the UNIDO programme creates a 'push-pull' market dynamic for EnMS and ESO services and projects.

61 For case studies around the implementation of Energy Management Systems by companies, see https://www.cleanenergyministerial.org/resources/

62 For more information see: https://www.unido.org/news/unido-cop28-forging-agreements-and-partnerships

06 Financial Delivery Mechanisms

What?	This chapter provides an overview of various financial delivery mechanisms for renovating the installed base of motor systems to achieve higher energy efficiency.
Why?	Finance is a significant barrier to transforming the market to energy-efficient motor systems.
Key Questions	Some key questions to keep in mind: • What are the financial barriers to transforming the market to energy-efficient motors and motor systems? • Which economic policies or financial incentive programmes could effectively reduce or remove these financial barriers and facilitate market transformation in our country? • Which stakeholders should we engage to learn about financial barriers and work with to encourage the creation of new market-delivery mechanisms? • What new market-delivery mechanisms, such as energy service companies, leasing schemes or other approaches, could be effective in our country? • Are there bilateral or multilateral sources of technical assistance, grants or finance that would stimulate and accelerate the efficient motors market?

While financial barriers exist across the entire supply chain (see Table 7 for examples), the experiences of many countries show that policymakers most often target two barriers:

1. Reduce the cost of energy-efficient products for customers

    a. policies providing financial incentives to mitigate the initial purchase premium associated with energy-efficient equipment

    b. policies encouraging customers to consider the lifecycle costs of using equipment rather than simply the initial capital purchase cost.

3. Encourage investment in the supply of energy-efficient products

    a. Policies encouraging investments in equipment and tools needed to manufacture or service energy-efficient equipment

    b. Policies encouraging investment in the development of new innovative products.

Table 7: Some examples of financial barriers for the actors in the market under transformation

Actor	Financial barrier	Context
Customer	Higher upfront cost of an energy-efficient motor system relative to purchase of an inefficient one.	Customer uses capital equipment price to make purchase decision rather than evaluate total cost of ownership.
	Higher upfront cost of energy-efficient motor system relative to repair of existing inefficient one.	Customer uses capital equipment price to make purchase decision rather than evaluate total cost of ownership.
	Inadequate own funds to buy new equipment.	Desire to purchase equipment exists but inadequate own funds available to make purchase.
	Lack of access to bank loans to buy new equipment.	Desire to purchase equipment exists but unable to borrow to make purchase
	Internal Rates of Return (IRRs, a commonly used measure of returns on investments) are low and not at all attractive versus investments in their core business.	Hurdle rates for investing internal capital in industrial facilities are a payback in one – two years.
	View motor systems as infrastructure assets and are not interested to replace unless broken.	Not willing to use their credit or internal budget capacity for noncore business use.
	Lack of awareness and/or no confidence that estimated savings will be realised and can be measured and verified.	Must have confidence that estimated savings will be realised.
Lender	Unable to assess project technical risks or commercial returns from an energy efficiency project.	Project does not meet required lending criteria e.g., adequate security of repayment, rate of return; funding is not provided.
	Transaction size too small.	Transaction costs disproportionate to expected return in small projects.
	Current corporate lending practices require collateral which an energy efficiency project is unable to provide.	Projected future savings from energy efficiency are not treated as collateral.

Supplier	Cannot afford to hold additional, rarely requested, inventory.	At the start of market transformation suppliers are reluctant tie up capital in efficient products they cannot sell quickly.
	The cost of energy-efficient equipment can be higher.	Due to customer barriers (presented above) sales take longer or fall through; finding rare customers who wish to buy energy-efficient equipment is expensive.
	Suppliers lack the capital to buy materials to build products that have been ordered (i.e., provisional sales).	Provisional customer sales have occurred, but suppliers lack capital to provide solution.
	Suppliers lack the capital to upgrade service facilities.	New products can require new servicing approaches, but suppliers lack investment. Capital.
Manufacturer	Manufacturers lack funding for research and development into new MEPS compliant products.	Market transformation seeks to stimulate above the norm levels of product performance that may require above the norm levels of R&D investment; without R&D, funding local manufacturers' market share may be squeezed.
	Manufacturers need to retool to build new innovative products.	Upfront investment in retooling.

Numerous delivery mechanisms exist to enable policymakers to use the financial sources to support the market transformation to energy-efficient motors and motor systems (see Table 8 for examples). Each delivery mechanism will be effective at mitigating a particular financial barrier.

Market analysis should be undertaken to clearly understand and verify the targeted financial barriers in sufficient detail to select an applicable delivery mechanism along an appropriate configuration (e.g., the economic benefit is enough to mitigate the financial barrier for the identified market actors impacted by the financial barrier). The delivery mechanisms described below are not meant to cover the expenses of developing government policies and programmes.

Table 8: Common financing mechanisms for energy-efficient motors and motor systems

Programme Type	Definition/Purpose	Advantages	Disadvantages
Grants	Reduce the up-front costs associated with investing in energy-efficient motors and systems.	Easy implementation. Can accelerate market transformation. In some cases, can be offset through reduced energy subsidies.	Burden on government finances. Can distort normal market pricing. Money can only be given out once.
Tax relief or rebate or accelerated depreciation	Reduce the up-front costs associated with investing in energy-efficient motors and systems.	Uses existing tax system, low administration. • Proven ability to support large volume, productised equipment. • Often used in conjunction with product performance standards to reduce information asymmetry.	Minor burden on government finances. Existing tax system not designed to support efficient technology. This may hamper innovation and support for customised equipment. Only available to taxpayers in good standing.
Credit lines	Development banks provide commercial banks with access to funds at low interest rates with clear conditions for onwards lending to third parties.	Commercial banks lend at more favourable rates for energy efficiency investments.	Provides liquidity but may not overcome the full risk-return profile of energy efficiency projects.
Guarantees	Development banks agree (i.e., guarantee) to take on a level of potential financial losses (e.g., as a percentage of total loss, capped financial amount).	Encourages lenders to enter the energy efficiency market by reducing their risk barriers to entry.	Maybe useful in some sectors (energy-intensive industries) but not others (SMEs).
Insurance	Mitigation of performance risks of the technology not performing as expected.	Could de-risk energy efficiency projects for multiple actors. Like existing products.	Relatively new to market. Limited real-world experience.

Savings based lending	Lending against future savings from energy efficiency projects.	Enables companies and developers to access finance for energy efficiency Projects. Can be closely targeted on demand and supply-side actors.	Risk of default, but experience shows this can be lower than typical bank default levels.
Energy Service Companies (ESCOs)	ESCOs are businesses that secure funding, develop, implement, and assume the technical and commercial risks for energy efficiency improvements. Compensation is normally tied to long-term energy savings being achieved.	Reduces the risk and up-front costs through energy performance contracts. Installation and management costs of assets for efficiency upgrades are included in the Contract.	Can be challenging to measure and verify savings. Profit focus favours investment in products with a short payback. Need strong regulatory and financial institutions. Need case studies that verify estimated energy efficiency savings with proven performance measurement and verification.
Vendor financing and leasing	Reduced upfront capital requirements—consumer rents the asset instead of purchasing it. There is usually an option for the consumer to purchase the asset at a depreciated value eventually.	No impact on Lessee's Profit & Loss statement as lease rental is paid through energy savings. No capital investment required.	Best applied where a mature asset leasing market already exists and when the assets have a current market value that exceeds financed amount.
Utility demand side management	Utility supports energy efficiency investments by electricity users to flatten the load curve. Provides a medium for subsidy/ loan disbursement and repayment.	Reduced upfront costs through demand aggregation and bulk procurement. Ease of repayment through electricity bills in instalments.	More suited for standard energy-efficient motors sold in high volumes than for motor system upgrades that can be very user specific.

6.1 Grants, Rebates, Tax-Relief

Grants, rebates, or tax relief can reduce the up-front investment cost. Combined with the energy cost savings, this improves the expected rate of return on the investment, thereby strengthening the overall business case for investment.

Each of these financial incentives can be used to, for example, influence customer purchase decisions. The size of the financial incentive can be set to encourage the adoption of new technologies (i.e., create additional market demand) or, more subtly, alter purchase behaviour when the need to buy has been proven (e.g., tax relief can provide a financial "rudder effect" encouraging a customer to switch from purchasing an inefficient product to an efficient one).

A grant improves cash flow at the point of purchase, a rebate improves cash flow after the point of confirmed purchase (i.e., a reimbursement), and tax relief improves cash flow either at the time of purchase (e.g., purchase tax or VAT reduction) or at the end of the financial year (e.g., credit, capital allowance). Each requires the purchasers to be able to access different levels of interim capital. Each improves the business case for investment and the rate of return.

CASE STUDY: Motor systems, Switzerland

Switzerland has had policies in place since 2014 to encourage, enable, incentivise, and mandate efficiency improvements in motor systems. The experience gained over the years has produced several best practise case studies.

Financial incentive programs | TOPMOTORS

https://www.topmotors.ch/en/best-practices

CASE STUDY: Additional Depreciation—Energy Investment Scheme, 2023, Netherlands

The Netherlands allow companies investing in high-efficiency motors to avail an additional tax depreciation of 41.5 per cent over and above the customarily allowed depreciation rate for the following types of motors: a) high-efficiency motors >200 kW, with 2-, 4- or 6-, or 8-pole motors which comply with the IE4 efficiency class; b) Ex eb electric motors, designed for direct connection to the electricity grid, which comply with the IE3 efficiency class; c) electric motors designed for variable speed and not directly connected to the electricity grid which comply with the IE5 efficiency class.

On average, companies save about 10 per cent of their investment through lower taxes, on top of the savings in energy costs.

The government has an annual budget for this Scheme and may limit or suspend it if this is exceeded.

Energy Investment Allowance (EIA) | Business.gov.nl

CASE STUDY: FGEnergia Credit Guarantee Program for Energy Efficiency Projects, Brazil

The Brazilian National Energy Conservation Program – Procel is implementing the Credit Guarantee Program for Energy Efficiency (FGEnergia). FGEnergia, with a budget of 45 million Brazilian real (R$) (approximately US$9 million), is a program of the National Bank for Economic and Social Development – BNDES to guarantee credits granted by financial agents for Micro, Small and Medium Enterprises – MSMEs to carry out energy efficiency projects and/or activities. With the FGEnergia guarantee that covers up to 80 per cent of the principal, banks can be more flexible on or even waive conventional guarantees, thus providing access to energy-efficiency finance for MSMEs. Banks may also improve conditions, such as grace periods, terms, and rates, reducing total financing costs.

FGEnergia guarantees projects with a value between R$50 thousand and R$3 million and a duration between 12 and 84 months, with a grace period of up to 24 months. FGEnergia covers a default up to a limit of 15 per cent of the sum of the values released from the contracted operations weighted by the FGEnergia guarantee percentage.In 2023, FGEnergia worked with six financial agents and registered the contracting of the first two operations with a grant guarantee, totalling R$692,200 in value financed and R$533,760 in value guaranteed, with two distinct beneficiaries.

Going forward, the coverage of FGEnergia is being scaled up, and there are prospects for raising additional funds from third parties, both nationally and internationally.

FGEnergia - BNDES

CASE STUDY: Kayseri and Bursa OIZ Loan Support Programmes, Türkiye

As part of a larger "Technology Development in Organised Industrial Zones (OIZs)" project, the Turkish government offered banks a credit line of up to US$100,000 per company for onward lending for projects to replace IE1 motors with IE3 in the Kayseri and Bursa (OIZ) industrial complex. The precondition was that old motors would have to be surrendered and scrapped.

The initial experience was that out of 130 large (above 50 TOE with an average of 100 motors with an average capacity of 45 kW each) energy-consuming firms, only one firm applied for a loan. A survey determined the following reasons for the unwillingness of the other firms to apply for a loan:

- Firms do not want to hand in the replaced motors as it made more economic sense to resell them to the refurbished motors market (60 per cent of respondents)
- Energy efficient motors are not in their short-term investment plan (52 per cent)
- Electricity consumption share of motors is low (40 per cent)
- Do not want a new credit line (37 per cent)
- Do not want to pay for energy audits (35 per cent)
- Using energy-efficient motors already (26 per cent)
- Do not believe the benefits (or profits) from replacement (20 per cent)
- Do not want to allocate time/stop the production (16 per cent)
- Thinks that procedures are complicated/bureaucracy is high (12 per cent)
- Unaware of the support programme (three per cent)

This experience provides insights into the barriers that motor replacement financing programmes could face and would be helpful in the design of similar programmes in the future.

New Generation OIZ Model for Technological Transformation of Industrialists | United Nations Development Programme (undp.org))

6.2 Credit Lines and Partial Risk Guarantees

Lending to energy efficiency projects often lags because local banks' traditional corporate, asset-based lending practices do not allow these to offer attractive project-based financing terms to facility owners or project developers. Also, they cannot evaluate and manage the risks of energy efficiency projects. They are unwilling to invest time to acquire such skills due to the small transaction sizes and the resulting perception of a small-sized market opportunity. Larger governmental and/or international financial institutions driven by green objectives can provide dedicated credit lines (low-interest funds dedicated to lending to energy efficiency projects), technical support, and the sharing of lending risks with local banks[63].

Credit lines are one of the most common instruments used in energy efficiency finance interventions and are often provided at rates that are more favourable than those found in the local market. International experience has shown that credit lines can also provide a stable source of additional funding that can be lent by local banks to suppliers and users to stimulate the supply and demand for energy-efficient equipment. Caution must be exercised where credit lines are used to expand the funding of existing financial products as this can lead to further investment in existing markets reducing transformative change to energy-efficient markets.

Partial risk guarantees, which are usually publicly funded, encourage financiers to expand into markets that are perceived as too risky under normal conditions. The guarantor accepts a fixed percentage of losses incurred by the financier for either performance or credit failure. Partial risk guarantees may be better suited to large projects (e.g., energy efficiency projects at a large energy intensive company) with greater risk-return profiles.

6.3 Insurance

Insurance can mitigate the risk of an energy-efficient technology not performing as expected, covering the losses for the customer, supplier and financier, or a select combination of them. As part of due diligence, the insurer evaluates the technical and economic viability of the energy efficiency project and then offers an insurance product with a risk-weighted premium. Such insurance gives investors confidence that the energy efficiency project can deliver the projected commercial returns using the proposed technology. Improved confidence reduces the financing cost of capital, and this reduced cost of capital may more than offset the insurance premium.[64]

63 IEA (2017) Policy Pathways Brief - Joint Public-Private Approaches for Energy-Efficiency Finance 2017 – Analysis - IEA
64 Principles for Sustainable Insurance – United Nations Environment – Finance Initiative (unepfi.org)

6.4 Savings-Based Lending

Conventionally, loans are secured through the borrower's physical or financial assets. However, company owners and developers can find this securitisation challenging to overcome. SMEs often lack existing financial assets and have limited physical assets (i.e., below the level required for securitisation). Equally, lenders consider SMEs risky investments and ask for prohibitively high rates of return, i.e., interest payment.

Providing savings-based lending can overcome this barrier to capital. International experience has shown that fiscal incentives focused on stimulating savings-based lending can significantly boost the supply and demand for energy-efficient equipment. Such incentives also deliver cost-effective environmental and wide-ranging economic benefits (e.g., cost savings, new jobs, and new markets).

Central to successful savings-based lending programmes have been lender-driven technical verifications of the identified revenue streams due to energy-efficient technology. Such technology reduces energy costs, and these savings can be used to repay the loans.

6.5 Energy Savings Performance Contracting through ESCOs

An energy service company (ESCO) is a commercial business that provides a broad range of turnkey energy solutions, including energy audits, system designs, financing, and implementation of energy efficiency projects. ESCOs represent a mechanism for effectively delivering energy efficiency finance, as funds are provided to the ESCO rather than to the energy user through one or more of the instruments described earlier, such as credit lines. There is no capital cost to the energy user.

ESCOs often act as project developers for a comprehensive range of energy efficiency measures, assuming technical and commercial risks. The difference between ESCOs and other energy efficiency companies is that ESCOs use performance-based contracting. Therefore, their compensation is directly linked to the actual energy savings on the client site. The energy user pays an agreed regular fee to the ESCO, usually lower than the energy cost savings using the ESCO's technology, leaving behind a surplus. An ESCO programme requires strong financing partners and an enabling legal and regulatory framework for success. THE ESCO financing model is not without its challenges – apart from contracting complexity, the projected energy savings depend on usage patterns and energy prices that may vary from estimates.

CASE STUDY: National Energy-Efficient Agriculture Pumps Programme, India

Many governments in emerging economies subsidise energy tariffs to improve affordability or political standing. Subsidies hide the true energy cost and discourage up-front spending and the development of financing mechanisms for energy-efficient technologies. Reducing energy subsidies is only sometimes feasible or desirable because this can conflict with expanding energy access. However, it is possible to reduce energy subsidies by subsidising energy-efficient equipment through grants.

In India, electricity is heavily subsidised and is sometimes free for farmers due to political reasons. With almost no disincentive to energy costs, farmers use inefficient agricultural pumps, as these are cheaper than efficient ones. According to the publicly owned ESCO, Energy Efficiency Services Limited (EESL), there were an estimated 21 million grid-connected agricultural pump sets in India, which consumed about 187 billion kWh of energy every year, accounting for about 18 per cent of national energy consumption at the start of the programme (2016). EESL offers to replace inefficient pump sets with labelled ones. These superior pump sets have a built-in smart control panel, a smart meter, and a SIM card. The SIM card enables the farmer to switch the pumps on and off from his mobile phone, and the smart meter enables him to monitor consumption in real-time.

The costs of the labelled pump sets have been kept down through public tendering and bulk procurement. EESL bears the costs of the pump sets and recovers these through savings in energy subsidies from the state-owned distribution utilities.

The programme is expected to save 50 billion units of energy per year, which translates into an annual savings of approx. INR 200 billion (around US$2.4 billion) on agricultural subsidies. The programme also provides training and awareness to the farmers and technicians on the best practices for using and maintaining energy-efficient pumps. As of August 2023, nearly 246,000 farmers have benefitted from the programme, which is also aligned with the PM-KUSUM Scheme that promotes solar pumps for irrigation.

National Energy Efficient Agriculture Pumps Programme — Vikaspedia

6.6 Vendor Financing and Leasing

Leasing agreements establish a fixed-payment contract where the consumer rents the asset instead of purchasing it. The finance for the leasing contract may be derived from a financial institution, the equipment vendor, or some other source. A country's tax and incorporation laws will have some impact on how the lease operates.

Leasing balances the lease rental with energy savings and, therefore, is neutral to the profit and loss account of the lessee during the payback period. The lease payments to be made by the lessee are fixed and not linked to the achievement of project savings. However, in an industrial context, the asset is usually a bespoke equipment or system and, therefore, is required to be reflected in the user's balance sheet. This is unlike photocopiers and automobiles, for example, which may stay on the lessor's books.

Several different financing structures can be applied, including an "operating lease" whereby the manufacturer offers the lessee a fixed short-term lease and transfers only the right to use the equipment for a fixed monthly rent, after which it remains the property of the owner. Another financing structure is a "hire purchase agreement" allowing for gradual payment for the equipment over the defined operating period, and at the end of the contract the assets, now fully paid off, automatically become the property of the lessee or customer.

6.7 Utility Demand-Side Management

Demand-Side Management (DSM) refers to all market interventions by electricity distribution utilities to flatten the load curve by reducing the ratio of peak to average demand. The economic rationale for doing this is that while investments in power infrastructure are driven by peak demand, the returns on those investments are proportional to the average energy sold. Promoting end-use energy efficiency solutions is one such market intervention.

DSM programmes can aggregate demand, enable bulk procurement, and be used to channel subsidies and loans on favourable terms for investments in energy-efficient motor systems. Energy users repay the loans through energy savings in monthly electricity bills over a certain agreed period. The utility bears the programme costs, which include consumer awareness and information campaigns.

A regulatory driver or enabler is usually needed for DSM programmes.

UNEP´s United for Efficiency has available downloadable material on innovative financing mechanisms:

1. (2019) "Manual of Financing mechanisms and Business Models for Energy Efficiency", which provides an overview of financing mechanisms encouraging energy-efficiency investments in the residential, commercial and public sector.

Available at: https://united4efficiency.org/resources/manual-financing-mechanisms/

2. (2023) Case Studies report with lessons learned from the market-based financing mechanisms deployed in Ghana, Senegal and Rwanda to facilitate consumer purchases of energy efficient appliances.

Available at: https://united4efficiency.org/resources/using-finance-to-accelerate-adoption-of-more-energy-efficient-and-climate-friendly-appliances/

C. General

07 Environmental Sustainability and Health

What?	This chapter provides a summary of the policy and legal framework for designing motor system components for durability, repairability, and recycling, as well as for regulating and mitigating health and safety risks during the equipment's lifecycle.
Why?	Motor system components contain metals, rubber, plastics, and other materials that can be recycled/recovered/reused, as well as small quantities of materials that could be hazardous if simply dumped in a landfill. Ensuring necessary norms and regulations can achieve a "circular economy" objective.
Next?	• Some key questions to keep in mind: • How effectively does the collection of old motor system components take place in our country? • Are regulations for the recycling of metals in place? • Are regulations for the safe handling of hazardous materials in place? • Are norms for safeguarding health and safety in industry in place?

Environmentally sound management policies promote, encourage, incentivise, and mandate the minimisation of the impact on human health and the environment over the life stages of the components of electric motor systems, namely

- **Design:** Policies focus on designing for circularity—durability, repairability, reuse, remanufacturing, and recycling.
- **Production:** Policies focus on the raw materials and production techniques involved in manufacturing the product, including hazardous substances and the risks these may pose to workers' health and safety.
- **Usage:** policies (covered extensively in the preceding chapters) focus on the considerable environmental impact during the use phase (i.e., from indirect power plant-related emissions).
- **Repairs:** policies focus on facilitating repairs during the product's operational life.
- **End-of-Life:** policies focus on establishing, managing, and financing end-of-life collection, recycling and environmentally sound management, and final disposal.

7.1 Policy and Legal Framework

In most countries, overarching national environmental regulations define the legal framework automatically applicable to motor systems suppliers as well. U4E recommends adopting a "Circular Economy Strategy" modelled on the one adopted by the European Union with policies to encourage, incentivise and mandate circularity. A Circular Economy Strategy is a transformative approach to production and consumption that aims to extend the lifecycle of products, reduce waste, and minimise the environmental impact of economic activities. Circularity can be achieved through policies that promote, encourage, incentivise, and mandate durability, repairability, reuse, remanufacturing, and recycling. As for energy-using products and systems, the total environmental impact must be carefully assessed e.g. an old inefficient motor kept in operation often has a more significant environmental impact than replacement with a new, more efficient motor - the environmental impact of manufacturing a new motor (including material extraction) is offset by the environmental impact reduction due to the lower energy consumption of the efficient new motor, and the recycling of the material of the replaced motor.[65]

7.1.1 Designing Motor Systems For Durability

Durable products last longer, require less maintenance and replacement and save resources and energy. Durability also enhances customer satisfaction and loyalty, brand reputation, and competitiveness. Environmental policies should encourage manufacturers to design motor systems for durability (refer to Chapter 12.1 of the "Technical Annex" for techniques to design motors, VSDs, fans, pumps, and compressors for durability).

7.1.2 Designing Motor Systems for Repairability

Policies should

- Require manufacturers to provide professional repairers with access to spare parts, repair information, and tools for up to 20 years (the typical lifetime of motors) after the product is placed on the market. The obsolescence rate for electronics technologies must also be considered and replacement with equivalent sub-assemblies or units should be permissible.

- Prohibit the use of design features that prevent or discourage repair, such as welded parts.

- Provide for easy disassembly, availability of spare parts, and provision of repair manuals.

- Provide a right to repair for consumers, which will guarantee access to affordable and high-quality repair services, spare parts, and repair information.

7.1.3 Designing Motor Systems for Recycling

Environmental policies should require motor system manufacturers to design these for recycling from the beginning by considering the following aspects:

- Material selection: Products should use recyclable, biodegradable, or compostable materials and avoid toxic, hazardous, or non-recyclable materials.

- Products should also use fewer types of materials and avoid mixing incompatible materials that are hard to separate.

- Products should be designed to be easy to disassemble, repair, reuse, or remanufacture.

65 Modelling stock, material, and environmental impacts of circular economy product policies. Trade-offs between early replacement and repair of electric motors Robin Barkhausen a,b,*, Antoine Durand a, Yan Yi Fong b, Vanessa Zeller b, Clemens Rohde a,b a *Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany b Technical University of Darmstadt, Germany*

- Products should also have clear labels or markings that indicate the type and composition of the materials used and how to recycle them properly.

(refer Chapter 12.3 of the “Technical Annex” for techniques to design motors, VSD’s, fans, pumps, and compressors for recycling).

7.1.4 Financing Environmentally Sustainable Management

Recycling is a US$200 billion global industry, with over 800 companies employing more than 1.6 million people in over 70 countries.

The industry focuses on all sources of ferrous and nonferrous metals, plastics, rubber, paper, and e-waste, among others, and is, therefore, much larger in scope than motors alone. The individual businesses in the recycling industry operate and finance themselves as self-sustaining commercial entities without reliance on any form of public finance.

The intrinsic value of the metals used in motor systems, particularly copper, as well as that of other trace elements carried by it and recoverable during copper recycling (such as platinum, palladium, gold, silver, arsenic, selenium, tellurium, nickel, cobalt, tin, zinc), the cast iron or aluminium frame, permanent magnets (if any), magnetic steel etc. ensures that these are invariably sold at the end of life to a recycler, and are not disposed of in a landfill. The recycler recovers the cost of collection, transportation, and processing by selling the reprocessed metals and other materials as raw materials to the respective production chain at a profit.

The recycling industry’s profit motive drives the environmentally sustainable management of motors at the end of their lives and is thus self-financing.

7.2 Health

This section presents an overview of the potential health risks associated with general manufacturing and the operation of heavy machinery.

Handling objects in production, such as trucks and lifting equipment, requires appropriate safe distances, handling, and lifting instructions to avoid safety hazards.

During the production of electric motors, potentially hazardous chemicals are used in the rotor assembly, stator impregnation, rotor die-casting and surface treatment of parts and assembled motors. Workers are exposed to the risk of touching chemicals, inhaling vapours or dust, and the risk of high heat from melted aluminium. Induction heaters used to produce local heating of objects may impose a risk through electromagnetic radiation. Testing of motors involves potentially dangerous levels of voltage and current. Induction heaters used to produce local heating of objects may impose a risk through electromagnetic radiation.

Women in particular may be more prone to negative health impacts, as exposure to certain chemicals and heavy metals in manufacturing can have reproductive health implications among women of child bearing age, including fertility issues, pregnancy complications, and birth defects.[66]

66 More information available at: “Gender and the sound management of chemicals and waste”, SAICM, UNEP 2017. https://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_6_gender_document.pdf

Documented risk assessments are recommended to ensure workplace health and safety of critical work phases—the scope and depth depend very much on the requirements of local health and safety authorities and applicable health and safety legislation.

In general, the intent is to classify and rank risks by probability of occurrence and degree of hazard (e.g., using a scale from 1 to 3). The multiplication of probability and degree of hazard results in the risk severity from minimal to unbearable and helps to define the necessary mitigating actions, for example:

- Using protective clothing or eyewear
- Hearing protection
- Local removal of potentially hazardous vapours, gases, or dust, required ventilation to do so
- Specific work instructions for safe operation and ergonomic work methods
- Regular health inspections to track and identify symptoms and levels of exposure that might be related to identified risks.

The repair of motors includes some of the same work as new production, so similar precautions are needed.

In the use of motors, the risks are like any operation of heavy machinery.

It Is important to note that all machinery, tools, and personal protective equipment (PPEs) should be designed to accommodate different body types and sizes to reduce the risk of injury for workers of all genders. Related training programs should address gender-specific risks and encourage a culture of safety that recognizes and mitigates these risks.

08 Resources

The following resources are available to support countries and regions in the development of energy-efficient motors and motor systems policies and regulations:

- American Council for an Energy-Efficient Economy (ACEEE) —a nonprofit, 501(c)(3) organization, acts as a catalyst to advance energy efficiency policies, programmes, technologies, investments, and behaviours. Focusing on the United States of America, ACEEE seeks to harness the full potential of energy efficiency to achieve greater economic prosperity, energy security, and environmental protection. ACEEE carries out its mission by: (1) conducting in-depth technical and policy analyses; (2) advising policymakers and programme managers; (3) working collaboratively with businesses, government officials, public interest groups, and other organizations; (4) convening conferences and workshops, primarily for energy efficiency professionals; (5) assisting and encouraging traditional and new media to cover energy efficiency policy and technology issues; and (6) educating consumers and businesses through our reports, books, conference proceedings, press activities, and websites. ACEEE was founded in 1980 by leading researchers in the energy field. Since then, it has grown to a staff of about fifty. ACEEE focuses on energy policy (federal, state, and local), research (including programmes on buildings and equipment, utilities, industry, agriculture, transportation, behaviour, economic analysis, and international initiatives.European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) — the members of CEMEP are the national associations in Europe that represent manufacturers of electric motors, variable speed drives, and uninterruptible power supplies. The organization allows industry to co-ordinate actions at the European level. Its Industry Group, Low-Voltage A.C. Motors, aims to support fair competition in the field of LV Motors in Europe through innovation and advanced technology in conjunction with technical expertise and practical policymaking assistance to relevant E.U. authorities. CEMEP publishes leaflets and position papers on energy efficiency in motor systems.

- CLASP — A nonprofit international organization promoting energy efficiency standards and labels (S&L) for appliances, lighting, and equipment. CLASP improves the environmental and energy performance of appliances and related systems, lessening their impact on people and the world. CLASP develops and shares practical and transformative policy and market solutions with global experts and local stakeholders. Since 1999, CLASP has worked in over fifty countries on six continents, pursuing every aspect of appliance energy efficiency, from helping structure new policies to evaluating existing programmes.

- The Climate Group — an award-winning, international nonprofit with offices in Greater China, North America, India, and Europe. Its goal is to help leaders transition to a prosperous low-carbon economy driven by the rapid scale-up of clean and renewable energy. It partners with the world's most influential business, state, regional, finance and civil society leaders. For over a decade, it has worked to demonstrate the economic and business case for the low-carbon economy and create the political conditions necessary for a strong global framework that addresses climate risks and maximizes climate opportunities. The global climate deal struck at the Paris COP represents a new beginning: the chance to accelerate our low-carbon future. The Climate Group works with governments, businesses, and investors to implement the Paris Agreement, holding them accountable where appropriate through reporting mechanisms and ensuring that the emissions curve is bent downward to secure a thriving, clean economy for all.

- EASA — an international trade organization of more than 1,700 electromechanical sales and service firms in 70 countries. Through its many engineering and educational programmes, EASA provides members with a means of keeping up to date on materials, equipment, and state-of-the-art technology. EASA also provides engineering consulting services to members and works with manufacturers, industry organizations and government agencies to promote better repair standards. It also sponsors numerous training and educational programmes. EASA has developed an international accreditation programme for service centres based on the standard *ANSI/EASA AR 100: Recommended Practice for the Repair of Rotating Electrical Apparatus.*

- European Commission Joint Research Centre (EC JRC) —the European Commission's science and knowledge service employs scientists to conduct research and provide independent advice and support to European Union policy. It conducts a biennial international conference on energy efficiency in motor system Energy Efficiency in Motor-Driven Systems (EEMODS) in odd years, bringing together policymakers and energy efficiency experts from industry, research labs, universities, and standardisation organizations to discuss the progress of electric motor systems energy efficiency policies and technologies.

- European Council for an Energy-Efficient Economy (eceee) — a membership-based nonprofit association. As Europe's largest and oldest NGO dedicated to energy efficiency, they generate and provide evidence-based knowledge and analysis of policies, and they facilitate co-operation and networking. ECEEE members are found among private and public organizations, as well as among all those professionals from all sectors who share ECEEE's goals. ECEEE offers governments, industry, research institutes and citizen organizations a unique resource for evidence-based knowledge and reliable information. ECEEE promotes the understanding and application of energy efficiency in society and assists its target groups—from policymakers to programme designers to practitioners—with making energy efficiency happen. ECEEE is registered as a Swedish organization and has its secretariat in Stockholm. ECEEE participates actively in the European policymaking process, the organization participates in several European Union policymaking and advisory forums, and frequently comments on European energy policy through position papers and responses to public consultations. ECEEE has also held expert workshops and briefings for policymakers.
  It has co-operated with the European Commission, the Parliament and the European Union presidency to hold expert seminars. These institutions appreciate the competence and integrity offered by ECEEE's network of members.

- IEA — International Energy Agency is an autonomous organization that ensures reliable, affordable, and clean energy for its 28 member countries and beyond. The IEA's four principal focus areas are energy security, economic development, environmental awareness, and engagement worldwide. Founded in response to the 1973/4 oil crisis, the IEA's initial role was to help countries coordinate a collective response to major disruptions in oil supply through the release of emergency oil stocks. The IEA has a staff of 260 enthusiastic professionals (energy analysts, modellers, data managers/statisticians, technicians, secretaries and support staff) working together on global energy challenges.

- IEC —International Electrotechnical Commission is a global intergovernmental standards organization of 82 member countries and 82 affiliate countries based in Geneva. IEC creates and publishes international standards related to electrical equipment. IEC standards provide the foundation for international harmonisation of electric motor energy efficiency classification and testing standards. IEC Standards have been referenced extensively throughout this Policy Guide.

- 4E EMSA— Electric Motor Systems Platform EMSA, an IEA Technology Cooperation Programme supported by eight IEA member countries and the European Commission. EMSA promotes the opportunities for energy efficiency in motor systems by disseminating best practice information worldwide. It supports the development of internationally harmonised test standards and policies to improve the energy performance of new and existing motor systems. EMSA has published a series of reports related to motor systems since 2009, and publishes a bi-annual Newsletter.

- IEC Conformity Assessment Association (IECEE) — the Association uses IEC Standards and members reciprocally to recognise conformity certificates. IECEE comprises 57 member countries, nearly 80 participating National Certification Bodies and close to 500 Testing Laboratories. The IECEE Certification Body scheme aims for “one product, one test, one certificate.” The IECEE Global Motor Energy Efficiency Programme initiative aims to create a regime under which a single test in an accredited test laboratory anywhere in the world will be recognised in any member country.

- IIP — a not-for-profit organization funded by the Climate-Works Foundation to promote the efficient use of energy in industry. IIP maintains global databases on Industrial Efficiency Policies, Programmes, Financing and Technology. IIP has a country focus on China, India, and the United States of America.

- ICA — a not-for-profit organization of the global copper industry, with the mandate to promote the sustainable use of copper. ICA has conducted regional and national programmes for the promotion of electric motor energy efficiency through policies, standards, and regulations in developed and developing countries since 1994. It has been a leading participant in international efforts and actions for the advancement of the cause of energy efficiency and climate change mitigation. Among its various initiatives, ICA sponsors and administers Leonardo Energy, a dedicated portal for sustainable energy professionals. Leonardo Academy hosts several free on-line training programmes including on energy-efficient motors and motor systems suitable for self-learning at the trainee’s own pace and convenience. The training material comprises a video recording, presentation slides and a short learning test.

- IEE – the UNIDO IEE programme builds on more than thirty years of experience and unique expertise in the field of sustainable industrial development. By combining policy development assistance and training for all market players, UNIDO IEE aims to remove the key barriers to continuous improvement of energy efficiency in industries. The programme hinges on two core concepts: energy system optimisation and energy management standards.

- ISO – International Organization for Standardization is an independent non-governmental organization with a membership of 170 national standards bodies. It is based in Geneva. ISO creates and publishes international standards related to mechanical equipment. ISO standards provide the foundation for international harmonisation of mechanical applications’ energy efficiency classification and testing standards. ISO Standards have been referenced extensively throughout this Policy Guide.

- LBNL — a member of the United States of America laboratory system supported by the Department of Energy (DOE) - United States of America. It is managed by the University of California and conducts research across a wide range of scientific disciplines. The Energy Analysis and Environmental Impacts Division, International Energy Studies Group at LBNL performs economic, engineering, and environmental analyses in support of efficiency standards and regulations development internationally, including for electric motors.

- National Electrical Manufacturers Association (NEMA) — in addition to its other activities, the association has been at the forefront of efforts to transform motors markets in the United States of America and internationally to the highest efficiency levels. NEMA publishes over 600 standards, application guides, white papers, and technical papers.

- National Institute of Standards and Technology (NIST) — a physical United States of America-based science laboratory supported by the United States of America Department of Commerce with a focus on measurement infrastructure. The National Voluntary Laboratory Accreditation Program (NVLAP) provides third-party accreditation to testing and calibration laboratories based on ISO/IEC 17025:2005, including for the energy efficiency testing of motors. NVLAP has accredited test laboratories outside the United States of America in China, Mexico, and Viet Nam.

- SEAD Initiative – an initiative of the Clean Energy Ministerial, SEAD seeks to engage governments and the private sector to transform the global market for energy-efficient equipment and appliances. SEAD initiated an international collaboration of technical and policy experts in solid-state lighting, promoting alignment and improvements in the scope and stringency of international standards and labeling programmes. Current SEAD member governments include Australia, Brazil, Canada, the European Commission, Germany, India, Indonesia, Mexico, Russian Federation, Saudi Arabia, South Africa, Sweden, Republic of Korea, United Arab Emirates, United Kingdom of Great Britain and Northern Ireland; and China and the United States of America maintain an observer status.

D. Technical Annex

09 Components Of A Motor System

What?	A brief review of the technical aspects of variable speed drives, electric motors, fans, pumps, and air compressors as components of a motor system.
Why?	Provides the technical basis for the discussions and policy recommendations in Part I - U4E Motors Policy Guide as well as Part II - U4E Model Regulations for Motor Systems.

The main components of an electric motor system are: an electric motor, a variable speed drive (VSD) and a driven application i.e., a pump, a fan, or an air compressor[67].

9.1 Variable Speed Drives

A Variable Speed Drive (VSD) is a power electronic device that varies the speed of an electric motor. Other names are used for such devices as well e.g. Variable Frequency Drives (VFD's), Inverters, Converters, Complete Drive Modules (CDMs) or simply "Drives".

A VSD converts the fixed voltage and frequency of the power supply into a variable voltage and frequency that it supplies to the motor. It consists of three main components: a converter, a DC link (capacitors), an inverter, and auxiliaries such as the control power supply, an electronic control circuit, a user interface, and a cooling fan. The converter (comprising a diode bridge rectifier or an IGBT bridge in the case of an "active infeed") converts the AC power from the mains to DC power. The DC link (comprising an inductor-capacitor filter circuit) smooths out the DC power and provides a stable DC input to the inverter. The inverter (comprising an IGBT bridge circuit) inverts the DC power back to AC power with a variable frequency and voltage that can be adjusted to control the motor speed.

The IGBTs are switched on and off through the Pulse Width Modulation (PWM) technique at a much higher modulating frequency that causes the output voltage waveform to contain the desired fundamental frequency and unwanted spectral components at the switching frequency and its integer multiples but only much lower harmonics of the fundamental than a rectangular waveform. The output current resulting from this voltage waveform being applied to the inductive motor consequently shows a nearly sinusoidal waveform with a small, superimposed ripple current.

67 See for more detailed information and guidelines for motors, VSDs and applications: IEC TS 60034-31:2021, Ed.2 Selection of energy-efficient motors including variable speed applications – Application guidelines.

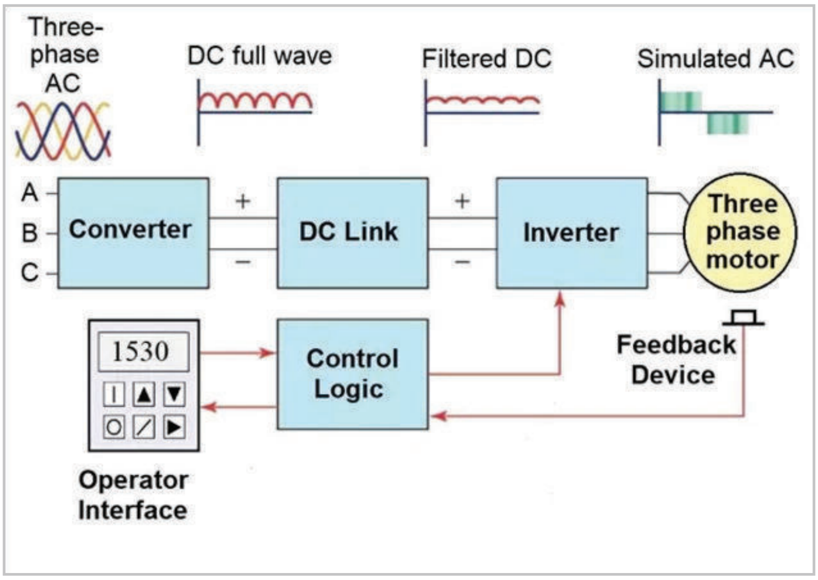


Figure 17: Main components of a Variable Speed Drive [in blue][68]

9.2 Electric Motors

9.2.1. Electric Motor Basics

An electric motor is a device for converting electrical energy into mechanical energy, i.e., motion.

The two main components of a motor are a stationery assembly of electromagnetic coils arranged around a cylindrical axis, called the stator winding, and a moving mechanical shaft called the rotor, which is free to rotate concentrically within the stator. The rotor is mounted on bearings at both ends of a sturdy cast-iron or steel housing, which is rigidly attached to a terrestrial surface.

9.2.2 Relevant Electric Motor Technologies

There are several electric motor technologies, as elaborated below. Of these, **induction motors (IM)** are the most common due to the simplicity of their design, ruggedness and low-cost.

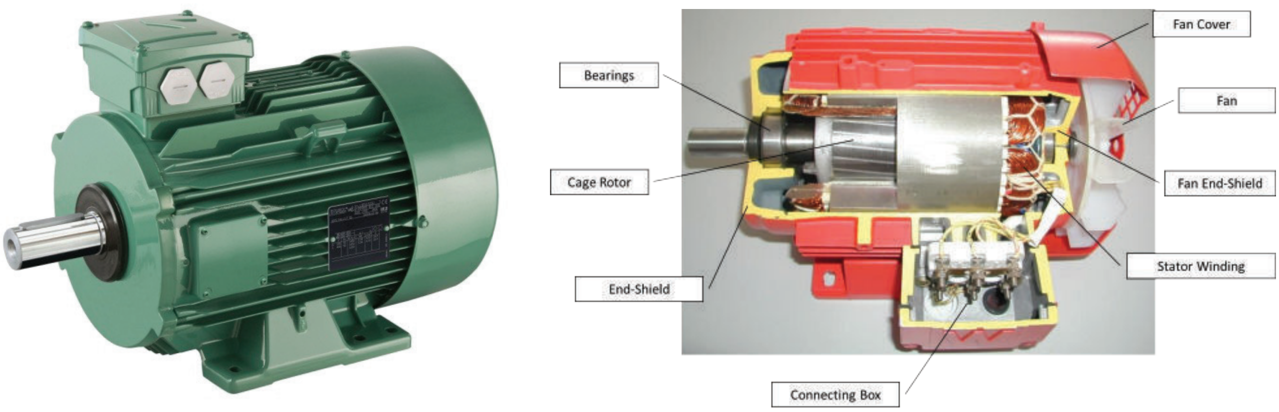


Figure 18: An induction motor[69]

68 (Image courtesy: www.plctechnician.com)
69 Cutout motor image courtesy : Institute of Systems and Robotics, University of Coimbra, Portugal University of Coimbra

A set of electric currents is passed through the stator electromagnetic coils to set up a primary magnetic field, which rotates in space around its axis, although the coils themselves do not move. The speed of rotation is proportional to the frequency of the electric supply. The relative movement of this primary magnetic field across the rotor coils or cage causes a current to flow in these by the principle of electromagnetic induction, giving this type of motor its name, “induction motor”. This rotor current, in turn, sets up a secondary magnetic field around the rotor. The primary magnetic field pulls the secondary magnetic field, and thus the rotor assembly along with it, as it rotates in space around its axis. In turn, the rotor drives the equipment attached to its shaft, completing the conversion from electricity to motion.

A **synchronous motor** (SM) is so named because its speed is proportional to the frequency of the 3-Ph AC supply. Unlike the induction motor, the secondary magnetic field is independent of the primary magnetic field and is produced either from a separate DC supply or by a permanent magnet. The latter design is also known as a **permanent magnet (PM)**motor. Unlike induction motors, synchronous motors cannot start directly when connected to a supply. These require an electronic controller or an additional winding like an induction motor rotor for starting. The latter design is called a **line start permanent magnet** motor (LS-PM).

A **reluctance motor** has only one magnetic field, created by the stator winding. The rotor is constructed of a ferromagnetic material and is shaped in such a way that its position within the stator magnetic field is always unstable except in one position (the point of least reluctance). When the stator magnetic field rotates, the rotor moves along with it. Design variants comprise “switched reluctance” motors (SRM) and “synchronous reluctance” motors (SYN-RM). By virtue of a cylindrical design, the synchronous reluctance motor has an equal number of stator and rotor poles and thus overcomes the torque pulsations of the switched reluctance motor, which must have unequal poles to rotate. Unlike induction motors, **reluctance motors** require an electronic controller with or without rotor position feedback for their operation.

As the name suggests, the **DC motor (DC)** operates on a DC supply. Unlike the induction motor, the secondary magnetic field is independent of the primary magnetic field and is produced either from a separate DC supply or by a permanent magnet. DC motors are used in applications with DC power, such as from a storage battery or with AC power and a switched-mode power supply. Examples include computer hard drives, CD/DVD players, cordless power tools, small battery-operated vehicles, automotive auxiliaries and toys. DC motors are also used in special large drive applications such as steel mill main drives and in highly efficient BLDC (Brushless DC) ceiling fans.

The **universal motor** derives its name from its ability to operate on both DC and single-phase AC. Its design is similar to that of a DC motor. Its use is limited to low-duty-cycle, high-speed applications, such as drilling machines, portable tools, and food processors.

9.2.3 Induction Motor Characteristics

Power Supply

The motors covered by energy-efficiency policies are fed by a 1-phase or 3-phase AC supply with a voltage less than 1000 V (low-voltage) and a frequency of 50 Hz or 60 Hz.

Power

Motors are classified according to the output mechanical power these deliver at the motor shaft at rated speed into Micro (<0.12 kW), Small (0.12-0.75 kW), Medium (0.75-375 kW) and Large (375 kW – 1'000 kW).

Speed and Number of Poles

The synchronous speed of a motor in revolutions per minute (RPM) is proportional to the supply frequency and inversely proportional to the number of magnetic poles[70] of the motor according to this formula

$$\text{Synchronous speed (RPM)} = \frac{120 \times \text{supply frequency}}{\text{no. of poles}}$$

Table 9: Typical synchronous speeds of motors

Number of poles	2	4	6	8
Synchronous speed in RPM at 50 Hz Supply	3,000	1,500	1,000	750
Synchronous speed in RPM at 60 Hz Supply	3,600	1,800	1,200	900

The most used pole configuration is 4-poles.

For induction motors, the rated speeds are slightly lower than the synchronous speeds. For this reason, these are also alternatively known as **asynchronous motors.**

Torque

The rated power (kW) and rated speed (RPM) of a motor together determine the rated torque (in Newton-meters or Nm) that the motor delivers at its shaft by the relationship

$$\text{Rated Torque (Nm)} = 9{,}550 \times \frac{\text{Rated Power (kW)}}{\text{Rated speed (RPM)}}$$

70 A physical magnet is conventionally described as having a north pole and a south pole, analogous to the earth's magnetic axis. The terminology is carried over to electromagnetism, where each magnet comprises a north-south pole pair. Thus a 6-pole motor comprises three electromagnets arranged symmetrically around a cylindrical axis, each with a north and a south pole.

Physical size

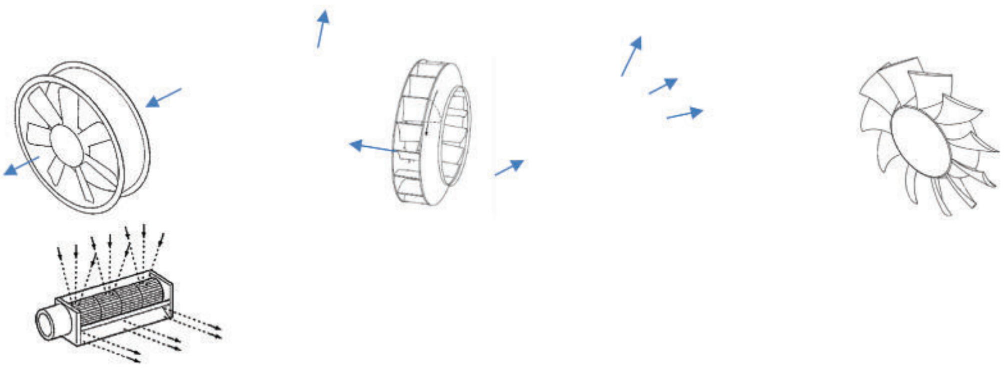
To ensure mechanical interchangeability, the mounting dimensions and shaft height of a standard motor from its base measured in mm must conform to the IEC 60072-1:2022 standard set by IEC for both 50 Hz and 60 Hz motors (called IEC frame sizes) or by NEMA for 60 Hz motors (called NEMA frame sizes). A typical IEC frame size series is 100,112,132,160 and so on. This constraint on shaft height indirectly determines the length of the motor for a given type/design/kW/pole combination as well. This is reflected in the standardised designation by the letters S (short), M (Medium), L (Large) following the frame size number (e.g., 100L, 112S, 132M)

9.3 Fans

A fan is a machine with a bladed impeller on a shaft that is rotated to deliver a continuous flow of gas, typically air passing through it, and whose work per unit mass does not exceed 25 kJ/kg. The fan is driven by a prime mover (usually an electric motor) that may or may not be equipped with a VSD. The fan may or may not have a housing. A fan may have a free inlet or a ducted inlet. Similarly, it may have a free outlet or a ducted outlet.

Fan types

- An 'Axial fan' propels gas in the direction parallel to the rotational axis of the impeller with a swirling tangential motion.
- In a 'Centrifugal fan' the gas enters the impeller in a direction parallel to the rotational axis and leaves in a direction perpendicular to that axis.
- A 'Mixed flow fan' means a fan in which the gas path through the impeller is intermediate between the gas path in fans of the centrifugal and axial types.
- In a 'Cross flow fan' the gas path through the impeller is in a direction essentially at right angles to its axis, both entering and leaving the impeller at its periphery.



Axial flow flow | Centrifugal flow | Mixed flow | Cross

Figure 19: Basic types of flow in fans[71]

71 Source: Ecodesign fan review 2015

Industrial Fans are the subject of this Guide. Other applications include:

- Cooling: Fans can lower the temperature of a room, a device, or a person by blowing air over them, e.g. ceiling fans, desk fans, and laptop fans.

- Ventilation and Exhaust: Fans can improve the quality of air in a space by removing stale or polluted air and bringing in fresh or filtered air, e.g. ventilation ducts and exhaust fans for bathrooms and kitchens.

9.4 Rotodynamic Pumps

A rotodynamic[72][73] pump is a rotating hydraulic machine that causes a liquid to flow under pressure. At the basic level, a pump consists of:

- An impeller that rotates and imparts velocity to the liquid.

- A casing that channels the velocity of the liquid to cause it to flow out under pressure at the pump discharge point in a controlled and stable manner.

- A mechanical assembly comprising the pump shaft mounted on bearings, the sealing mechanism that keeps the pump from leaking, and structural components designed to handle the stresses and loads imposed on the pump during operation.

- The pump is driven by a prime mover usually an electric motor, that may or may not be equipped with a VSD (see Figure 21).

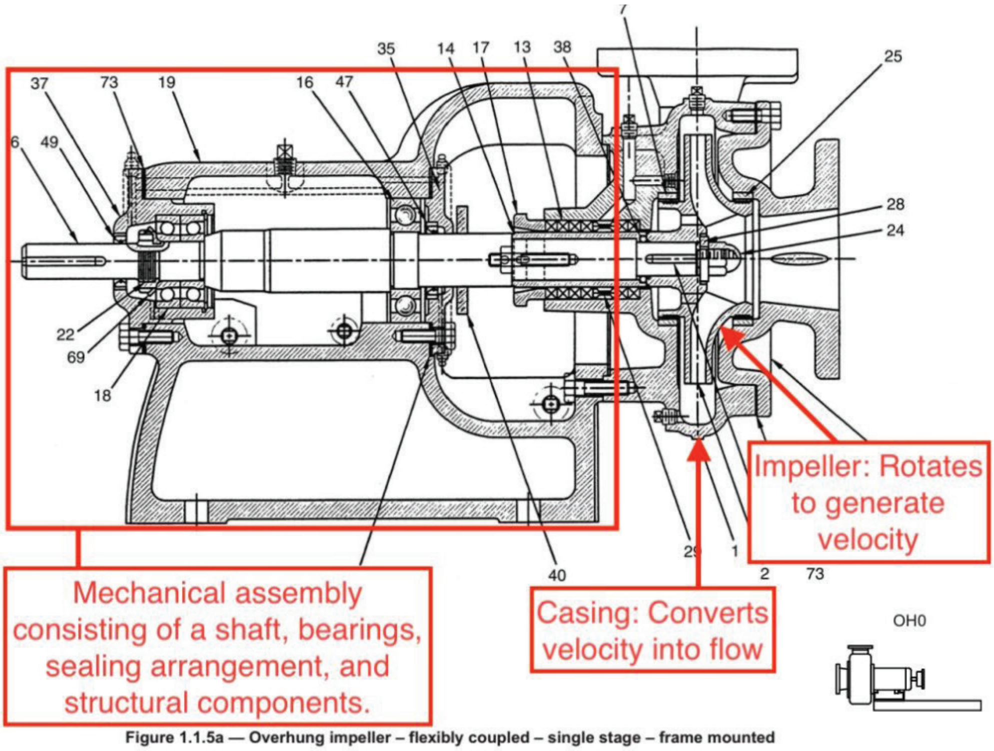


Figure 20: Frame-Mounted End-Suction Pump[74]

72 The term "centrifugal" (=moving outwards from the centre) is often used to refer to pumps that use rotation to impart energy to a liquid, but this includes mixed and axial-flow impeller designs, which makes it technically less accurate than the more general term "rotodynamic".
73 There are other pump types e.g., positive displacement pumps that move a liquid by trapping a fixed amount of it in a chamber and then forcing it out by reducing the volume of the chamber. These are not a subject matter for this policy guide.
74 Courtesy of the Hydraulic Institute, Parsippany NJ, www.Pumps.org

The different types of rotodynamic pumps are essentially permutations and combinations of different types of impellers and casings. Some common examples are centrifugal pumps, which have a curved or radial impeller and produce high head and low flow; axial flow pumps, which have a propeller-like impeller and produce low head and high flow; mixed flow pumps, which have a combination of radial and axial impellers and produce moderate head and flow; and regenerative turbine pumps, which have a ring-shaped impeller with many small blades and produce very high head and very low flow. Each type has its own advantages and disadvantages, depending on the required head, flow rate and efficiency.

Rotodynamic Pump types

- End Suction Own Bearing (ESOB) rotodynamic water pumps are a type of centrifugal pump that has a single inlet and outlet on opposite sides of the casing.

- These pumps are suitable for applications that require high flow rates and low pressures, such as irrigation, cooling, and water supply systems. These are also easy to install and maintain, as these do not require any external lubrication or alignment.

- End suction close coupled (ESCC) rotodynamic water pumps are a type of centrifugal pump that have the impeller mounted directly on the motor shaft which is extended to also become the pump shaft.

- These are commonly used for water supply, irrigation, heating and cooling systems, fire protection, and industrial applications.

- End suction close coupled inline (ESCCi) rotodynamic water pumps are a type of centrifugal pump of which the water inlet of the pump is on the same axis as the water outlet of the pump.

- Vertical multistage (MS-V) rotodynamic water pumps are a type of pump that use rotating impellers to increase the pressure and flow of water. These consist of multiple stages, each with an impeller and a diffuser, stacked vertically on a common shaft. The water enters the pump at the bottom stage and is pushed by the impeller to the next stage, where it gains more pressure and velocity. The process repeats until the water reaches the top stage and exits the pump.

- Vertical multistage rotodynamic water pumps are suitable for applications that require high pressure and flow, such as irrigation, water supply, firefighting, boiler feed, and industrial processes.

- Submersible multistage (MSS) Rotodynamic water pumps are a type of water pump that can operate under water, in boreholes or wells. They consist of a series of impellers that rotate and create pressure to move the water through the pump. The impellers are mounted on a shaft that is connected to a motor, which is also submerged in the water. The motor can be either oil-filled or water-filled, depending on the design and application of the pump. Submersible multistage Rotodynamic water pumps are used for various purposes, such as irrigation, drinking water supply, groundwater extraction, and industrial processes.

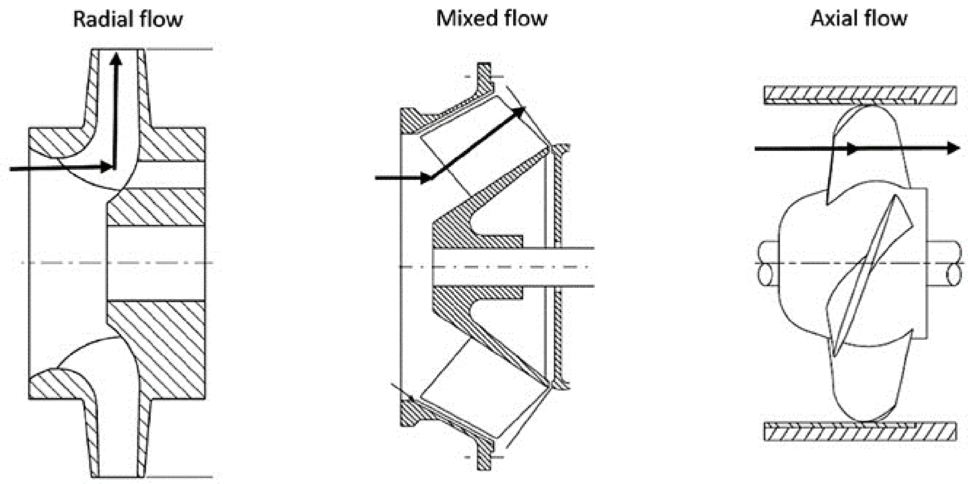


Figure 21: Basic types of Rotodynamic pumps[75]

9.5 Air Compressors

Compression of a gas is a thermodynamic process whereby the gas enters a compressor in one state (of pressure, volume, and temperature) and exits it in a state of increased pressure and temperature with a corresponding decrease in volume. Compressors can be classified into two main types: positive displacement and dynamic. Positive displacement compressors trap a fixed amount of gas in a chamber and then squeeze it, while dynamic compressors speed up the gas through a rotating impeller or a nozzle and then slow it down in a diffuser. The main difference between the two types is that positive displacement compressors produce a constant pressure, while dynamic compressors produce a variable pressure. These are widely used in various industries, such as refrigeration, air conditioning, power generation, and gas transmission. Compressors have many applications and benefits, such as improving the efficiency of thermodynamic cycles, increasing the mass flow rate of gases, and enabling the transport of gases over long distances.

Positive displacement air compressors (the subject of this guide) convert atmospheric air into pressurised air stored in a tank. The pressurised air can be transported and transformed into practical work such as powering pneumatic tools, inflating tyres, or spraying paint. There are different types of air compressors based on how they compress air, such as piston-type, rotary screw and centrifugal. Each type has advantages and disadvantages depending on the application and the required pressure level.

A rotary screw compressor typically comprises two very closely meshing spiral rotors to compress the gas. Gas enters at the suction side and moves through the threads as the screws rotate. The meshing rotors force the gas through the compressor, and the gas exits at the end of the screws. The working area is the inter-lobe volume between the male and female rotors. It is more significant at the intake end and decreases along the length of the rotors until the exhaust port. This volume change is the compression. In an oil-flooded rotary-screw compressor, they are lubricating oil bridges the space between the rotors, both providing a hydraulic seal and transferring mechanical energy between the rotors, allowing one rotor to be entirely driven by the other. In an oil-free compressor, the air is compressed entirely through the action of the screws without the assistance of an oil seal. These have a lower discharge pressure and are used in applications where the spillage of oil is not acceptable.

75 image courtesy www.pumpsandsystems.com

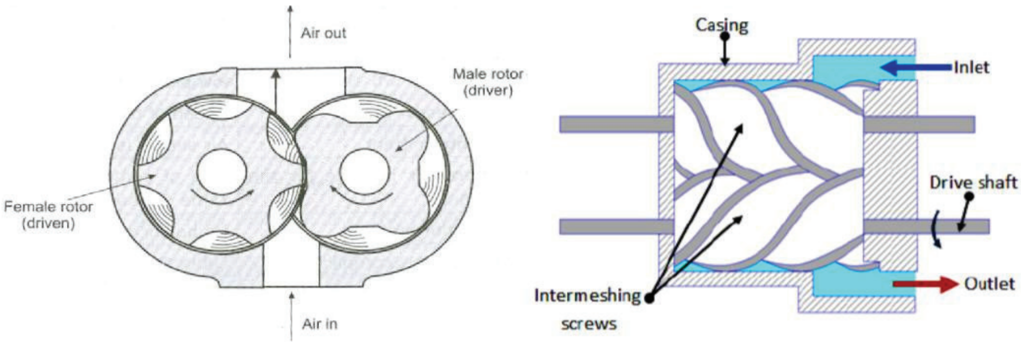


Figure 22: Rotary Compressors Principle[76]

A reciprocating compressor comprises a piston-cylinder with inlet and outlet valves. A crankshaft converts the rotary motion of a motor into the reciprocating motion of the piston. When the piston moves down, it creates a vacuum inside the cylinder and the inlet valve opens to allow atmospheric air to enter the cylinder. When the piston reaches its lowest position and reverses, the inlet valve closes and traps the air inside the cylinder. As the piston moves up, it compresses the air inside the cylinder. The pressure and temperature of the air increase and its volume decreases. When the piston reaches its highest position, it pushes the compressed air out of the cylinder through the outlet valve. The outlet valve opens and allows the compressed air to enter the tank through a check valve.

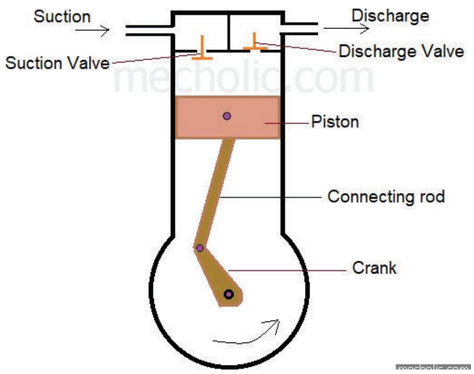


Figure 23: Reciprocating Compressors Principle[77]

9.6 Electric Motor Systems

An electric motor system comprises (see Figure 25):

- **Power Equipment:** The distribution transformer, which feeds the low-voltage bus, switchgear, meters, protection, command, and control.

- **Optional Starter or Variable Speed Drive:** When the motor operates at a fixed-speed, power is drawn directly from the main power supply. If a lot of power is needed to start a fixed-speed motor, an additional soft-start may be incorporated in the system. When the speed of the motor needs to vary, an electronic speed controller (alternatively known as a variable speed drive, variable frequency drive, inverter, or converter) is used.

- **An electric motor**

76 Image courtesy www. learnmech.com
77 Image courtesy www.mecholic.com

- **Mechanical Transmission:** The motor shaft may be coupled directly to the driven equipment through a coupling, a gearbox, a belt and pulley, or a chain and sprocket arrangement. There could additionally be an electromagnetic clutch for decoupling and a drum or disc brake for stopping quickly.

- **Driven Equipment:** This could be a water pump, a fan or blower, a gas compressor, a conveyor to move materials, or some type of production machine.

- **Mechanical Controls and Process Components:** The remainder of the process can include pipes to carry liquids or gases, and valves, throttles, and dampers to control the flow of liquids or gases.

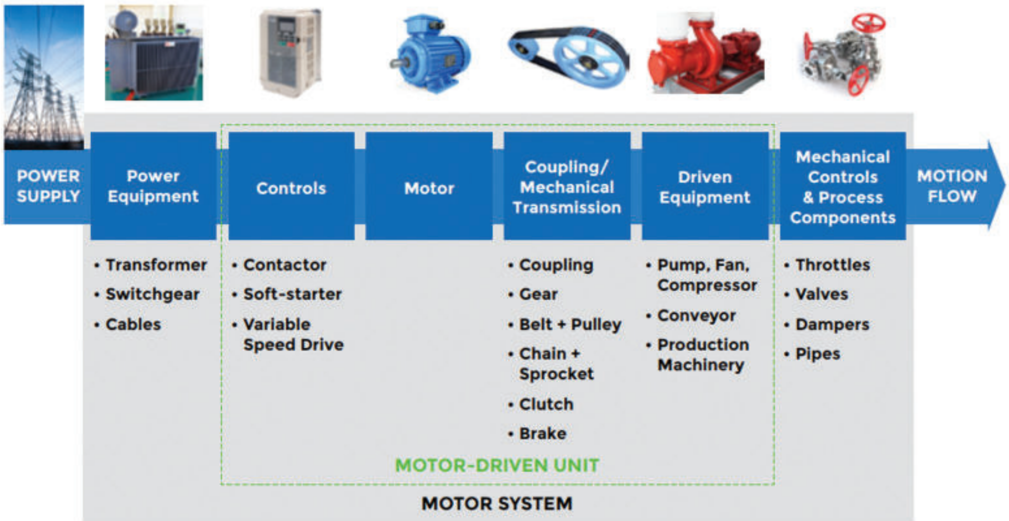


Figure 24: Components of a motor system[78]

78 Modified from the original figure created for the 2017 edition of the U4E Motors Policy Guide jointly with the Institute of Systems and Robotics, University of Coimbra.

10 Energy Efficiency Metrics

What?	An overview of the metrics used world-wide to define the energy efficiency of variable speed drives, electric motors, fans, pumps, and compressors as well as of complete motor systems. An overview of energy efficiency standards and regulations worldwide.
Why?	Provides the technical basis for the discussions and policy recommendations in Part I - U4E Motors Policy Guide as well as Part II - U4E Model Regulations for Motor Systems

The conventionally used metric of energy performance is energy-efficiency, i.e., the percentage of electrical power that is used productively, specified at a unique operating point. An alternative metric that is increasingly being used for motor systems is a comparison of the aggregate energy used in an application over a defined period with an idealised benchmark.

10.1 Energy Efficiency of Electric Motors

Sources of Energy Losses

The process of converting electrical energy into mechanical energy delivered at the motor shaft incurs losses, as it must:

- Overcome resistance to the flow of current in the electrical coils of the stator and the rotor (called “stator I2R” and “rotor I2R” losses respectively)
- Set up the stator and rotor magnetic fields, parts of which leak (called “core losses”)
- Compensate for electrical losses caused by the magnetic fields (part of core losses)
- Overcome the friction in the mechanical bearings (part of “windage and friction losses”)
- Overcome the air resistance to the rotor and fan (part of “windage and friction losses”)
- Compensate for additional load losses[79] (called stray load losses).

This portion of the input electrical energy that is not converted into usable output mechanical energy is lost as heat.[80]

The relative proportion of the individual energy loss components and their variations with motor size is shown in Figure 26.

79 In addition, motors operated through variable frequency drives have heat losses due to their non-sinusoidal waveforms
80 A more detailed treatment of energy loss components of induction motors is available in IEC TS 60034-31:2021

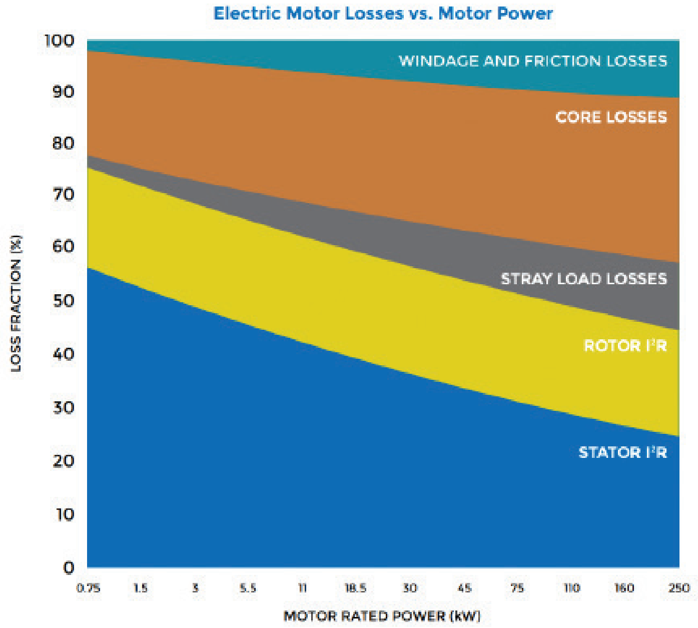


Figure 25: Typical fraction of losses in 50-Hz, four-pole squirrel cage induction motors[81]

Energy Efficiency

The percentage of the input electrical energy converted into usable mechanical energy is defined as the energy efficiency of a motor. The International Electrotechnical Commission (IEC) is an international standards organization that prepares and publishes standards for electrical equipment.

IEC 60034-30-1:201482 categorises fixed-speed electric motors based on their energy efficiency as IE1, IE2, IE3 or IE4 (highest efficiency defined as on date). Similarly, IEC TS 60034-30-2:2016[83] classifies variable-speed electric motors as IE1, IE2, IE3, IE4 or IE5 (highest efficiency as on date).

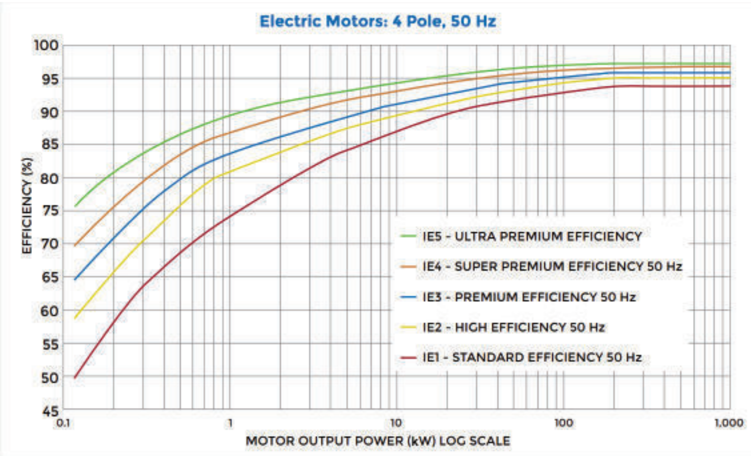


Figure 26: Example of IEC motor efficiency levels for a 4-pole motor operating at 50 H, similar curves exist for motors operating at 60 Hz[84]

81 de Almeida, Anibal T., and others (2014) EuP Lot 30: Electric Motors and Drives. ISR University of Coimbra and Atkins.
82 IEC 60034-30-1:2014 Efficiency classes of line operated AC motors
83 IEC TS 60034-30-2:2016 Efficiency classes of variable speed AC motors
84 IE1 to IE4 curves are derived from the efficiency tables in the IEC 60034-30-1:2014 Standard. Although efficiency

Improving Induction Motor Energy Efficiency

The energy efficiency of induction motors can be improved by incorporating the design improvements shown in Figure 28, as well as through improved manufacturing practices. In practice, motor manufacturers typically use a combination of design improvements that depend on the prevailing relative costs of the materials.

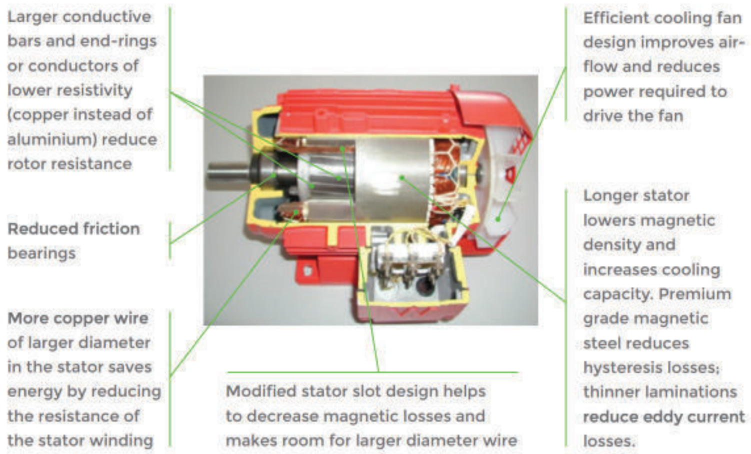


Figure 27: Induction motor design improvements for higher efficiency[85]

A relatively small improvement in the energy efficiency percentage is equivalent to a substantial reduction of energy losses. By way of illustration, in the example of a 45 kW, 4 pole, 50 Hz motor, the difference in the efficiencies of IE4 and IE1 motors is only 3.7 per cent, but this is equivalent to a 47 per cent reduction in energy losses, as can be seen in Table 1

Table 10: Comparison of efficiency classes for a 45 kW, 4-pole 50 Hz motor (2014)

Efficiency Class	Losses (Watts)	Loss reduction (%)	Energy Efficiency (%)
IE1	4,073		91.7
IE2	3,335	-18	93.1
IE3	2,771	-32	94.2
IE4	2,170	-47	95.4

Improvements in induction motor design have ensured a steady reduction of losses and increases in energy efficiency over the years. Figure 29 shows the progressive reduction of losses in the best available design of a 45 kW, 4-pole induction motor since 1960. It shows that any motor built in 1990, if still in operation, would be less efficient than IE1, the lowest efficiency class today. This underscores the energy savings potential from the replacement of old motors and the risks of locking-in motor inefficiency given their long life.

tables are not provided for IE5 in the Standard, the IE5 curve is based on the goal stated in the Standard to reduce losses by around 20 per cent compared with IE4 in future editions. Source: IEA 4E EMSA.
85 Source: Institute of Systems and Robotics, University of Coimbra, Portugal

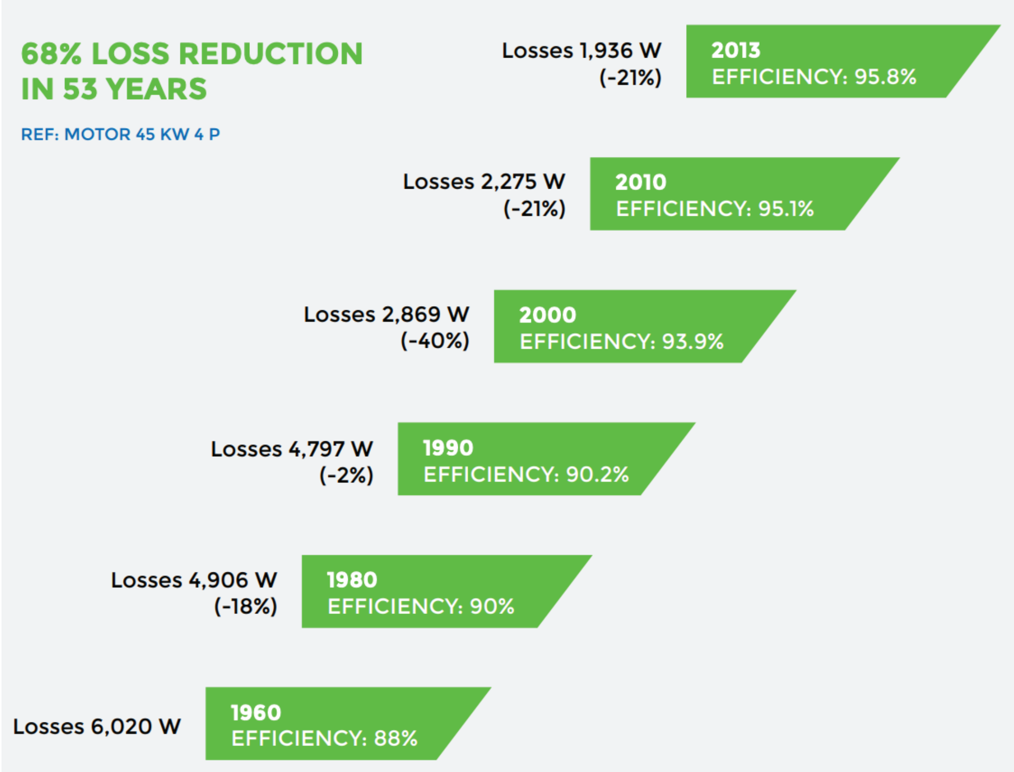


Figure 28: Induction motor energy efficiency improvements over the years — Example of 45 kW, 4- pole 1960 – 2013

A comprehensive treatment of the subject can be found in the 2011 IEA publication "Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems".

The energy efficiency metric of a Power Drive System (PDS) i.e. a system that consists of an electric motor and a Variable Speed Drive, is defined as efficiency class IES0 to IES2 for Power Drive Systems, in the standard IEC 61800-9-2:2017 Ed.1[86], see the next paragraph.

10.2 Energy Efficiency Metrics of Variable Speed Drives (VSD's)

Sources of Energy Losses

The main sources of energy losses in a VSD are:

- On-state and Switching losses in the IGBTs and free-wheeling diodes of the inverter section;
- On-state losses in the diodes of the converter section, alternatively On-state and Switching losses in the IGBTs of the converter section;
- An input inductor or filter is sometimes provided to smooth harmonics, and this causes losses.
- Losses in the DC link;
- Losses in current conductors;

86 IEC 61800-9-2:2023 Ed.2, Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters.

- Stand by and control losses;

- Losses in cooling fan (if any).

Energy Efficiency Metric for VSD's

IEC 61800-9-2: 2017 has defined IE ("International Efficiency") codes for the energy efficiency of VSDs as below:

The losses of a theoretical "Reference" VSD (termed as a "Reference Complete Drive Module" in the standard) have been calculated using a "semi-analytical model". This Reference VSD has been assigned the Energy Efficiency class "IE1".

A VSD is classified as IE1 if its relative losses are within ±25 per cent of the losses of the Reference VSD.

A VSD is classified as IE0 if its relative losses are higher than the losses of the Reference VSD by 25 per cent or more.

A VSD is classified as IE2 if its relative losses are at least 25 per cent lower than the losses of the Reference VSD.

The energy efficiency metric of a Power Drive System (PDS), i.e. a system that consists of an electric motor that operates in conjunction with a Variable Speed Drive is defined as efficiency class IES0 to IES5 for Power Drive Systems, in the standard IEC 61800-9-2:2023 Ed.2[87]. This metric is not yet (2024.04) applied in MEPS regulations.

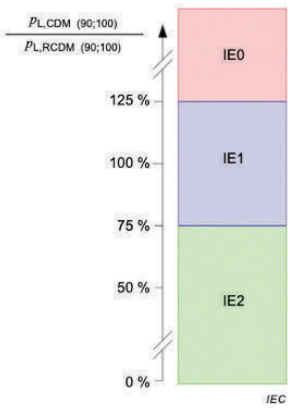


Figure 29: Relative losses of IE codes for VSDs (reference VSD=100 per cent) as defined in IEC 61800-9-2: 2017

10.3 Energy Efficiency Metrics of Fans

Sources of Energy losses

There are various sources of energy losses in a fan system:

- Friction between the gas stream and the impeller surface as well other rotating and stationary parts in its path including the fan housing and ducting.

87 IEC 61800-9-2:2023 Ed.2, Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters.

- Fan bearings.
- Mechanical vanes, throttles, dampers, or valves that may be provided to vary the flow rate at the outlet of a fixed-speed fan.
- In case a transmission belt is used between the motor and the fan instead of a direct coupling.
- Compression losses.
- Losses in the variable speed drive and the motor.

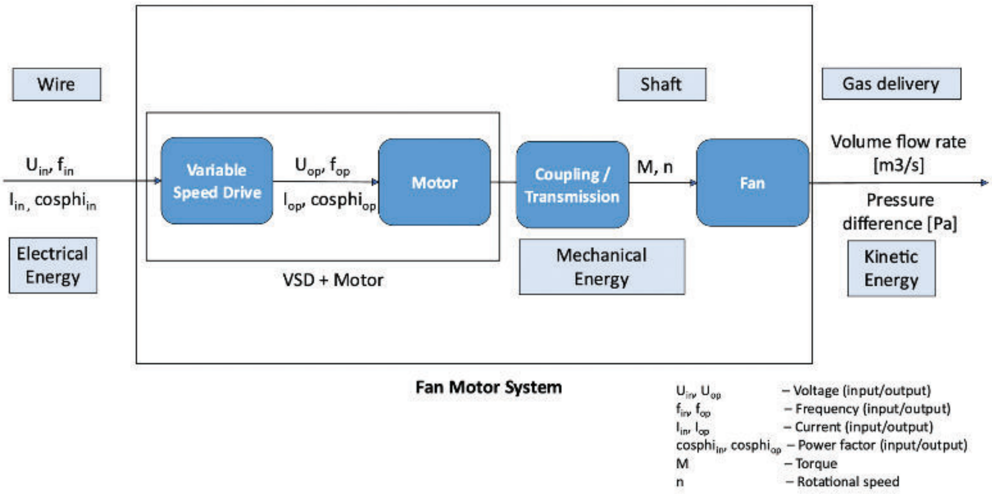


Figure 30: Energy conversion in a Fan Motor System

Fan Energy Efficiency

The “air-to-shaft” energy efficiency of a **standalone fan** is the ratio between the output power of the fan (=energy delivered by the fan to the gas per second) and the input mechanical power to the fan (=mechanical energy delivered at the fan shaft per second by the motor and transmission) *at a given operating point (pressure, flow).* It is to be noted that a fan may or may not be equipped with a motor when placed on the market or put into service.

Energy efficiency regulations for fans refer to terms like static pressure, dynamic pressure, total pressure, stagnation pressure, and Mach number. These terms are defined below.

- Static pressure is the pressure the air applies to the walls perpendicular to the airstream.
- Dynamic pressure is the pressure that results from the movement of air through the fan. It is related to the air’s kinetic energy and depends on the air’s speed and density.
- Total pressure is the sum of all static and dynamic pressure, reflecting the total increase in mechanical energy imparted by the fan.
- Stagnation pressure is the static pressure at a point in the airflow where velocity is zero, and all kinetic energy has been converted into pressure energy (is-entropically).
- The Mach number is a dimensionless quantity in fluid dynamics primarily used to determine the approximation with which a flow can be treated as an incompressible flow.

Different metrics have been developed to specify, measure, and regulate fan efficiencies. The ISO standard ISO 12759:2010, Fans — Efficiency classification for fans, includes four parts defining different fan efficiency metrics:

1. **Fan Efficiency Grade (FEG)** is an "air-to-shaft" metric that classifies standalone fans into different grades according to their total efficiency at their best efficiency operating point (BEP). FEG is a two-digit classification of fan designs according to impeller size by the standard ISO 12759-3:2019, Part 3. A fan with a higher FEG is more efficient than one with a lower FEG at their respective BEP operating points.

2. **Fan Motor Efficiency Grade (FMEG)** is an "air-to-wire" metric that extends FEG by including the motor and transmission as well as the VSD (if present) in addition to the fan. FMEG is a two-digit parameter ("N") defined in ISO 12759-4: 2019, Fans — Efficiency classification for fans — Part 4. The minimum energy efficiency a fan must achieve at its best efficiency operating point (BEP) is derived from the FMEG parameter by way of equations that depend on the type and size of a fan as well as whether there are ducts at its inlet and/or outlet. A fan with a higher FMEG is more efficient than one with a lower FMEG at their respective BEP operating points.

3. An efficiency vs. airflow plot is a steep bell curve for a fan. This means that a fan with a lower FEG or FMEG operating close to its peak efficiency operating point may paradoxically consume less energy than another with a higher FEG or FMEG operating further away from its peak efficiency operating point. Therefore, a fan must operate near its peak efficiency to realise the benefits of a high FEG or FMEG.

4. **Fan Energy Index (FEI)** is an "air-to-wire" efficiency metric to be published as ISO 12759-6, Efficiency classification for fans — Part 6. It is the ratio of the fan electrical input power of the selected fan at the desired duty point over a reference electrical power (of a reference fan); this is not necessarily the fan's best efficiency point. This enables the selection of a fan system that is the most efficient at the desired duty point. If the selected fan system is more efficient than the reference fan system, the FEI will be more than 1 and vice-versa. A fan system with an FEI of, e.g., 1.1 will save approximately 10 per cent of energy compared to a fan with an FEI of 1.0.

10.4 Energy Efficiency Metrics for Rotodynamic Pumps

Sources of Energy losses

There are three main types of energy losses in a rotodynamic pump:

- Hydraulic losses are caused by the fluid's interaction with the impeller and the pump's casing. These include friction losses due to viscous drag, shock losses due to sudden changes in flow direction or velocity, and eddy losses due to swirling flows.

- Mechanical losses are caused by friction between the pump's moving parts, such as bearings, seals, and couplings. These also include windage losses due to air resistance and noise losses due to vibration and sound emission.

- Volumetric losses are caused by fluid leaking from the high-pressure side to the low-pressure side of the pump through clearances, gaps, or valves.

There are additional sources of energy losses in a pump system:

- In case a transmission belt is used between the motor and the pump instead of a direct coupling.
- Losses in the variable speed drive and the motor.

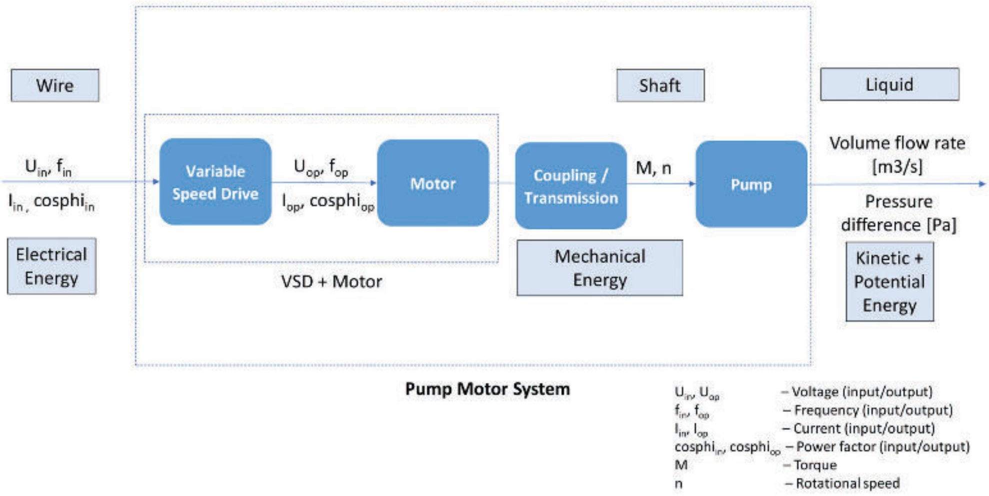


Figure 31: Energy conversion in a Pump Motor System

Pump Energy Efficiency

Hydraulic pump efficiency is the percentage of the mechanical input power at the pump shaft that is transferred by the pump to the liquid.

Different metrics have been developed to specify, measure, and regulate pump efficiencies.

Efficiency Index (EI)

In China, the standard GB19762 defines and specifies the water pump (from now on the pump) basic requirements, the pump efficiency, and the minimum allowable energy efficiency values and evaluating values of energy conservation of centrifugal pump for fresh water. The standard only addresses the efficiency of the pump.

Minimum Efficiency Index (MEI)

The metric used in the U4E model regulations is the MEI index (Minimum Efficiency Index). The MEI is a dimensionless indicator for hydraulic performance and a measure of the quality of the pump's sizing in relation to performance. The higher the MEI value, the better the sizing of the pump about the performance, and the lower the annual energy consumption due to the use of the pump.

Pumps available on the market are given a percentile ranking as a standalone product (i.e. not including motor and drive) using a mathematical calculation based on efficiencies at the Best Efficiency Point (BEP), 75 per cent of the BEP (part load), and 110 per cent of the BEP (overload). For example, if a pump has an MEI of 0.4, that means 40 per cent of the pumps available on the market are less efficient than that pump. Thus, the higher the MEI, the greater the pump's efficiency. The MEI applies specifically to water pumps. This metric is defined in standard EN16480 and has been used in the first generation of European Union pump regulations.

In the European Union MEPS for clean water pumps (Regulation 547/2012), a MEI = 0.7 is defined as a benchmark value, meaning that the pumps with a MEI > 0.7 are considered to have the best possible pump design. The difference between MEI = 0.4 and MEI = 0.7 is about 3.5 per cent-points in energy efficiency[88].

Energy Efficiency index (EEI)

The EEI is a pump-unit energy efficiency index that includes motor controls (VSD) and transmission in addition to the basic pump and considers the load profile and duty cycle. EEI represents a ratio between the average consumption of the pump unit and the reference pump consumption. The lower the value, the better the pump unit. It has specific load and duty profiles applicable for the European Union market to particular pumps e.g., circulators (i.e. in heating systems) and clean water pumps and is described in the European standards EN 16297-x series (covering wet rotor circulators) and EN 17038-xseries (covering general requirements, single stage pump units, booster sets and submersible multistage pump units respectively).

The EEI has been adopted in the European Union Ecodesign regulations covering circulators (EC No. 641/2009 and 622/2012) and is envisaged to be included in the revised European Union regulation currently under preparation for clean water pumps (with differences in load and duty profile though).

Pump Efficiency Index (PEI)

The PEI is a pump efficiency metric like the EEI, adopted by Department of Energy (DOE) - United States of America, and includes controls (motor, VSD) in addition to the basic pump. It also considers a load profile and duty cycle.

There are two indices - PEICL (constant load) and PEIVL(variable load). PEICL applies to pumps sold without continuous or noncontinuous controls. PEIVL applies to pumps sold with either continuous or noncontinuous controls. Pumps available on the market were ranked (without controls) according to their "Pump Energy Rating" (PER), which is a weighted average of the pump's energy performance at specific load points. The baseline (PERSTD) was established at the 25th percentile. The PEI of a particular pump is simply the ratio of its PER to the PER of the baseline pump.

$$PEI_{CL} = PER_{CL} / PER_{STD} \qquad \text{(constant load)}$$

$$PEI_{VL} = PER_{VL} / PER_{STD} \qquad \text{(variable load)}$$

A PEI greater than 1.00 indicates that the pump consumes more energy than allowed by the DOE's energy conservation standard and does not comply. A value less than 1.00 indicates that the pump consumes less energy than the level required by the standard and is complying. The PEI of a specific pump can be established either by a physical test or through calculations.

10.5 energy Efficiency Metrics for Air Compressors

Sources of Energy losses

The main types of energy losses in an air compressor are:

- **Friction losses:** These are the losses due to the friction between the moving parts of the compressor, such as pistons, cylinders, valves, bearings, etc.

88 Ecodesign Pump Review EC 547/2012, EC 2018.

- **Leakage losses:** These are the losses due to the leakage of air from the compressor system. Leakage losses depend on the pressure difference between the inlet and outlet of the compressor and the quality of the seals and fittings.

- **Heat losses:** These are the losses due to the heat transfer from the compressor to the surroundings.

- **Pressure drop losses:** These are the losses due to the pressure drop in the pipes, fittings, valves, filters, regulators, etc. that connect the compressor to its load.

- There are additional sources of energy losses in a compressor system:

- In case a transmission belt is used between the motor and the compressor instead of a direct coupling.

- Losses in the variable speed drive and the motor.

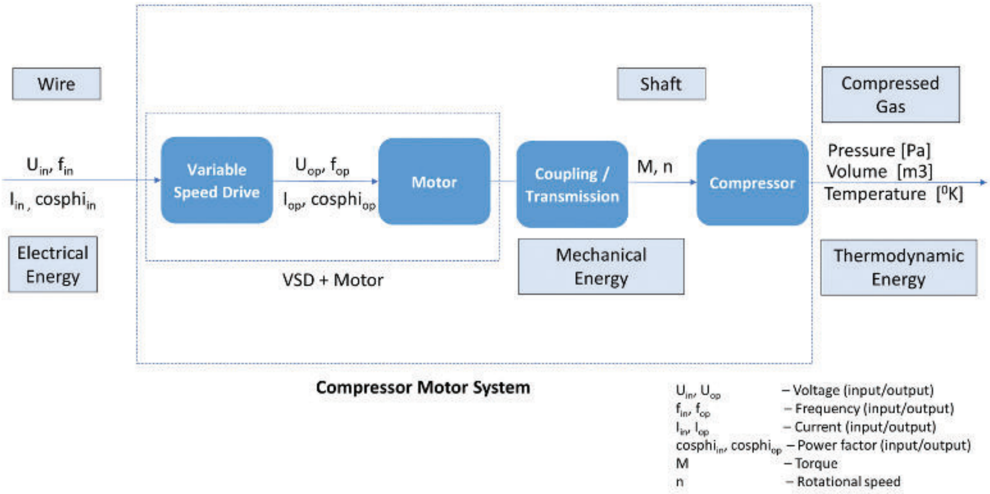


Figure 32: Energy Conversion in a Compressor Motor System

Efficiency Metrics

Isentropic Efficiency: (United States of America, European Union)

In thermodynamics, an isentropic process is a theoretical but useful construct in which there is no increase in entropy, which is not possible in practice. Isentropic power is the power theoretically required in an ideal compressor to compress an ideal gas from a given inlet pressure to a given discharge pressure under constant entropy. Shaft power is the mechanical power required at the drive shaft of a practical compressor to compress the given gas from a given inlet pressure to a given discharge pressure. Isentropic efficiency is the ratio of the isentropic power to the shaft power.

The isentropic efficiency makes it possible to quantify the energy losses of the compressor when compared to an ideal isentropic process. Isentropic efficiency and the methods for testing it are defined in the international test standard ISO 1217:2009/Am. 1:2016 for positive displacement compressors. It is used as a metric in United States of America regulations.

The metric isentropic efficiency allows an easier comparison of energy efficiency of standard air compressor packages, as it is a dimensionless efficiency value. The efficiency is based on an assessment of the basic package of a compressor, which is the most basic unit that can operate safely, reliably and continuously, at harmonised standard rating conditions (defining air temperature, moisture, reference inlet pressure, and temperatures of cooling media) at a single outlet pressure. The isentropic efficiency of variable speed packages is a weighted average of the efficiency at different volume flow rates.

Specific Power Use (China)

Specific power use is the required input shaft power per unit of compressor actual volume flow rate. It is defined in ISO 1217:2009 and is used in Chinese regulations. It enables an easy calculation of the energy consumption and costs.

Comparing both metrics shows that Isentropic Efficiency is more universal applicable as it does not vary with the actual pressure, see also Figure 35.

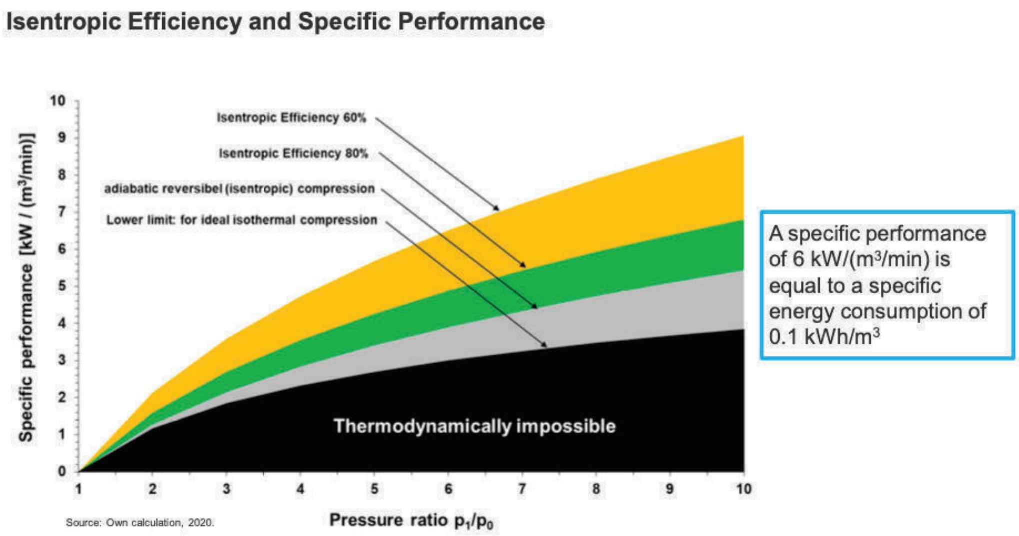


Figure 33: Isentropic Efficiency and Specific Performance[89]

10.6 Motor System Efficiency – Extended Product Approach

The theoretical energy efficiency of a motor system at any given operating point (a given combination of flow and head in the example of a pump) can be derived from the standalone energy efficiencies of individual components at the same given operating point through simple multiplication as shown in the Figure 36. However, component level efficiencies are provided by manufacturers for only a limited number of operating points and not for any operating point; interpolation of losses and efficiencies of components can resolve this for the motor and VSD (i.e. PDS) with IEC TS 60034-31:2021 and data coming from efficiency models and curves from the driven equipment, see Figure 37.

89 P. Radgen, IER, Motor Summit 2020, Switzerland

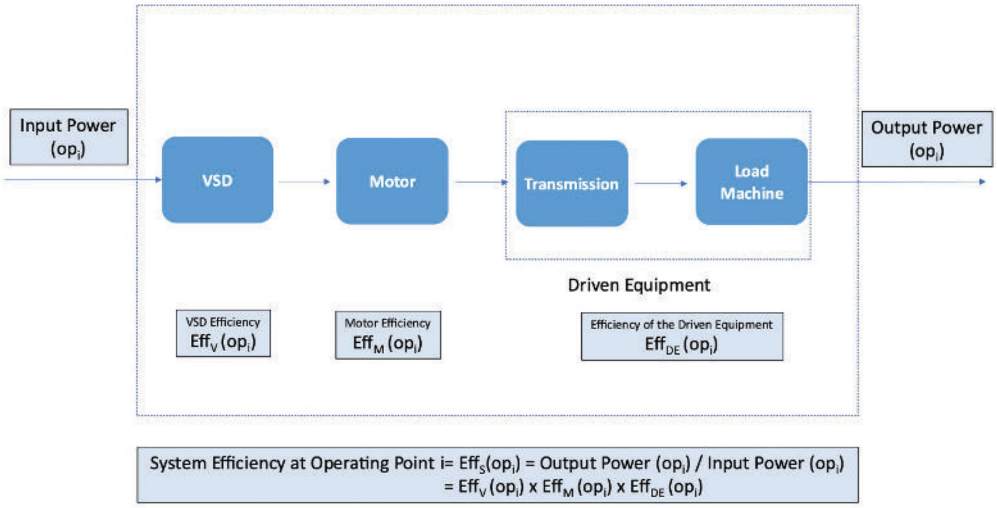


Figure 34: Theoretical system efficiency at any given operating point i (opi)

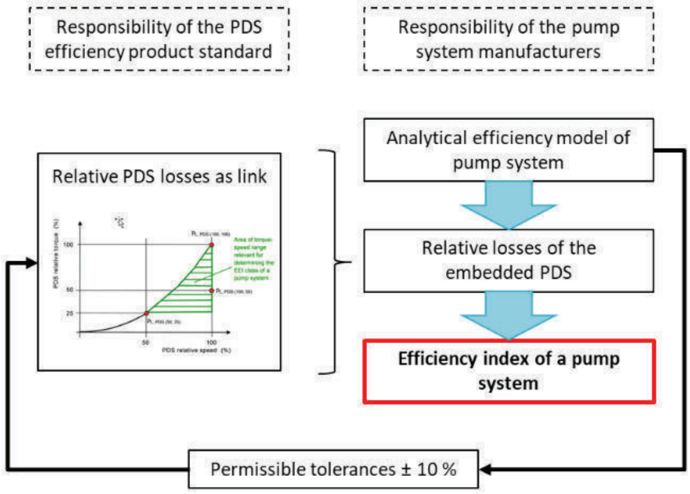


Figure 35: Example of how the SAMs of the PDS and the pump system shall interact with the resulting efficiency index of a pump system[90]

Besides a practical motor system does not operate at any one idealised operating point incessantly. In practice, the system operating point has a wide range, and it varies over time according to the requirements of the application. Further, the load on the motor depends on the torque vs. speed profile of the load machine. Consequently, a combination of the most efficient components at one idealised operating point does not ensure the most efficient motor system and the most energy savings in a practical application.

90 source: IEC 61800-9-1:2017 Ed.2 CDV

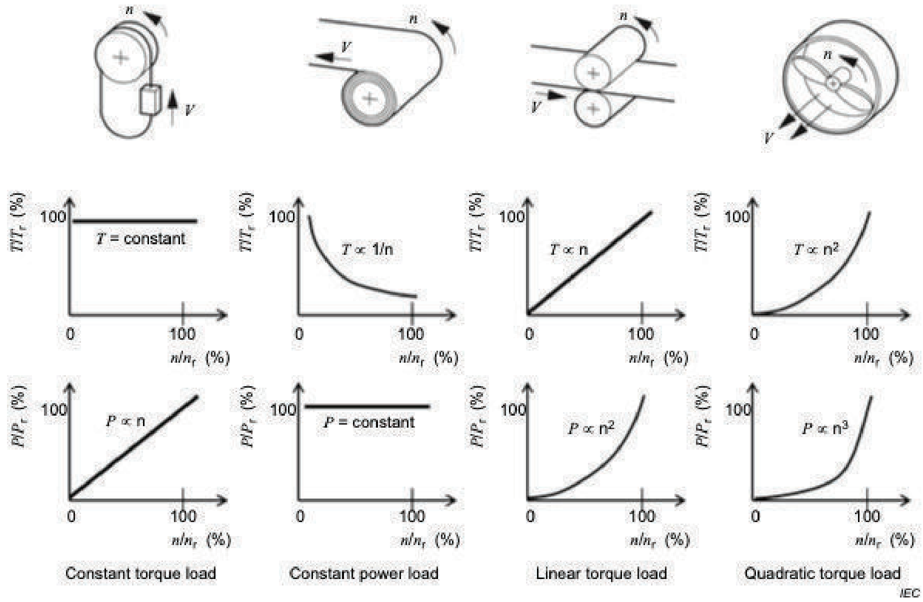


Figure 36: Typical Torque vs. Speed characteristics of load machines[91]

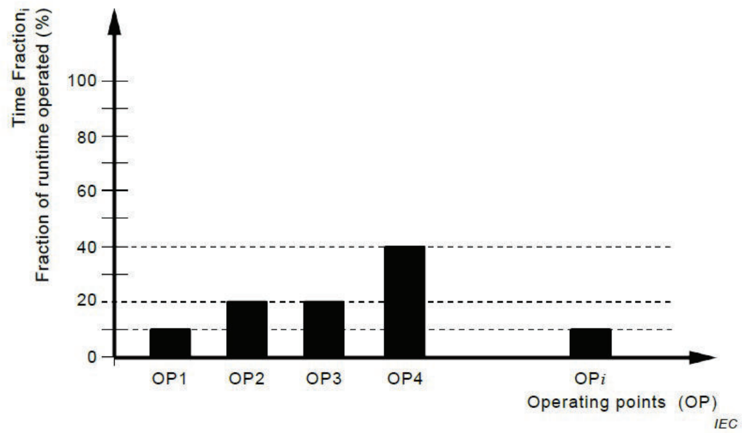


Figure C.2 – Example of operating points over time

Figure 37: Example of Load vs. Time characteristics of an application[92]

It is with these considerations that the standards IEC 61800-9-1:2017 and IEC 61800-9-2:2017 have introduced the "Extended Product Approach" (EPA) to determine the Energy Efficiency (EE) of a motor driven system. This approach provides a methodology using "Semi-Analytical Models" (SAM) to determine the relative power losses of

- Motors at any operating point from a manufacturer's published data of power losses expressed in percentage of the rated output power at the following different operating points of speed and torque respectively: (25;25) (25;100) (50;25) (50;50) (50;100) (90;50) (90;100).

- VSD's at any operating point can be determined from a manufacturer's published data of power losses in percentage of the rated apparent output power at the following different

91 source: IEC 61800-9-1:2017 Ed.2 CDV
92 Source: IEC 61800-9-1:2017 Ed.2 CDV

operating points for relative motor stator frequency versus relative torque-producing current (0;25) (0;50) (0;100) (50;25) (50;50) (50;100) (90;50) (90;100); as well as standby losses, generated when the VSD is powered up but is not providing current to the load.

- The IEC standard 60034-2-3 ED2:2023 (FDIS) includes an Informative Annex with suggestions for additional operating points in the overspeed area (100-200 per cent speed) and the overtorque area (100-125 per cent; <100 per cent speed), covering fan specification.

- Driven equipment at any operating point.

An optimal motor system for the given application can then be constructed by matching the appropriate Motor and VSD to the torque vs. speed characteristic (load profile) of the load machine, and then to the load vs. time characteristic (duty profile) of the application. This would result in a combination of components (VSD, Motor, Load Machine) that provides the maximum energy savings.

The standard IEC 61800-9-2 : 2023 ed.2 defines Efficiency classes IES1 to IES5 for Power Drive Systems (i.e. motor and VSD).

10.7 Improving the Energy Performance of Motor Systems

Very often, more energy can be saved by optimising the motor system and changing operating practices than by merely using more efficient individual components.

Right-sizing

Getting the motor size right is an easy way to maximise efficiency. Motors typically operate at peak efficiency when at 75 per cent load, but they are often oversized for the application as margins of safety in design, manufacturing, and procurement cascade one on top of the other. Sometimes, these are oversized out of concern for the power quality (e.g. wide voltage fluctuations) or due to inaccurate assumptions about what is needed to drive the system.

Adding a Capacitor

Another simple measure is to install capacitors for compensating the reactive power drawn by motors, which is usually necessary to meet the power utility's requirements of a minimum power factor for the industrial plant. This reduces the current drawn from the main power supply, the energy losses in upstream equipment, and the size of the upstream power equipment.

Adding a Variable Speed Drive

In conventional pumps, compressors, fans and exhausters, the motor is run at a fixed-speed and the flow of liquid or gas is adjusted mechanically with a valve, throttle, or damper in the fluid pipeline. In effect the power draw remains the same under all conditions (only the frictional losses are varied). This is an inefficient way of adjusting the fluid flow.

Considerable energy savings are possible if the speed of the motor (and therefore the power draw) is reduced with the help of a VSD when a lower flow rate is required, thus eliminating inefficient mechanical components like throttles and dampers.

The use of a VSD can also:

1. enable the elimination of mechanical gearboxes between the motor shaft and the driven equipment in applications requiring a constant torque over the speed range, thus leading to further energy savings;

2. provide higher starting torque up to the maximum torque of the motor;

3. reduce the startup current of the motor and thus improve voltage fluctuations in the supply network; and

4. enable the use of more efficient pumps in fixed speed applications.

On the one hand a VSD adds losses to the motor system (the VSD's own energy losses as well as the additional losses caused in the motor by harmonics), but on the other, a VSD introduces a new degree of freedom to the system design, which can be used to optimize the efficiency of a pump, leading to reduced energy consumption for example. If the motor is required to operate at speeds below the rated operating point for some periods of time, the addition of a VSD may improve the overall system energy performance by up to 40 per cent. However, even in constant load applications, the use of VSD can make sense, due to factors such as: oversizing of motor, difference between design load and actual load, possible modifications in the process over time etc. The decision to use a VSD or not is therefore to be made on a case-by-case basis, depending on the factors mentioned above.

Changing the transmission

In applications where gears are unavoidable, such as when high torque is needed at low speeds, frictional losses in the gear teeth can be minimised by choosing a motor with a nominal speed as close as possible to the speed of the driven equipment. The choice of gear is also very important. Gear efficiency varies greatly depending on the design. Sometimes it is necessary to have a soft transmission (such as a belt and pulley between the motor and the driven equipment) to allow for vibrations. Traditional V-shaped belts can have losses as high as 7 per cent, which can be reduced to 1 – 2 per cent by using a chain and sprocket or a flat belt design.

Optimising the selection of components

Finally, the energy efficiency of the driven equipment can be improved through proper selection for given process conditions and improvements in design. The piping design (bends, diameter) can also be improved.[93]

A comprehensive treatment of the subject can be found in the 2011 IEA publication "Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems"., IEC Guide, IEA 2017, EMSA Audit Guide, and more.

93 Detailed guidelines and tools for targeting and implementing efficiency improvements in electric motor systems are available at http://www.leonardo-academy.org/course/view.php?id=363

10.8 Motor Driven System Energy Performance Standards

The International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), the National Electrical Manufacturers Association (NEMA) provide energy performance metrics and testing standards for motors, variable speed drives and driven applications which serve as the foundation for national and regional energy performance standards and regulations. These are supplemented with standards developed by professional and industry organizations such as IEEE, ANSI, ASHRAE and AMCA.

The related IEC, ISO, NEMA and other regional standards are shown in Tables 11-15.

Table 11: Motor System Standards for testing and efficiency classification

Component	Scope	Testing Standard	Efficiency Classification Standard				Performance Requirement
				efficiency metric	P [I]	EP [I]	Mandatory MEPS [II]
Motor	3-phase induction motors (Low Voltage < 1'000 V)	IEC 60034-2-1 IEC 60034-2-3	IEC 60034-30-1 IEC TS 60034-30-2	IE, International Energy efficiency class	x		50+ countries (incl. EU)
Converter	Variable Frequency Converter (VFC, VSD)	IEC 61800-9-2	IEC 61800-9-2	IE, International Energy efficiency class	x		EU
Pump	Rotodynamic water pump	ISO 9906	EU: EN 16480 EU: EN17038-1,-2,-3,-4 US: p431, subpart Y *) CN: GB19762	MEI, Minimum Efficiency Index EEI, Energy Efficiency Index PEI, Pump Efficiency Index EI, Efficiency Index	x x	 x x 	EU **) EU **) USA China
Fans	Industrial	ISO 5801 ISO 13350	ISO 13349 ISO 12759-1, -2 ISO 12759-3 ISO 12759-4 ISO 12759-5 ISO 12759-6	*Vocabulary and definitions* *General information; standard losses* FEG, Fan Efficiency Grade FMEG, Fan Motor Efficiency Grade JFMEG, Jet Fan Motor Eff. Grade FEI, Fan Efficiency Index	 x 	 x x	 China EU **) EU **) USA ***)
Air compressor	Compressor package	ISO 1217, Am. 1:2016	CN: GB 19513 US: p431, subpart T *)	Compressor efficiency grade Isentropic efficiency		x x	China USA

I) P = product, EP = extended product (motor, control, transmission, pump/fan/compressor)
II) MEPS = Minimum Energy Performance Standard (set as requirement by regulators)

*) see eCFR.gov for definitions, test standard and efficiency requirements
**) MEPS under revision
***) MEPS under development

Source: EMSA 05.2024

EU = European Union
USA = United States of America

Table 12: IEC energy performance metrics and testing standards for motors and variable speed drives

STANDARD	TITLE
IEC 60034-1:2022	Rotating electrical machines - Part 1: Rating and performance
IEC 60034-2-1:2024	Rotating electrical machines – Part 2.1: Standard methods for determining losses and efficiency from tests
IEC 60034-2-3:2024	Rotating electrical machines – Part 2.3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors
IEC 60034-30-1:2014	Rotating electrical machines – Part 30.1: Efficiency classes of line operated AC motors (IE code)
IEC TS 60034-30-2:2016	Rotating electrical machines – Part 30.2: Efficiency classes of variable speed AC motors (IE-code)
IEC TS 60034-31:2021	Rotating electrical machines – Part 31: Guide for the application
IEC 61800-9-1:2017	Adjustable speed electrical power drive systems – Part 9.1: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – General requirements for setting energy efficiency standards for power driven equipment using the extended product approach (EPA) and semi analytic model (SAM)
IEC 61800-9-2:2023	Adjustable speed electrical power drive systems – Part 9.2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters

Similarly, the International Organization for Standardization (ISO) provides energy performance metrics and testing standards for driven equipment such as pumps, fans and compressors as shown in 13.

Table 13: Relevant ISO energy performance metrics and testing standards for pumps, fans & compressors

STANDARD	TITLE
ISO 9906:2012	Rotodynamic pumps — Hydraulic performance acceptance tests — Grades 1, 2 and 3
ISO 4409:2019	Hydraulic fluid power — Positive-displacement pumps, motors, and integral transmissions — Methods of testing and presenting basic steady state performance
ISO 12759 **ISO 12759-1:2023** **ISO 12759-2:2019** **ISO 12759-3:2019** **ISO 12759-4:2019** **ISO 12759-5:2021** **ISO 12759-6**	Fans — Efficiency classification for fans - Part 1: General requirements Part 2: Standard losses for drive components Part 3: Fans without drives at maximum operating speed Part 4: Driven fans at maximum operating speed Part 5: Jet fans Part 6: Calculation of the fan efficiency index
ISO 5801:2017	Fans — Performance testing using standardized airways
ISO 1217:2009/Am. 1:2016	Displacement compressors — Acceptance tests — Amendment 1: Calculation of isentropic efficiency and relationship with specific energy
ISO 5389:2005	Turbocompressors — Performance test code
ISO 11011:2013	Compressed air — Energy efficiency — Assessment

Table 14: NEMA energy performance metric for motors, power drive systems (PDS) and complete drive modules (CDM)

STANDARD	TITLE
NEMA MG 10011: 2024	Power Index Calculation Procedure—Standard Rating Methodology for Motors, Power Drive Systems, and Complete Drive Modules.

Table 15: CEN publications, Methods and procedures for determining the performance of rotodynamic pumps

STANDARD	TITLE
EN 16480:2021	Pumps - Rotodynamic pumps - Minimum required efficiency of water pumps and determination of Minimum Efficiency Index (MEI)
EN 17038-1:2019	Pumps - Methods of qualification of the Energy Efficiency Index for rotodynamic pump units – Part 1: General requirements and procedures for testing and calculation of Energy Efficiency Index (EEI)
EN 17038-2:2019/AC:2021	Part 2: Testing and calculation of Energy Efficiency Index (EEI) of single pump units
EN 17038-3:2024	Part 3: Testing and calculation of energy efficiency index (EEI) of booster sets
EN 17038-4:2023	Part 4: Testing and calculation of energy efficiency index (EEI) of submersible multistage pump units

11 Designing Motor Systems for Circularity

What?	A brief review of the techniques for designing variable speed drives, electric motors, fans, pumps, and compressors for durability, repairability and recycling.
Why?	Provides the technical basis for the environment policies based on the principles of circularity described in Part I – Policy Guide

Circularity means that equipment is kept in use for as long as possible, and waste and environmental impacts are reduced or eliminated. Circularity can be achieved by designing motor systems for durability, repairability and recycling.

11.1 Designing Motor Systems for Durability

Durable products last longer, require less maintenance and replacement, and save resources and energy. Durability also enhances customer satisfaction and loyalty, as well as brand reputation and competitiveness.

11.1.1 Electric motors

Designing electric motors for durability requires a comprehensive understanding of the operating conditions, the performance requirements, and the failure modes of the motor. It also requires a careful selection of the components, a rigorous testing and validation process, and a regular maintenance and monitoring program.

The materials used in the motor should be chosen to resist corrosion and abrasion. The insulation should be able to withstand over-voltages and overload currents without breaking down. The cooling arrangements should be designed to maintain the optimal temperature of the motor and prevent overheating. The bearings should be lubricated and aligned properly to reduce friction and vibration. The protection devices should protect from faults, such as short circuits, overloads, overcurrent, and overvoltage.

11.1.2 Variable speed drives

VSDs generate high voltage and current spikes that can damage the insulation and windings of the motors. These can be mitigated by filters, reactors, or snubbers.

VSDs can cause parasitic currents in the motor shaft and bearings, which can lead to premature wear and failure of the bearings. These can be mitigated by insulated bearings or shaft grounding devices.

VSDs also produce harmonic distortion in the power supply, which can affect power quality and cause overheating, vibration, and noise in the motors and other equipment. These can be mitigated by harmonic filters or active power factor correction.

11.1.3 Water pumps

The materials used for the pump components, such as the impeller, casing, shaft, and seals should be resistant to corrosion, erosion, abrasion, and fatigue, and should have adequate strength and stiffness to withstand the operating conditions.

The pump selection and size should be matched to the requirements of flow rate and head with a suitable safety margin to avoid cavitation, surging, and overheating.

The pump should be properly aligned, balanced, lubricated, and protected from external factors, such as dirt, debris, vibration, and shock. The pump should also be regularly inspected, cleaned, and repaired to prevent failures and extend its service life.

11.1.4 Fans

The material of the fan blades, hub, and casing should be suitable for the intended application and environment. For example, metal fans are more durable than plastic fans, but they are also heavier and more expensive. Plastic fans are lighter and cheaper, but they may degrade faster under elevated temperatures or UV radiation. Some materials may also corrode or rust when exposed to moisture or chemicals.

A well-designed fan should have a smooth airflow and minimal turbulence, which reduces noise and vibration. The fan should also have a balanced distribution of mass and inertia, which prevents wobbling and wear. The size of the fan should match the required airflow rate and pressure drop, as well as the available space and power supply.

The fan should have safety features that prevent damage or injury in case of malfunction or failure. For example, the fan should have a guard or grille that protects the blades from foreign objects or fingers. Protection devices for overload, short circuit and overheating should be provided.

11.1.5 Air compressors

One of the key aspects of designing air compressors for durability is choosing the appropriate type and size of the compressor, based on the intended use and the available space. Reciprocating air compressors are simple and inexpensive, but they produce high noise and vibration levels, which can affect the structural integrity of the compressor and the surrounding equipment. Rotary air compressors are more compact and quieter, but they require more lubrication and cooling systems, which can increase the maintenance costs. Centrifugal air compressors are suitable for high-pressure and high-volume applications, but they are complex and expensive to operate and maintain. Axial air compressors are efficient and flexible, but they are sensitive to inlet flow distortions and surge phenomena, which can damage the compressor blades.

Another important aspect of designing air compressors for durability is selecting the appropriate materials and coatings for the compressor components, such as the cylinder, piston, valve, rotor, stator, impeller, diffuser, and casing. The materials and coatings should have high strength, stiffness, toughness, hardness, corrosion resistance, wear resistance, thermal conductivity, and fatigue resistance. They should also be compatible with the working fluid (air or gas) and the lubricant (oil or grease). Some of the common materials used for air compressor components are cast iron, steel, aluminium, copper, brass, bronze, titanium, nickel alloys, and composite materials. Some of the common coatings used for air compressor components are chrome plating, nickel plating, anodizing, powder coating, ceramic coating, and thermal spray coating.

A third important aspect of designing air compressors for durability is optimizing the geometry and configuration of the compressor components to reduce stress concentrations, friction losses and leakage losses.

11.2 Designing Motor Systems for Repairability

Products should be designed with repairability in mind from the beginning by considering the following aspects:

- Provide access to spare parts, repair information, and tools for up to 10 years after the product is placed on the market;
- Do not use design features that prevent or discourage repair, such as welded parts;
- Provide for easy disassembly.
- Implementing these steps will also make it more probable that the equipment will maintain efficiency after repairs.

Note: an assessment of the main costs and benefits linked to repairability needs to be made for each product. Aspects such as the cost for the spare parts stock, production, storage, recycling, and quality assurance need to be considered alongside the benefits due to a longer lifecycle/usage.

11.3 Designing Motor Systems for Recycling

Products should be designed with recycling in mind from the beginning by considering the following aspects:

- Material selection: Products should use materials that are recyclable, biodegradable, or compostable, and avoid materials that are toxic, hazardous, or non-recyclable.
- Products should also use fewer types of materials and avoid mixing incompatible materials that are hard to separate.
- Products should be designed in a way that makes them easy to disassemble, repair, reuse, or remanufacture.
- Products should also have clear labels or markings that indicate the type and composition of the materials used and how to recycle them properly.

11.3.1 Electric Motors

The average material content used in the manufacturing of induction motors[94] is depicted in Table 17.

Table 16: Average material content used in the manufacturing of induction motors[95]

	Cast iron frame motors	Steel frame motors
Cast iron	35-45%	5-15%
Steel	46-55%	70-80%
Aluminium	1-3%	1-3%
Copper	7-11%	7-11%
Plastic, rubber, insulation materials etc.	Less than 1%	Less than 1%
Stainless steel	Less than 1%	Less than 1%
Brass	Less than 1%	Less than 1%
Other	Less than 1%	Less than 1%

At the end of life of an induction motor, the cast iron, steel, aluminium, copper, stainless steel, and brass parts, which constitute more than 98 per cent of the material content, are fully recyclable. The recycling of metals not only conserves valuable natural resources, but also requires less energy than extracting the respective metal from its ore.

Apart from metals, an electric motor uses a small quantity of rubber and plastic for the fan and terminal board, which are recyclable as well. The electronic printed circuit boards, electrolytic capacitors and semiconductor devices used in variable speed drives should be handled in accordance with regulations covering e-waste.[96]

Recycling electric motors involves several steps, such as dismantling, shredding, separating, and recovering. Each step requires different equipment and techniques, depending on the type and size of the motor. Some of the challenges in recycling electric motors are:

- Removing the copper windings from the iron core, which can be done manually or by using a machine that cuts and pulls the wires.

- Separating the different metals and materials, such as steel, aluminium, copper, plastic, and magnets, which can be done by using magnets, eddy currents, air classifiers, or optical sorters.

- Recovering the rare earth elements from the permanent magnets, which can be done by using chemical leaching, solvent extraction, or precipitation.

94 The ferrite magnets used in ferrite-based permanent magnet motors comprise a compound of iron with other metals and are therefore more challenging to recycle than pure metals. Although the same process is followed for collection, the recycling industry is still gathering experience with these new products. The handling of the rare earth metals Nd, Dy, Tb and Pr used in rare-Earth based permanent motors at end of life presents entirely different challenges from the common metals used in induction motors. These topics are less relevant for developing countries and are not covered in this policy guide. A research project on these topics MORE is currently being conducted by a German consortium. See http://www.isi.fraunhofer.de/isi-en/n/projekte/MORE_en.php

95 ABB. Brochure on Recycling Instructions number ABB/LV Motors/3GZF500930-5 B

96 For an example of e-waste regulations in a developing country see http://www.moef.gov.in/sites/default/files/EWM%20Rules%202016%20english%2023.03.2016.pdf

11.3.2 Variable Speed Drives

The general considerations applicable to e-waste apply to VSDs as well. Like other e-waste, at end-of-life VSDs can generate hazardous materials, such as lead, mercury, cadmium, and brominated flame retardants, which can leach into the soil and water or release toxic fumes when burned. Further, e-waste often contains valuable metals, such as gold, silver, copper, and platinum, which are wasted when not recovered.

11.3.3 Pumps, Fans, and Air Compressors

Some of the design strategies for improving the recyclability of mechanical equipment like Pumps, Fans and Air Compressors are:

- Selecting materials that are compatible, easy to identify, and widely recycled.
- Avoiding the use of adhesives, coatings, and fasteners that hinder the separation and recycling of materials.
- Designing modular and standardized components that can be easily replaced, repaired, or upgraded.
- Providing clear information and instructions on how to disassemble, recycle, or dispose of the products and their components.

12 Technology Trends and Market Developments

What?	An overview of Motor System Technology trends and market developments
Why?	Provides the market background for the discussions and policy recommendations in Part I - Policy Guide.
Next?	Some key questions to keep in mind: What does the motors and motor systems market look like in my country? What proportion of demand does the domestic industry meet? How concentrated or fragmented is it? Which are the main application areas?

12.1 Electric motors

12.1.1 Technology Trends

The induction motor has been the mainstay of fixed-speed applications ever since it was invented in the late 19th century due to its simplicity of connection and operation. Its ruggedness was enhanced with the development of die-cast aluminium rotors in the 1940s, which replaced fabricated copper rotors.

The development of mass production techniques for copper rotor die-casting during the last decade has enabled induction motors to meet even (an envisaged[97]) IE5 efficiency levels. Other alternative techniques for reaching high-efficiency levels in induction motors exist, as well. Developments in power electronics during the last three decades have made it possible to control motor speed in an easy and cost-effective way making these the preferred choice for variable-speed applications as well.

However, the market dominance of induction motors is being challenged by permanent magnet motors and reluctance motors, particularly in applications requiring the motor speed to be variable. Table 18 provides a comparison of the technologies. One barrier for the rapid uptake of the newer motor technologies is the already high level of investment in induction motor technologies made by manufacturers around the world.

97 An IE5-efficiency class for line operated AC motors is not defined yet, in IEC 60034-30-1:2014. IEC TS 60034-30-2:2016 specifies efficiency classes for variable speed rotating electric machines and includes an IE5-efficiency class.

The cost of switching production is not appealing unless there is sufficient demand for these new motors. Induction motors are, therefore, expected to continue to dominate the market for both fixed-speed and variable-speed applications in the foreseeable future, with increasing inroads by permanent magnet motors (particularly in electric vehicles) and reluctance motors.

According to a report by Expert Market Research (EMR), the global low voltage electric motors market is projected to reach US$34.8 billion by 2026, registering a CAGR of 6.3 per cent during the forecast period of 2020-2026 (EMR, 2021). Another report by Future Market Insights (FMI) estimates that the global low-voltage motor demand is anticipated to be valued at US$39.1 billion in 2022, forecast to grow at a CAGR of 5.2 per cent to be valued at US$75 billion from 2022 to 2032 (FMI, 2021).

Table 18 : Comparison of different commercially available motor technologies

Motor Technology	Induction Motors	Permanent Magnet Motors	Reluctance Motors
Age of technology commercialisation	Since late 19th century	21st century	21st century
Share of installed stock (globally)	> 80 per cent	Negligible	Negligible
Best commercially available efficiency levels	IE4*	IE5*	IE5*
Efficiency Standard*	IEC 60034-30-1:2014		IEC TS 60034-30-2:2016
Variable frequency drive essential?	No	Yes	Yes
Cost-effective for fixed speed applications?	Yes	Conditional *	Conditional *
Design of rotor	Aluminum diecast/copper fabricated or die-cast	Rare earth (neodymium /dysprosium) or ferrite core permanent magnets	Magnetic steel
Mechanical sturdiness	Intermediate	Least sturdy due to the potential for demagnetization from shocks and vibration	Most sturdy due to simplicity of the rotor
Comparison of total motor weight for IE4 efficiencies	Heaviest	Lightest	Intermediate

(note *: can be positive depending on the type of driven application e.g. for pump and fan applications at constant speed and adjusted operating point)

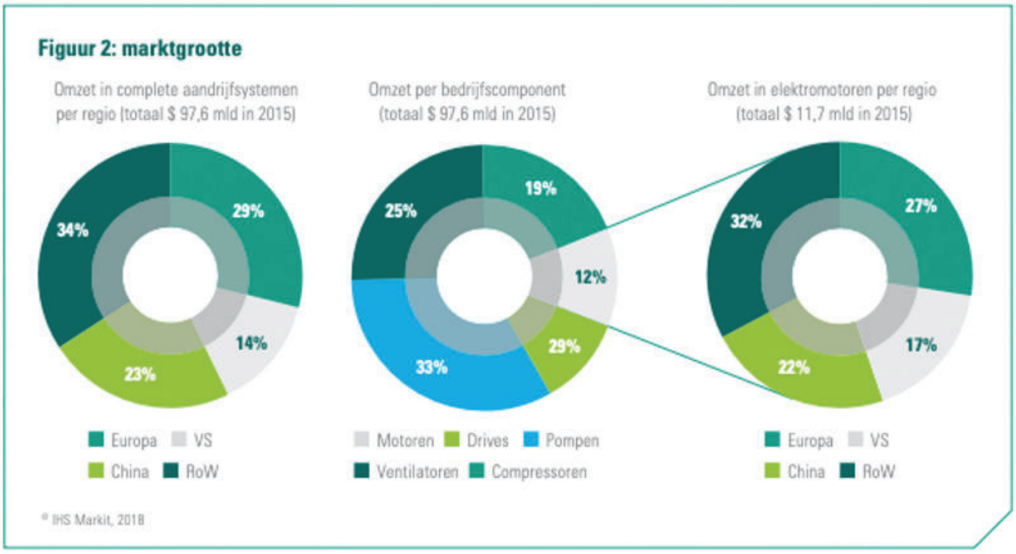


Figure 38: World market for low-voltage motors 2018, in units [million] and CAGR [percentage p.a.][98]

12.1.2 Market Structure

The global low-voltage induction motors market is shared between four multinational companies with a combined market share of 30-40 per cent, and about 1,500 small- and medium-sized domestic manufacturing companies[99]. The multinational companies serve individual markets through regional and local manufacturing facilities.

The three largest markets for new motors are China, Europe, and United States of America. Major induction motor manufacturing locations Brazil, China, Europe, Mexico, and United States of America. In addition, there is a significant market for second-hand repaired and reconditioned motors in e.g., Brazil, Turkey, and other countries.

	Noord- en Zuid-Amerika		Azië-Pacific		EMEA
1	ABB	1	Wolong	1	Siemens
2	WEG	2	Siemens	2	ABB
3	Nidec	3	ABB	3	Wolong
4	Regal Beloit	4	TECO	4	WEG
5	TECO	5	Hitachi	5	Nidec

© IHS Markit, 2018

Figure 39: The largest electric motor manufacturers by region in 2017[100]

The global trend in sales of low-voltage motors has been toward ever-increasing average efficiency levels since 1995. This trend is expected to continue due to the adoption of market-transformation policies by governments. This leads to a transition in the relative market shares of motor efficiency classes. While IE1 had a share of 40 per cent in 2016, this reduced to 26 per cent in 2022, and the share of IE3 increased from 17 per cent to 28 per cent. However, this is more reflective of the higher weightage of industrialised countries in the global statistics;

98 ABNAMRO, Drive technology: digitalization is the driving force behind chain consolidation (in Dutch), 2019.
99 IHS 2016; IHS/Informatech, P. Reine, EEMODS 2019
100 Source: IHS Markit, 2018

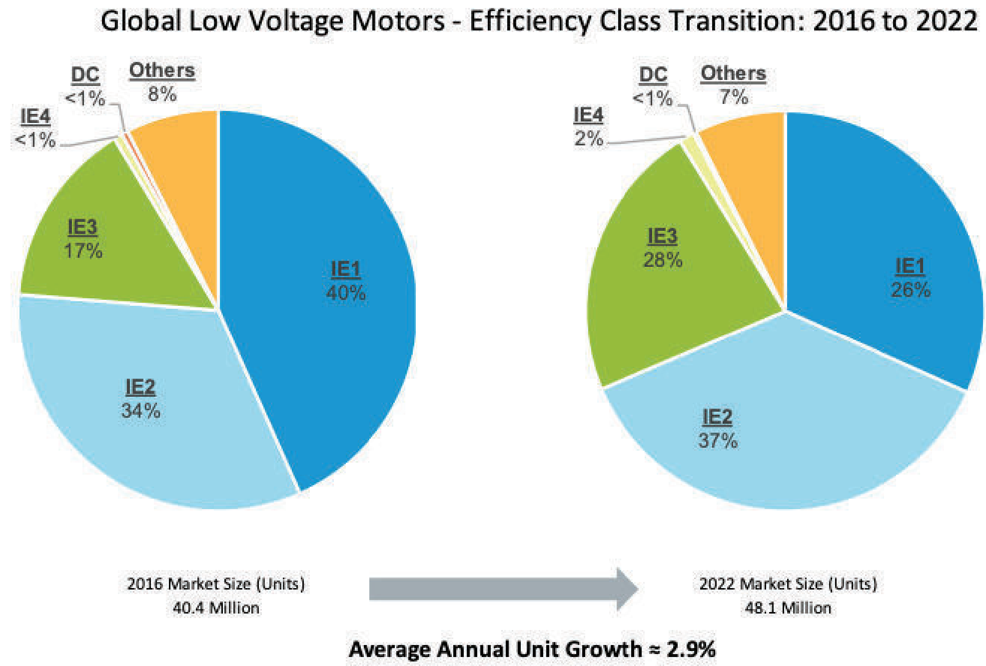


Figure 40: Global market LV-motors in 2016 and efficiency class transition to 2022 (in Units)[101]

12.2 Variable Speed Drives

The global market for variable speed drives (VSDs) is expected to grow significantly in the coming years, driven by the increasing demand for energy efficiency, reduced wear and tear, and improved process control. According to a recent report by Markets and Markets, the VSD market size is projected to reach US$32.6 billion by 2026, at a compound annual growth rate (CAGR) of 5.7 per cent from 2021 to 2026. The major factors driving the market growth include the rising adoption of VSDs in renewable energy generation, the growing industrialization and urbanization in emerging economies, and the stringent regulations on energy efficiency and carbon emissions. Some of the key players in the VSD market are ABB, Siemens, Schneider Electric, Danfoss, Rockwell Automation, Eaton, Yaskawa, Mitsubishi Electric, WEG, and Hitachi.

12.3 Fans

The global market for fans is anticipated to grow from US$13.5 billion in 2020 to US$18.8 billion by 2027, at a CAGR of 4.5 per cent, according to a new report by Grand View Research, Inc. The market growth is attributed to the increasing demand for energy-efficient cooling solutions in the residential and commercial sectors.

12.4 Rotodynamic Pumps

The global market for water pumps is expected to grow at a compound annual growth rate (CAGR) of 4.4 per cent from a value of approximately US$67.76 billion in 2023 to US$99.82 billion by 2032 according to a recent report by Expert Market Research. The main factors driving the market growth are infrastructure investments, the chemical industry, and irrigation.

An example of the market shares per pump type is shown in Figure 43.

101 Source: IHS Markit, Reine P. EEMODS 2019

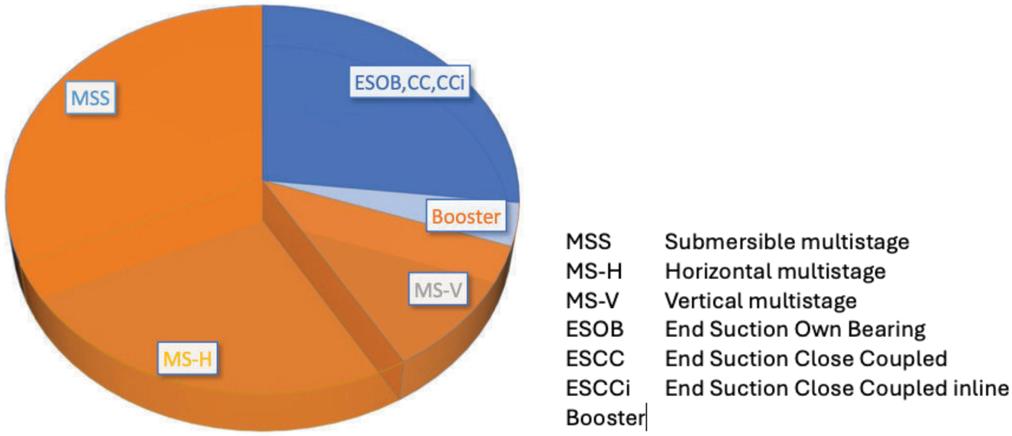


Figure 41: Market shares of clean water pump units in scope of European Union Regulation, Annual sales, 2014: 3.0 million units [102]

12.5 Air Compressors

The global market for air compressors is expected to grow at a compound annual growth rate (CAGR) of 4.5 per cent from 2020 to 2027, reaching US$40.43 billion by 2027, according to a new report by Grand View Research, Inc. The increasing demand for energy-efficient and environmentally friendly air compressors is driving the market growth. Moreover, the rising adoption of air compressors in emerging markets such as China, India, Brazil, and South Africa is creating new opportunities for the market players.

102 Estimate by EUROPUMP, 2019. The figure considers the clean water pumps in scope of the European Union regulation and not other type of pumps.

References

4E EMSA (2014). *Policy Guidelines for Electric Motor Systems Part 2: Toolkit for Policy Makers*. First edition. Zurich: IEA 4E Electric Motor Systems Annex.

4E EMSA (2016). *Policy Guidelines for Motor Driven Units Part I*. Zurich: 4E EMSA.

4E EMSA (2018). *EMSA Energy Audit Guide for Motor Driven Systems*. Zurich: 4E EMSA.

4E EMSA (2018). *Policy Guidelines for Motor Driven Units Part II*. Zurich: 4E EMSA.

ABB (2002). *Environmental Product Declaration AC Low Voltage Flameproof Motor, Type M3JP 180*. Vaasa, Finland: ABB Oy / BA Electrical Machines, LV Motors.

ABN AMRO (2019). *Aandrijftechniek: digitalisering zet aan tot consolidatie (Drive technology: digitalization is the driving force behind chain consolidation)*. Amsterdam: ABN AMRO.

Ayres, I. and Braithwaite, J. (1992). *Responsive Regulation: Transcending the Deregulation Debate*. New York: Oxford University Press.

Barkhausen, R. et al. (2024). Modeling stock, material and environmental impacts of circular economy product policies. Trade-offs between early replacement and repair of electric motors. *Resources, Conservation & Recycling*, 205, p.107600.

BNDES (2023). *FGENERGIA*. [online] Available at: https://www.bndes.gov.br/wps/portal/site/home/financiamento/garantias/bndes-fgenergia/normativos-fgenergia[Accessed 27 Mar. 2024].

Bureau of Energy Efficiency (2019). *Perform Achieve Trade (PAT)*. [online] Available at: https://beeindia.gov.in/en/programmes/perform-achieve-and-trade-pat [Accessed 27 Mar. 2024].

Bureau of International Recycling (BIR) (2024). *The Industry: Recycled Materials Supply 40% of the Global Raw Material Needs*. [online] Available at: https://www.bir.org/en/the-industry [Accessed 27 Mar. 2024].

CEMEP LV Motors Industry Group (2023). *Motor Sales in Europe*. Brussels: The European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP).

CLASP (2005). *S&L Guidebook*. [online] Available at: https://www.clasp.ngo/research/all/s-l-guidebook-english-version/ [Accessed 27 Mar. 2024].

CLASP (2023). *Net Zero Heroes: Scaling Efficient Appliances for Climate Change Mitigation, Adaptation and Resilience*. Washington: CLASP.

Clean Energy Ministerial (2024). *Resources: Clean Industry*. [online] Available at: https://www.cleanenergyministerial.org/resources/?_sectors=clean-industry [Accessed 27 Mar. 2024].

climatefundsupdate.org (2024). *Global Climate Finance Architecture*. [online] Available at: https://climatefundsupdate.org/about-climate-finance/global-climate-finance-architecture/ [Accessed 27 Mar. 2024].

Confederation of Indian Industry (CII) (2024). *Motor Rewinder Certification System (MRCS)*. [online] Available at: https://www.cii-competitiveness.in/motor-rewinder-certification-system [Accessed 27 Mar. 2024].

Copper Development Association (2008). *Motor Management Plan*. [online] Available at: https://copper.org/environment/sustainable-energy/electric-motors/case-studies/a6141.php [Accessed 27 Mar. 2024].

de Almeida, A., Falkner, H., Fong, J. and Jugdoyal, K. (2014). *EuP Lot 30: Electric Motors and Drives*. Coimbra, Portugal: ISR University of Coimbra and Atkins.

de Almeida, A. et al. (2000). *VSDs for Electric Motor Systems*. Coimbra, Portugal: University of Coimbra, ISR under European Commission SAVE II Programme.

EASA (2024). *EASA: The Electromechanical Authority*. [online] Available at: https://easa.com/ [Accessed 27 Mar. 2024].

ECONOLER (2014). *Motor Repairs: Potential for Energy Efficiency Improvement*. Washington D.C.: SEAD.

Efficiency Valuation Organisation (EVO) (2024). *What is M&V?*. [online] Available at: https://evo-world.org/en/m-v/what-is-m-v [Accessed 27 Mar. 2024].

Energy Efficiency Services Ltd. (EESL) (n.d.). *National Motor Replacement Program*. [online] Available at: https://eeslindia.org/en/nmrp/ [Accessed 27 Mar. 2024].

EU_MORE (2024). *Accelerating Early Replacement of Old Inefficient Electric Motors in Industry and the Service Sector*. [online] Available at: https://eu-more.eu/ [Accessed 27 Mar. 2024].

European Commission (2009). *Commission Regulation (EC) No 643/2009 of 22 July 2009 Implementing Directive 2005/32/EC of the European Parliament and of the Council with Regard to Ecodesign Requirements for Household Refrigerating Appliances*. [online] Available at: https://eur-lex.europa.eu/eli/reg/2009/643/oj/eng [Accessed 27 Mar. 2024].

European Commission (2011). *Commission Regulation (EU) No 327/2011 of 30 March 2011 Implementing Directive 2009/125/EC of the European Parliament and of the Council with Regard to Ecodesign Requirements for Fans Driven by Motors with an Electric Input Power Between 125 W and 500 kW*. [online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02011R0327-20170109 [Accessed 27 Mar. 2024].

European Commission (2011). *Methodology for Ecodesign of Energy-Related Products (MEErP 2011)*. [online] Available at: https://op.europa.eu/en/publication-detail/-/publication/b7650397-32f1-436c-82c4-df39aef297a3[Accessed 27 Mar. 2024].

European Commission (2012). *Commission Regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans* [Online]. Available at: https://eur-lex.europa.eu/eli/reg/2012/206/oj/eng [Accessed 27 Mar. 2024].

European Commission (2012). *Commission Regulation (EU) No 547/2012 of 25 June 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water pumps*[Online]. Available at: https://eur-lex.europa.eu/eli/reg/2012/547/oj/eng [Accessed 27 Mar. 2024].

European Commission (2023). *Ecodesign impact accounting overview report* [Online]. Available at: https://energy-efficient-products.ec.europa.eu/product-list/industrial-fans_en [Accessed 27 Mar. 2024].

European Commission (2019). *Regulation on electric motors and variable speed drives (EU) 2019/1781* [Online]. Available at: https://eur-lex.europa.eu/eli/reg/2019/1781/oj [Accessed 27 Mar. 2024].

Ghana Energy Commission. (2022). *Electric Motors Regulations 2022 L.I2456* [Online]. Available at: https://repository.energycomlibrary.org/items/de5e7877-f7b2-45b7-889f-2de6a09e039a/full [Accessed 27 Mar. 2024].

Ghana Energy Commission. (2022). *Energy Commission (Energy Efficiency Standards and Labelling) (Industrial Fans) Regulations, Legislative Instrument 2444* [Online]. Available at: https://ghalii.org/akn/gh/act/li/2022/2444/eng@2022-07-05 [Accessed 27 Mar. 2024].

Government of India MOEF. (2016). *E-Waste (Management) Rules, 2016* [Online]. Available at: https://greene.gov.in/wp-content/uploads/2018/01/EWM-Rules-2016-english-23.03.2016.pdf [Accessed 27 Mar. 2024].

IEA. (2016). *World energy outlook*. Paris, France: IEA.

IEA. (2017). *Policy pathways brief: Public-private financing of energy efficiency*. Paris: IEA.

IEA. (2022). *World energy outlook*. Paris, France: IEA.

IEC. (2014). *IEC 60034-30-1:2014 Efficiency classes of line operated AC motors* (Ed. 1.0). Geneva: IEC.

IEC. (2016). *IEC TS 60034-30-2:2016 Efficiency classes of variable speed AC motors* (Ed. 1.0). Geneva: IEC.

IEC. (2017). *IEC 61800-9-2:2017 Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters* (Ed. 1). Geneva: IEC.

IEC. (2017). *IEC 61800-9-1:2017 Adjustable speed electrical power drive systems – Part 9-1: Ecodesign for power drive systems, motor starters, power electronics and their driven equipment* (Ed. 2). Geneva: IEC.

IEC. (2023). *IEC 61800-9-2:2023 Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters* (Ed. 2). Geneva: IEC.

Institute for Industrial Productivity (IIP). (2012). *Energy management programmes for industry*. Paris: IEA.

Institute of Standards and Industrial Research of Iran (ISIRI). (2010). *ISIRI 10634 Fans: Technical specifications and test methods for energy consumption and energy labeling instructions* [Online]. Available at: https://cprc-clasp.ngo/policies/isiri-10634-fans-technical-specifications-and-test-methods-energy-consumption-and-energy[Accessed 27 Mar. 2024].

Kelpsaite, L. (2021). *CLASP: Regional approach to policy compliance, SEAD regional workshop for East Africa roundtable discussion focused on lighting and cooling*. Paris: IEA.

Kemna, V. H. E. (2015). *Ecodesign fan review: Review study of Commission Regulation (EU) No 327/2011, Figure 3, p. 33* [Art]. European Commission.

Lane, K. (2021). *Introduction to SEAD and the product efficiency ladder approach for lighting and cooling: SEAD regional workshop for East Africa*. Paris: IEA.
Malinowski, J., & Korkeakoski, J. (2016). *CEMEP/NEMA joint presentation to the Motor Summit 2016*. Zurich: CEMEP/NEMA.

Malinowski, M. (2024). *Global motors life-cycle cost (LCC) analysis: Spreadsheets summary*. Washington D.C.: CLASP.

Mark Ellis and Associates. (2010). *Compliance counts: A practitioner's guidebook on best practice monitoring, verification, and enforcement for appliance standards & labeling*. Washington D.C.: CLASP.

Netherlands Enterprise Agency (RVO). (2023). *Energy investment allowance (EIA)* [Online]. Available at: https://business.gov.nl/subsidy/energy-investment-allowance/ [Accessed 27 Mar. 2024].

Netherlands Enterprise Agency. (2023). *What is the energy saving obligation?* [Online]. Available at: https://english.rvo.nl/topics/energy-saving-obligation/what-energy-saving-obligation [Accessed 27 Mar. 2024].

plctechnician.com. (n.d.). *Variable frequency drives: Basics and common applications of VFDs* [Online]. Available at: https://www.plctechnician.com/news-blog/variable-frequency-drives-basics-and-common-applications-vfds [Accessed 27 Mar. 2024].

Radgen, P. (2020). *Isentropic efficiency and specific performance* [Art]. University of Stuttgart IER.

Reinaud, J., & Goldberg, A. (2012). *Policy pyramids: An evaluation framework for industrial GHG mitigation policies*. Rome, Italy: International Energy Program Evaluation Conference.

Reine, P. (2019). *Presentation at EEMODS 2019*. Tokyo: IHS Markit.
SEAD. (2017). *Linking energy management systems and motor efficiency incentive policies* [Online]. Available at: https://www.cleanenergyministerial.org/content/uploads/2022/05/2-clasp-enms-and-emds-study-final.pdf [Accessed 27 Mar. 2024].

SPEED PROGRAM. (2024). *Reduction of energy consumption in industry through the optimisation of electric drives*[Online]. Available at: https://www.speed-program.ch/ [Accessed 27 Mar. 2024].

Standardisation Administration Committee of the PRC, 2007. *GB 19762-2007: The minimum allowable values of energy efficiency and evaluating values of energy conservation of centrifugal pump for fresh water.* [Online]
Available at: https://www.chinesestandard.net/PDF.aspx/GB19762-2007
[Accessed 27 March 2024].\

Standardisation Administration Committee of the PRC (2012) *GB 28381-2012: Minimum allowable values of energy efficiency and evaluating values of energy conservation for centrifugal blower.* [online] Available at: https://www.chinesestandard.net/PDF.aspx/GB28381-2012 [Accessed 27 Mar. 2024].

Standardisation Administration Committee of the PRC (2019) *GB 19153-2019: Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Displacement Air Compressors.* [online] Available at: https://www.chinesestandard.net/PDF.aspx/GB19153-2019 [Accessed 27 Mar. 2024].

Standardisation Administration of the PRC (2020) *Standard GB 19761: Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Fan.* [online] Available at: https://www.chinesestandard.net/PDF.aspx/GB19761-2020 [Accessed 27 Mar. 2024].

The World Bank Group (2020) *A STEP Up for Egyptian Industries – Egypt Mandates Higher Energy Efficiency Standards for Electric Motors.* [online] Available at: https://geowb.maps.arcgis.com/apps/MapJournal/index.html?appid=64f7067fe99e451eabc6222018529a7c [Accessed 27 Mar. 2024].

Thorat, S. (n.d.) *Rotary Compressors Principle.* [art] Learnmech.com.
UNDP (2019) *New Generation OIZ Model for Technological Transformation of Industrialists.* [online] Available at: https://www.undp.org/turkiye/news/new-generation-oiz-model-technological-transformation-industrialists [Accessed 27 Mar. 2024].

UNDP (n.d.) *Kazakhstan: Energy efficient standards, certification and labelling.* [online] Available at: https://www.undp.org/kazakhstan/projects/energy-efficient-standards-certification-and-labelling [Accessed 27 Mar. 2024].

UNEP (2012) *Principles for Sustainable Insurance.* [online] Available at: https://www.unepfi.org/insurance/insurance[Accessed 27 Mar. 2024]

UNEP (2016) *Enforcing Efficient Lighting Regulations Guidance Note.* Paris: UNEP.
UNEP (2024) *U4E Product Registration Systems.* [online] Available at: https://united4efficiency.org/product-registration-systems/ [Accessed 27 Mar. 2024].

UNEP (2024) *United for Efficiency.* [online] Available at: https://united4efficiency.org/ [Accessed 27 Mar. 2024].

UNIDO (2009) *UNIDO and Energy Efficiency: A low-carbon path for industry.* Vienna: UNIDO.

UNIDO (2010) *Motor-driven Systems Optimization (MSO) training programme.* [online] Available at: https://www.industrialenergyaccelerator.org/general/infographic-unidos-motor-driven-systems-optimization-mso-training-programme/ [Accessed 27 Mar. 2024].

University of Coimbra, I. (2017) *Induction Motor.* [art] University of Coimbra.
Unlimited Energy (2021) *Cost Benefit Analysis to introduce Minimum Energy Performance Standards (MEPS) for Electric Motors in South Africa.* Johannesburg: CLASP.

US Department of Energy (2016) *10 CFR Chapter II Sub-chapter D Subpart T: Compressors.* [online] Available at: https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-431/subpart-T?toc=1 [Accessed 27 Mar. 2024].

US Department of Energy (2016) *10 CFR Part 431 Subpart Y – Pumps.* [online] Available at: https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-431/subpart-Y [Accessed 27 Mar. 2024].

US Department of Energy (2023) *Energy Conservation Program: Energy Conservation Standards for Electric Motors.*[online] Available at: https://www.federalregister.gov/documents/2023/06/01/2023-10019/energy-conservation-program-energy-conservation-standards-for-electric-motors [Accessed 27 Mar. 2024].

US Department of Energy (2024) *10 CFR Chapter II Sub-chapter D Part 429 Subpart B Section 429.70: Alternative methods for determining energy efficiency and energy use.* [online] Available at: https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-429/subpart-B/section-429.70 [Accessed 27 Mar. 2024].

US Department of Energy (2024) *10 CFR Chapter II Subchapter D Part 429: Certification, Compliance, and Enforcement for Consumer Products and Commercial and Industrial Equipment.* [online] Available at: https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-429 [Accessed 27 Mar. 2024].

US Department of Energy (2024) *Energy Conservation Program: Energy Conservation Standards for Fans and Blowers.* [online] Available at: https://www.federalregister.gov/documents/2024/01/19/2023-28976/energy-conservation-program-energy-conservation-standards-for-fans-and-blowers [Accessed 27 Mar. 2024].

US Department of Energy (2024) *Industrial Efficiency and Decarbonization Office: Motor Systems.* [online] Available at: https://www.energy.gov/eere/iedo/motor-systems [Accessed 27 Mar. 2024].

US Department of Energy (2024) *Instructions for CCMS Reporting Certification & Templates, Electric Motors.* [online] Available at: https://www.regulations.doe.gov/ccms/help/instructions-for-ccms-reporting-certification-and-template-v5-electric-motors [Accessed 27 Mar. 2024].

van Werkhoven, M. (2014) *Example of IEC motor efficiency levels for a 4-pole motor operating at 50 Hz.* [art] 4E EMSA.

van Werkhoven, M. (2024) *Motor System Standards for testing and efficiency classification.* [art] 4E EMSA.

van Werkhoven, M. (2024) *Overview of MEPS with IE-levels for electric motors worldwide.* [art] 4E EMSA.

van Werkhoven, M. (2024) *Scope of coverage and levels of MEPS for electric motors worldwide.* [art] 4E EMSA.

van Werkhoven, M. (2024) *Testing standards, energy efficiency metrics and MEPS for electric motor systems.* [art] 4E EMSA.

Viegand Maagøe A/S (2018) *Review study of ecodesign and energy labelling for pumps.* [online] Available at: https://www.ecopumpreview.eu/ [Accessed 27 Mar. 2024].

Vikaspedia (2020) *National Energy Efficient Agriculture Pumps Programme.* [online] Available at: https://en.vikaspedia.in/viewcontent/energy/policy-support/energy-efficiency/national-energy-efficient-agriculture-pumps-programme [Accessed 27 Mar. 2024].

www.mecholic.com (2024) *Reciprocating Compressor Working, Applications, Advantages, Disadvantages.* [online] Available at: https://www.mecholic.com/2019/03/reciprocating-compressors-working.html [Accessed 27 Mar. 2024].

www.pumps.org (n.d.) *Frame-Mounted End-Suction Pump.* [art] Hydraulic Institute, Parsippany NJ.

www.pumpsandsystems.com (n.d.) *Basic Types of Rotodynamic Pumps.* [art] Pumps & Systems, Cahaba Media Group, PO Box 530067, Birmingham, AL 35253.

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