Danish Energy Agency

Ministry of Energy and Mineral Resources
Republic of Indonesia

Indonesia-Denmark Energy Partnership Programme (INDODEPP)

GUIDELINE FOR ELECTRIC MOTOR SYSTEMS

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GUIDELINE FOR ELECTRIC MOTOR SYSTEMS

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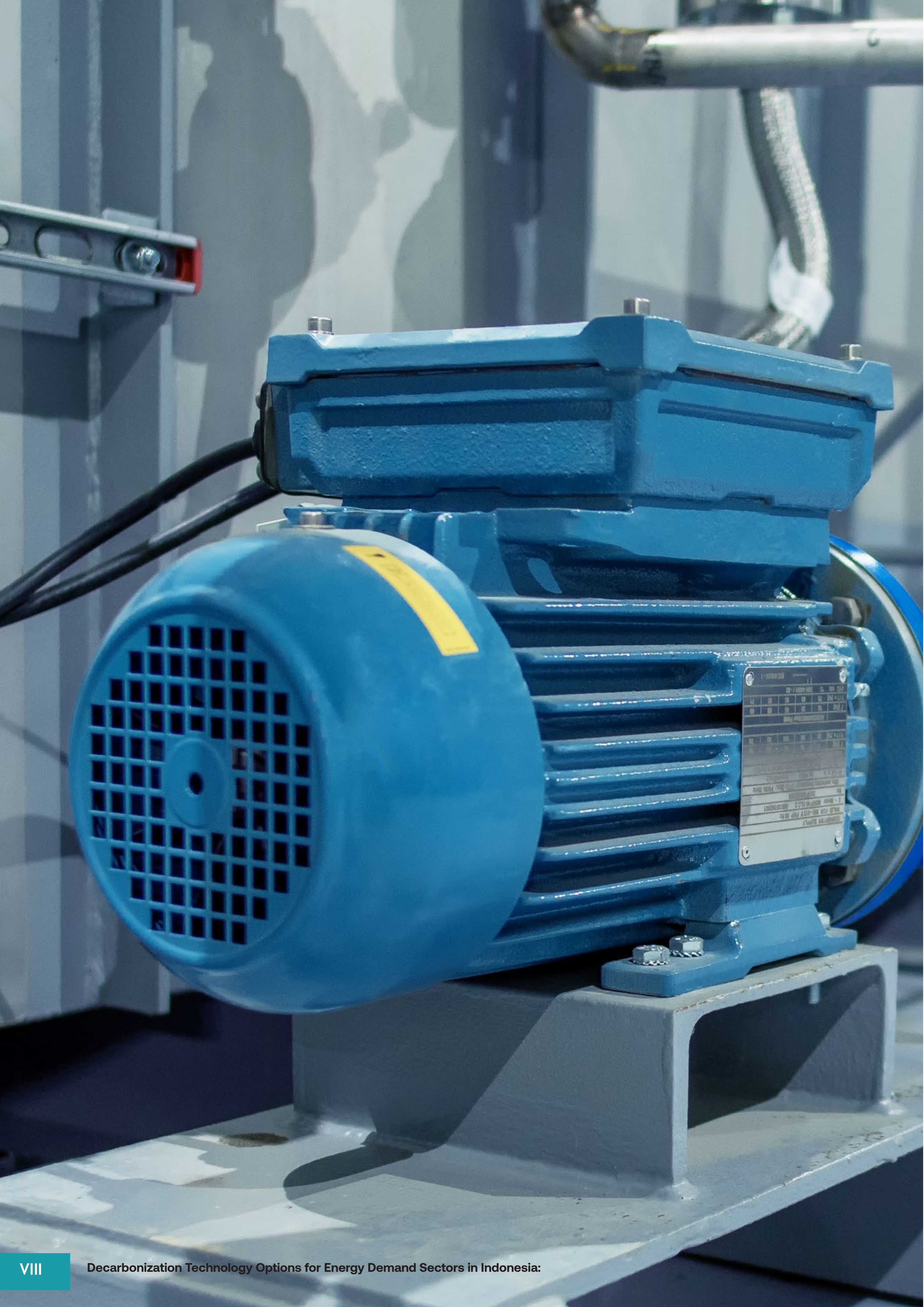


FOREWORD

All praise and gratitude are due to God Almighty, for by His grace and blessings, we can witness the publication of the *Guideline for Electric Motor Systems in Indonesia*. This guideline represents a significant milestone in achieving the goals of decarbonizing the energy sector and realizing Indonesia's ambitious targets under the Nationally Determined Contributions (NDC) and Net Zero Emissions (NZE) in the future.

The energy sector holds a strategic role in supporting sustainable development and achieving global climate goals. In this context, efficient and sustainable electric motor systems are key to reducing greenhouse gas emissions and optimizing energy utilization, particularly in the industrial sector. Hence, this guideline has been developed to enhance the performance of electric motor systems in Indonesia by applying energy efficiency principles across various industrial sectors.

We extend our deepest gratitude to the Royal Danish Embassy for their invaluable support, provided through the Indonesia Denmark Energy Partnership Programme (INDODEPP), during the preparation of this guideline. Our sincere thanks also go to all stakeholders—ranging from experts and practitioners to relevant institutions—who have worked diligently and collaboratively to complete this document on time.

With the publication of the *Technical Guideline for Industrial Electric Motor Systems*, we hope to encourage the industrial sector and the public to pay greater attention to energy efficiency and the critical role of technology in achieving broader decarbonization goals. We trust that this guideline will serve as a valuable reference for policymakers, industry players, and the general public in building a greener, more sustainable, and competitive future.

Thank you for all the support provided. May this guideline contribute positively to the advancement of Indonesia's energy sector.

Hendra Iswahyudi
Director of Energy Conservation
Ministry of Energy and Mineral Resources of the Republic of Indonesia

PREFACE

Efficient energy use in the industrial sector, particularly through the integration of energy-efficient technologies, has become increasingly critical in the global endeavour to promote sustainability and climate resilience. Industries globally accounted for 37% (166 EJ) of global energy use in 2022, making them a crucial focus area for energy efficiency efforts. Motors are essential components in various industrial processes and play a pivotal role in energy usage. According to the International Energy Agency (IEA), industrial motors and drives alone are responsible for about 40% of industrial electricity consumption, emphasizing the urgency of adopting energy-efficient technologies to mitigate climate change impacts.

In Indonesia, the industrial sector currently accounts for around 43% of the country's total energy consumption, and projections suggest a doubling of energy demand by 2050 without intervention. Within this context, widespread adoption of energy-efficient technologies, such as high-efficiency motors emerge as a crucial strategy to alleviate energy burdens, enhance sustainability, and bolster resilience against escalating energy demands.

In Denmark, the strategic adoption of energy-efficient technologies has been instrumental in achieving remarkable reductions in industrial energy consumption. Denmark ranks among the most energy-efficient countries in the world, with the second-lowest energy intensity across all sectors in Europe, indicating significant improvements in energy efficiency relative to GDP output. As of July 2023, Denmark has been following the latest EU Eco-design of electric motors, which mandates that motors sold in the market should comply with the IE4 energy efficiency standard.

Recognizing the urgency of addressing energy-saving potentials in the industrial sector, the Danish Energy Agency (DEA) and the Danish Embassy, in collaboration with the Directorate of New Renewable Energy and Conservation (EBTKE), Ministry of Energy and Mineral Resource (MEMR) in Indonesia, are in partnership through the Indonesia-Denmark Energy Partnership Programme (INDODEPP). One of the deliverables under INDODEPP is the development of a Technology Guideline for Industrial Applications, focusing on energy-efficient industrial motors as part of the activities.

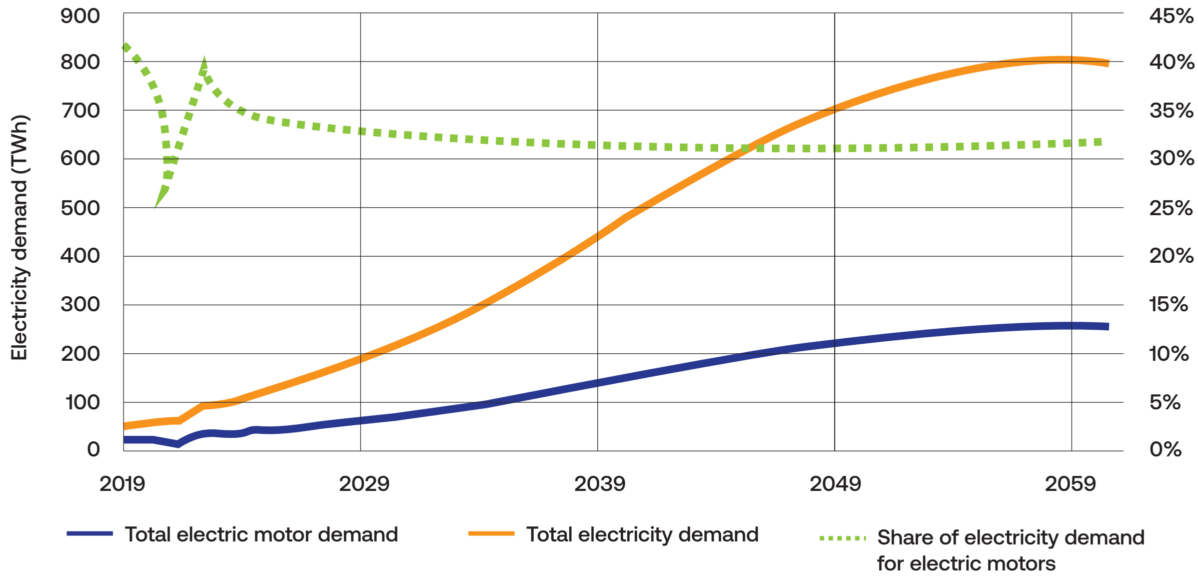
To ensure the accuracy and relevance of the Technology Guideline in an Indonesian context INDODEPP first conducted a Scoping Study workshop to discuss scope, methodologies, content and data for the development. The first draft of the Technology Guideline was then presented and discussed at a Consultation Workshop with key stakeholders, including relevant line ministries, institutions, agencies and associations involved in the industrial sector in Indonesia. The Consultation Workshop provided crucial local insights, enhancing the report's credibility and utility for Indonesian stakeholders.

This Technology Guideline aims to serve as a resource to support data-driven decision-making for industrial practitioners and government agencies in selecting energy-efficient equipment. It provides guidance on implementing energy management practices, including the replacement or upgrading of low-performing motors with high-efficiency ones, in alignment with the recently enacted Government Regulation No. 33/2023 on Energy Conservation. This regulation mandates that industrial facilities with an annual energy consumption of ≥ 4,000 TOE implement regular energy management measures.

AIM AND CONTENTS OF THE GUIDELINE

The aim of the Technology Guideline is to assist The Directorate General of New Renewable and Energy Conservation (EBTKE), under the Ministry of Energy, Mineral and Resources (MEMR) with developing tools, schemes and framework conditions which increase the rate of implementation of energy efficiency in industries in Indonesia.

According to IEA electric motor-driven systems, the largest single-energy end use, account for more than 30% of Indonesian electricity consumption within the industry sector. In some industrial sectors the electricity consumption of motors accounts for 60 – 70 % of the total electricity consumption . In combination with a general long lifetime of electric motors this entails to a need to focus on energy efficiency of electric motor-driven systems and especially in case of new establishment of industrial production facilities. In light of this, EBTKE has identified electric motor-driven systems in the industry as an important focus area.



The Technology Guideline aims to describe solutions and measures to address when planning and purchasing new equipment or when assessing energy efficiency of existing systems and plants or planning rehabilitation or upgrading. The guideline describes a recommended workflow to address electricity consumption of electric motor-driven systems and to reach a detailed understanding of how to reduce Total Costs of Ownership (TCO), meaning both the investment cost and the cost of operation and maintenance.

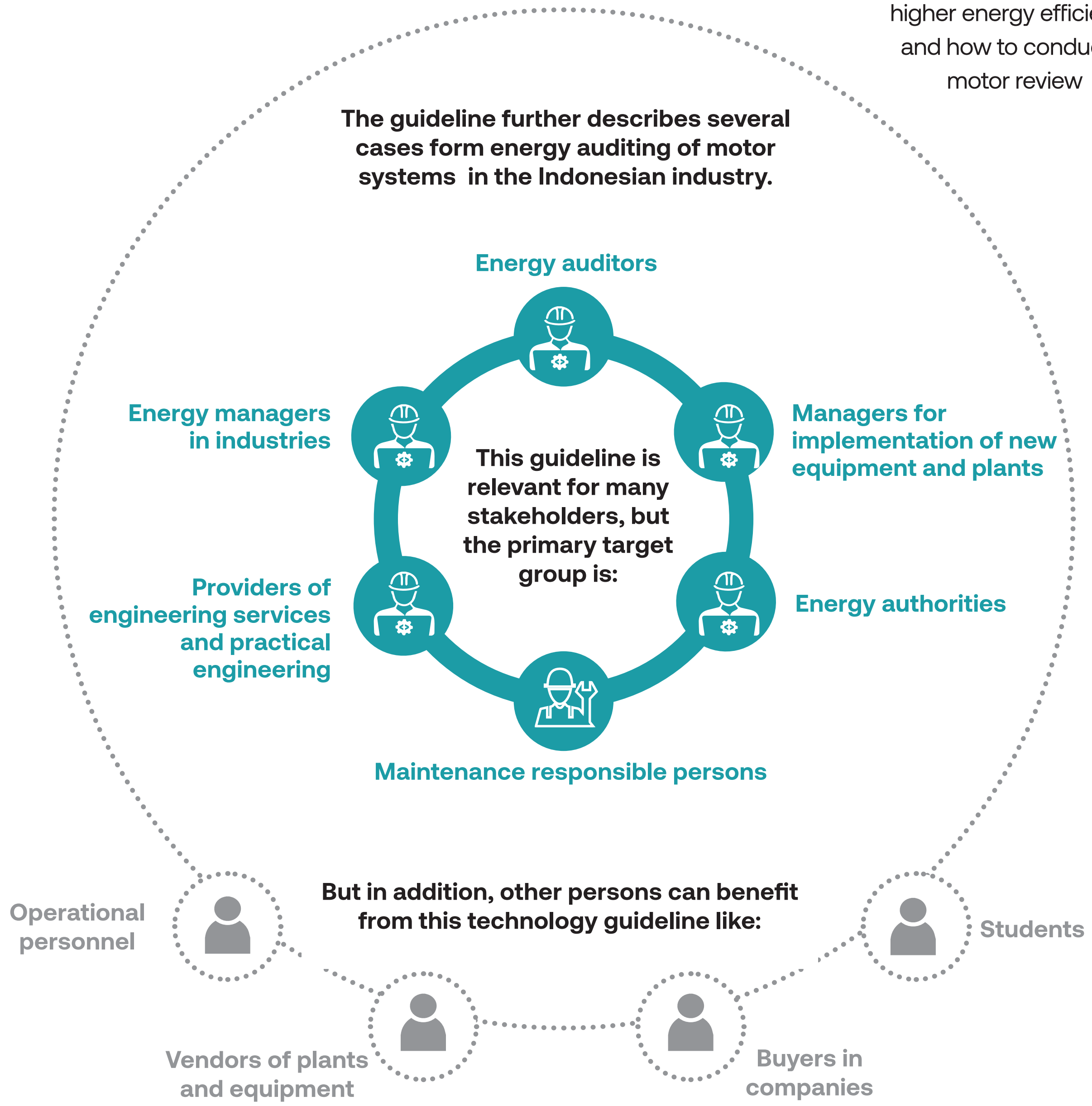
This guideline serves four main purposes.

The first is to give insights into international experience and motor classification, and the Indonesian motor market

The second part of the guideline concerns the energy efficiency of electrical motors themselves

The third section describes methods to achieve energy efficiency in systems including an electrical motor

The fourth part of the guideline gives an instruction in how assess the financial impact of choosing motors with higher energy efficiency and how to conduct a motor review



Throughout the guideline calculation examples are made using representative motor prices, electricity prices and prices of installation, which have been obtained with the assistance of motor vendors and local energy consultants. The prices are strictly meant as guidelines to be used in examples of various business cases and calculating total cost of ownership (TCO) and should therefore only serve as a rough guideline for enterprises looking to replace or invest in energy efficient motors. When planning to replace motors enterprises should base financial decisions on concrete, up to date prices from vendors and current electricity prices.

The first chapter concerns motor technology in brief. Only the main types of motors as well as methods of power transfer are shortly described.

The second chapter account for the international experience. Based on the work of The International Electrotechnical Commission, IEC, the approach of continually introducing requirements with higher demand for energy efficiency is described and the impact of the regulation as well in the European market.

The third chapter deal with the current situation in the Indonesian market.

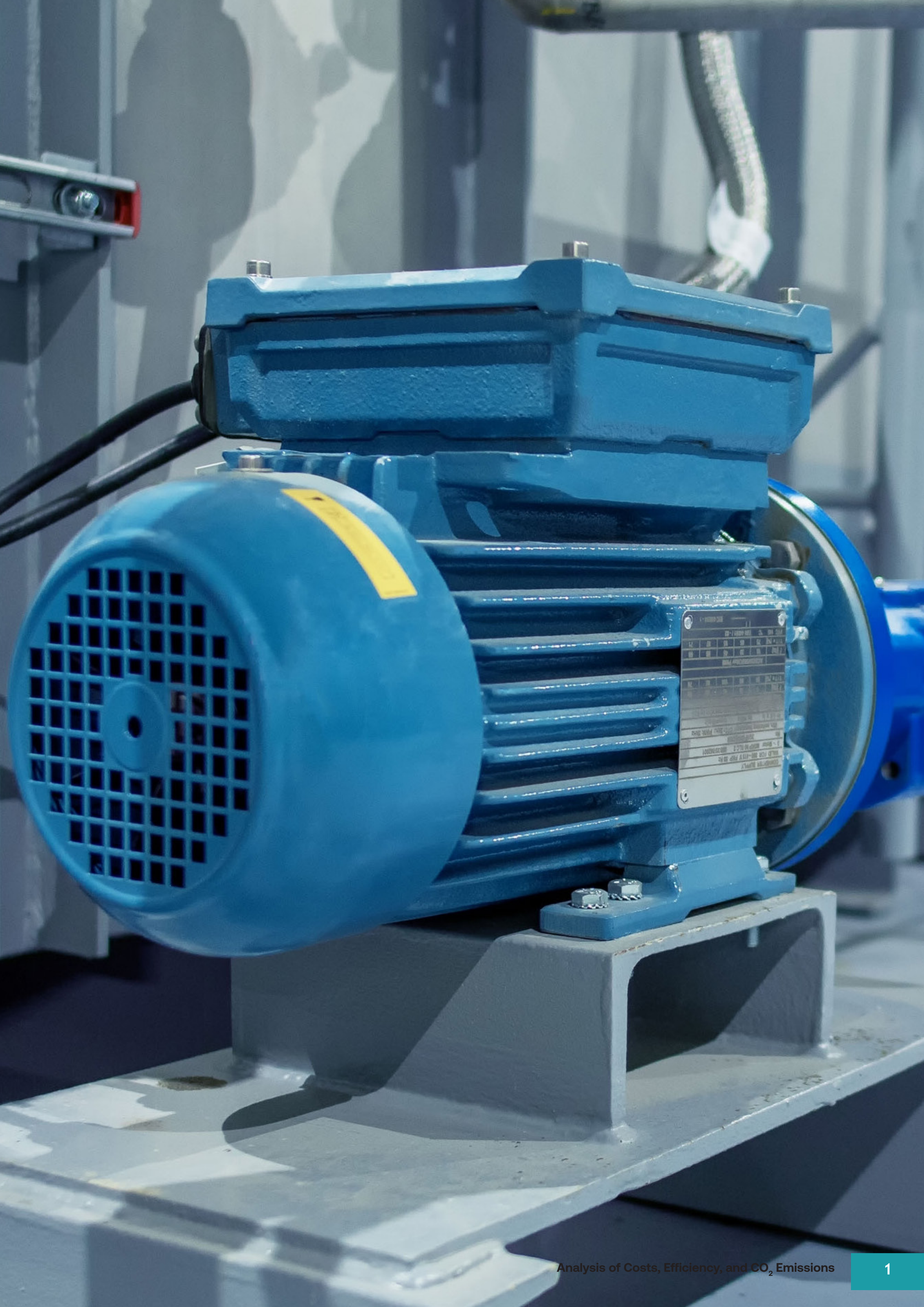
The fourth chapter concerns the energy efficiency of electrical motors themself.

Chapter five address regulation systems and the advantage of using VSD instead of control with valves and dampers.

The sixth chapter illustrates the principles of a motor review as well as how to identify energy savings due to improved motor control and regulation.

Chapter seven includes selected examples from the energy audits conducted prior to this technology guideline.

The eighth chapter concerns the procurement process for motors including a guideline for using the Total Cost of Ownership, TCO, when purchasing motors. Design with energy awareness is described in the different phases of a project.



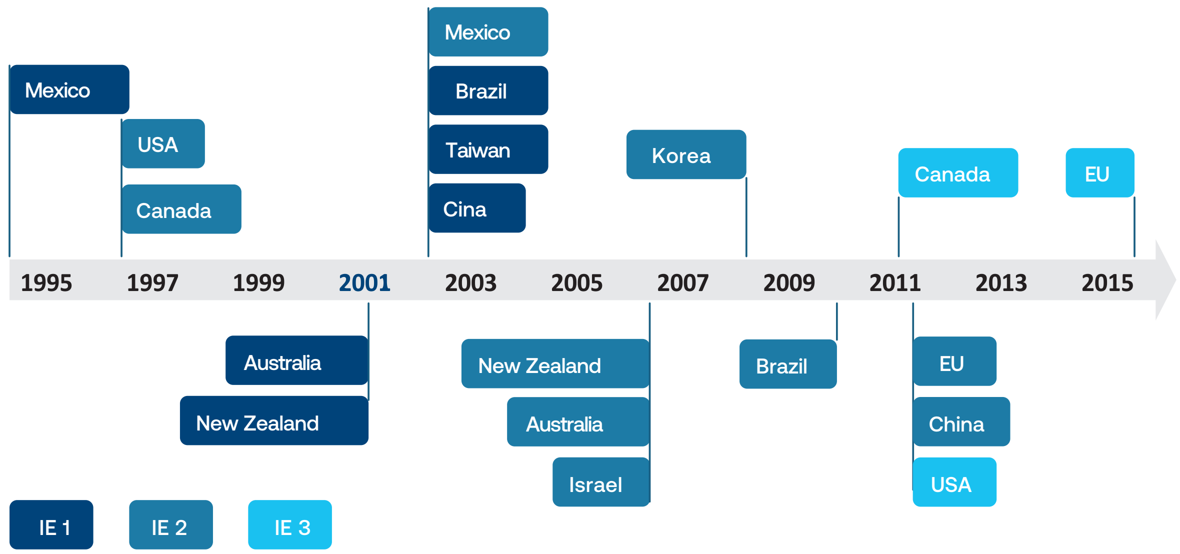
1. International experience

1.1 Examples of international best practices to promote energy efficiency

An example of a system to promote energy efficiency is the *Ecodesign* system, which describes a series of demands used for all members of the EU across many product types, including electrical motors and variable speed drives, to ensure that their environmental impact is kept at a minimum.

The demands are formally known as the ESPR regulation (Ecodesign Requirements for Sustainable Products), originally formulated in the 2009/125/EC directive, which was latest updated in 2024[1], and enforce demands related to sustainability including but not limited to energy efficiency, longevity, recyclability, carbon footprint, and are enforced for all included products placed in the EU market. **Figure 1** shows the timeline of various countries introducing Minimum Energy Performance Standards (MEPS) such as the Ecodesign regulation.

Figure 1 Timeline of introduction of MEPS in various countries.



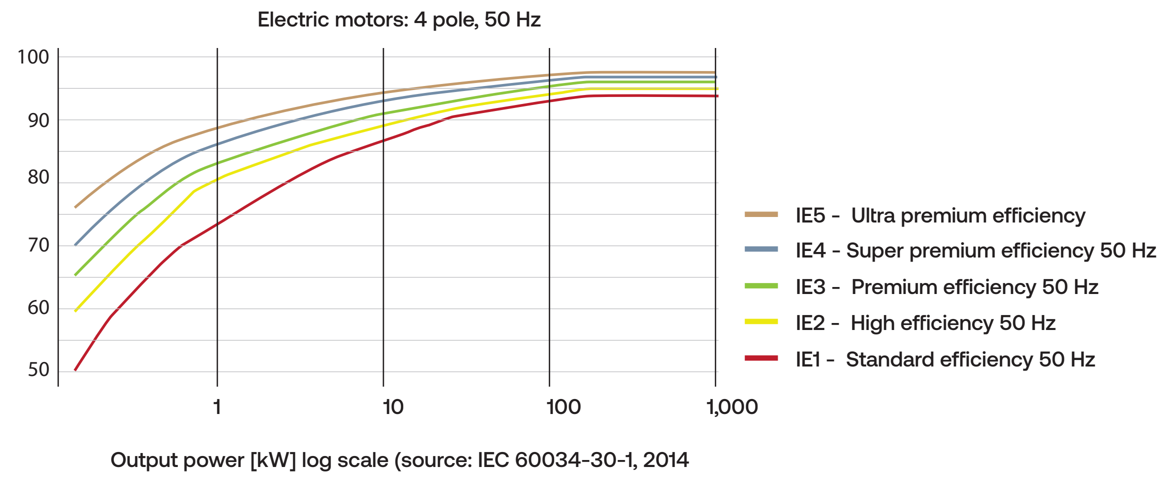
Source: UNIDO (2011) (adapted)

In the case of electric motors, they are defined in the Ecodesign requirements as a "*device that converts electric energy into mechanical energy in the form of a rotation (torque and speed)*" with the Variable Speed Drive (VSD) being defined as *"an electronic device that can be used to adjust the rotation speed of an electric motor according to the needs of the application"*. The 8 billion motors in the EU consume almost 50% of the electricity produced[2].

When defining energy efficiency of motors, the regulation expresses this in International Energy (IE) efficiency classes ranging from IE1 to IE5 with the former being the lowest and the latter being the highest[3], as seen on **Figure 2.**

1 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1781&qid=1719580391746
2 https://energy-efficient-products.ec.europa.eu/product-list/electric-motors_en
3 Defined by the International Electrotechnical Commission (IEC) 600034-30-1 standard on efficiency classes for low voltage AC motors.

Figure 2 Motor efficiency in percentage versus motor output power in kilowatt



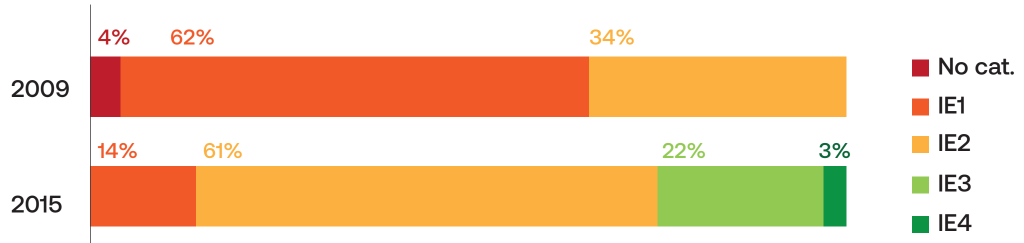
Source: International Electrotechnical Commission (IEC) 60034-30-1, 2024

Since the first ecodesign regulation was introduced, the demand for the efficiency class of the motors entering the EU market has been gradually increased. Meeting the requirements of the regulation is a responsibility for manufacturers as well as importers. By gradually increasing the regulations requirement to the motor efficiency classes, the motor market has been shifted towards using motors and variable speed drives with higher efficiency.

With a gradual increase in the Ecodesign regulations efficiency requirement of the motors, the IEC expanding the number of efficiency classes and the manufacturers improving their technology in order to live up to the heightened requirements, a symbiosis is created which continuously increases the efficiency of new motors in the EU. The impact of the regulation was summarized in 2024[4]. In the original EU regulation 640/2009 motor manufacturers could produce motors, which complied with either efficiency class IE3 or a lower efficiency IE2 motor with variable speed drive. The impact was a drop in sales of motors with IE1 class from 62% to 15% between 2009 and 2015, meaning a significant shift in the market towards using motors with higher efficiencies.

The requirement for VSD was later dropped in a revised regulation due to challenges in verifying their usage on IE2 motors and replaced with a requirement to use IE3 motors and regulation on the efficiency requirement of the variable speed drives. This development is shown on Figure 4, which also shows the introduction of the IE3 and IE4 classes.

Figure 3 EU Market share of motor efficiency classes in 2009 and 2015

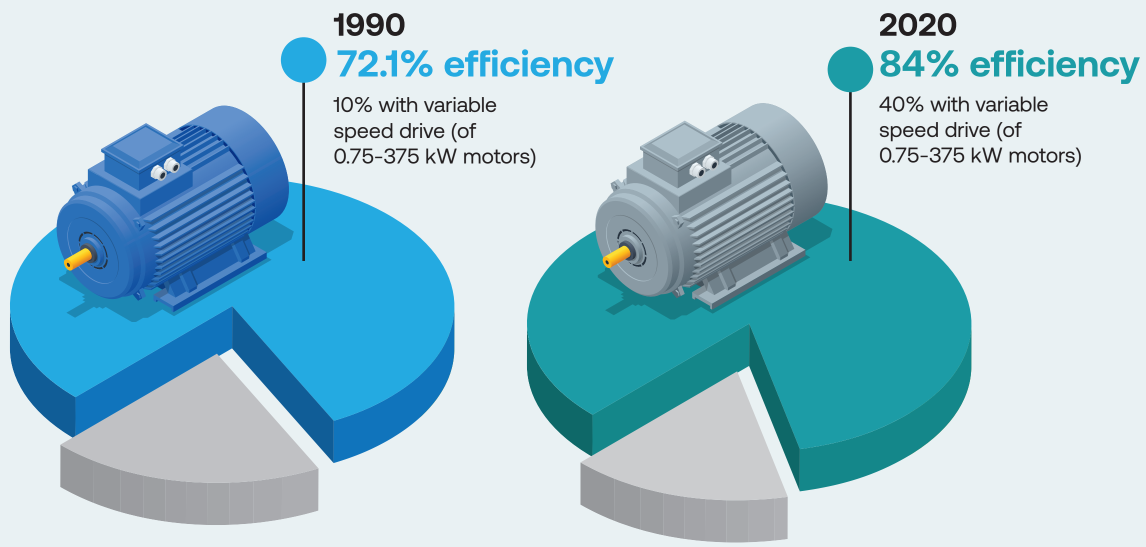


Sumber: Laporan Tinjauan Akuntansi Dampak Ecodesign 2023 – VHK 2024

Increasing the share of high-efficiency motors has meant an overall increase in average motor efficiency from 72% in 1990 to 82% in 2020, illustrated on Figure 5, which also indicates the increase in usage of variable speed drives.

4 Ecodesign Impact Accounting Overview Report 2023 – VHK 2024

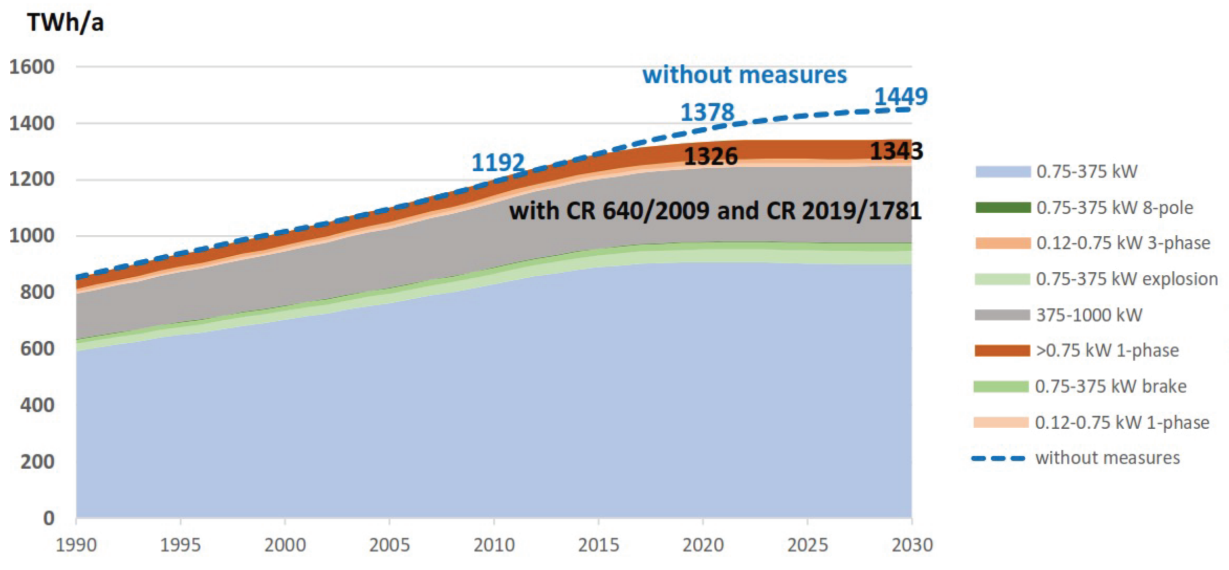
Figure 4 EU average motor efficiency from 1990 to 2020



Source: Ecodesign Impact Accounting Overview Report 2023 – VHK 2024

The impact on energy saving resulting from the regulation is shown on Figure 6. The electricity consumption from 2009 to 2020 would have increased from 1192 TWh/a to 1378 TWh/a, and to 1449 TWh/a in 2030, if no measures had been taken. Due to the ecodesign regulation, the electricity consumption instead increased to 1326 TWh/a in 2020 and is projected to increase to 1343 TWh/a in 2030, which is 106 TWh/a lower than without regulation. The resulting energy saving represents 4,5% of the total electricity consumption in the EU in 2020. In expenses this is estimated to save the EU a net amount of 11 billion euros in 2030 when also considering the cost of acquisition.

Figure 5 Projected electricity consumption with and without energy saving measures



Source: Ecodesign Impact Accounting Overview Report 2023 – VHK 2024

Energy savings resulting from the choice of motors with high efficiency classification will be enhanced by a long life. The importance of this is even greater when the actual lifetime exceeds the expected one. Studies show that motors get twice as old as their expected operating life.[5]

5 Swiss Agency for Efficient Energy Use, 2012

1.2 Incentives schemes for Promoting Efficient Industrial Electric Motors

Incentive schemes play a crucial role in accelerating the adoption of energy-efficient electric motors in the industrial sector. These schemes can help overcome economic barriers by making the transition to efficient equipment more financially attractive. This subchapter explores various types of incentive mechanisms, supported by case studies that illustrate successful implementations globally.

a. Voluntary Agreement Schemes (VAS)

A Voluntary Agreement Scheme (VAS) is one effective approach for promoting the use of higher-efficiency motors. In a VAS, companies voluntarily commit to implementing energy efficiency measures, such as upgrading to high-efficiency motors, in exchange for fiscal or non-fiscal benefits. These benefits can include tax reductions, grants, or preferential financing terms. A key feature of VAS is the mutual agreement on a payback period threshold for projects. Typically, projects with payback periods of less than a certain number of years are prioritized, ensuring rapid returns on investment. Below are the two (2) examples of the incentive scheme:

- **Denmark's Voluntary Agreement Scheme (VAS).** A Voluntary Agreement Scheme (VAS) is an effective approach to incentive the energy intensive industries implementing energy efficiency projects. In a VAS, companies voluntarily commit to implementing energy efficiency measures, such as upgrading to high-efficiency motors, in exchange for fiscal or non-fiscal benefits. These benefits can include tax reductions, grants, or preferential financing terms. A key feature of VAS is the mutual agreement on a payback period threshold for projects, typically prioritizing those with payback periods of less than four years, ensuring rapid returns on investment. In the period 1996 – 2013 more than 200 companies have joined the agreement scheme for shorter or longer periods, with period 2006-2011 saved 5.4 % of their energy consumption in average.

- **Netherlands' Long-Term Agreements (LTAs**) The Netherlands has implemented Long-Term Agreements (LTAs) with industrial sectors, which are a form of VAS aimed at enhancing energy efficiency. One notable outcome of these agreements is that participating companies The Dutch government supported this initiative by providing incentives, such as tax benefits and technical assistance, encouraging industries to invest in high efficiency equipment. More than 1,000 companies across 37 sectors have engaged in these agreements, contributing significantly to the Netherlands' national energy goals.

b. Performance-Based Financing Schemes

Performance-based financing schemes encourage the adoption of energy-efficient technologies by structuring financial incentives around the realized energy savings of a project. In these schemes, payments are tied directly to the performance of the installed equipment, such as energy-efficient motors, which allows companies to offset the initial investment through future energy savings. This model reduces financial risk for participants by requiring minimal or no upfront costs and enables a practical way to fund energy efficiency improvements in capital-intensive sectors.

- **India's National Motor Replacement Program – EESL**

  India's National Motor Replacement Program, administered by Energy Efficiency Services Limited (EESL), is a prime example of performance-based financing. EESL provides high-efficiency IE3 motors at a reduced cost with no upfront payment requirement for participants. The program's innovative financing model allows customers to repay the costs over a three-year period directly from the monetized energy savings achieved by the new motors. By removing the need for initial investment, EESL effectively lowers the economic barrier to motor replacement, accelerating the adoption of efficient technology across India's industrial sector.

  The programme is envisioned to achieve annual energy savings of 9,150 MWh, an annual cost savings of $902,112 and an annual CO2 emissions reduction of 8,050 tons. The NRMP estimates that capturing the country's entire market would lead to energy savings of approximately 22 million MWh and emission reductions of 18.3 million tons of CO2 per year.

c. Investment Subsidy Schemes

Investment subsidies are another popular incentive type that directly targets energy efficiency upgrades, such as replacing standard motors with premium efficiency ones. These schemes typically provide financial support to cover a percentage of the investment cost, lowering the initial financial burden for companies and improving project viability. Example of this scheme is as follows:

- **KOSGEB SME Development Support Programme – TEVMOT Project**

  One notable example is Turkey's KOSGEB SME Development Support Programme, which includes the TEVMOT Project for replacing inefficient electric motors. The programme offers substantial financial incentives, covering 60% of the replacement costs as recommended by energy audit reports. This support is capped at 80,000 Turkish Lira per firm. Additionally, if the new motors meet the domestic production criteria specified under the "Yerli Malı Tebliği," the support rate increases by an extra 15%. Participating SMEs must be registered with KOSGEB and located within designated pilot Organized Industrial Zones (OIZs). They also need to conduct energy audits and commit to recycling old motors for the incentive eligibility

d. Tax Incentive Schemes

Tax incentive schemes provide reductions in corporate tax rates or tax credits for companies investing in energy-efficient technologies. These schemes can serve as a substantial motivator for industrial facilities to transition to efficient electric motors. The following case study showcases tax break programme provided by the UK government on energy efficient investments on several significant energy users equipment, including motors.

- **United Kingdom's Enhanced Capital Allowances**

  The United Kingdom has implemented a successful tax incentive program called the Enhanced Capital Allowances (ECA), which encourages businesses to invest in energy-saving plant and machinery. The ECA scheme allows businesses to write off 100% of the investment cost of qualifying equipment against their taxable profits in the financial year of purchase. This immediate tax relief accelerates cost recovery and provides a substantial financial incentive for adopting energy-efficient technologies.

  Manufacturers can apply to have their products included on the Energy Technology Product List shown as follows:
  - Motors and drives
  - Air-to-air heat recovery
  - Automatic monitoring and targeting (AMT) equipment
  - Boiler equipment
  - Combined heat and power (CHP)
  - Compressed air equipment
  - Heat pumps
  - Heating, ventilation and air conditioning (HVAC) equipment
  - High speed hand air dryers
  - Lighting
  - Pipework insulation
  - Refrigeration equipment
  - Solar thermal systems
  - Uninterruptible power supplies
  - Warm air and radiant heaters
  - Waste heat to electricity conversion equipment.

  The programme provides an incentive for manufacturers to develop more efficient products, since inclusion can increase the financial return on their equipment and hence boost sales. Of course, for Enhanced Capital Allowances to be effective the company purchasing the equipment must be liable to pay corporation tax, otherwise there is no effect. The UK Enhanced Capital Allowance scheme was introduced in 2001 and an independent evaluation carried out in 2008 indicated that companies that were aware of the scheme tended to invest more in energy efficiency

e. Grants and Rebate Programs

Grant and rebate programs are designed to encourage businesses to invest in efficient technologies by offering direct financial incentives post-purchase or after project implementation. These incentives are generally simpler and quicker for companies to access compared to tax incentives. The country that has already implemented this scheme is as follows:

- **Chile's electric motor grants**

  The industrial and mining sectors account for about 38% of primary energy consumption in Chile. These sectors are heavily dependent on small motors for various tasks such as material handling and processing minerals. In 2009 Chile initiated a programme to encourage the replacement of traditional motors with high efficiency motors. With a total budget of USD 2.5 million the programme subsidised the purchase of high efficiency motors to equalise their cost with conventional units. The scheme covered motors up to 7.5 kW and in 2009 and 2010 over 5,000 motors were replaced.

f. Complementary Financing Programs

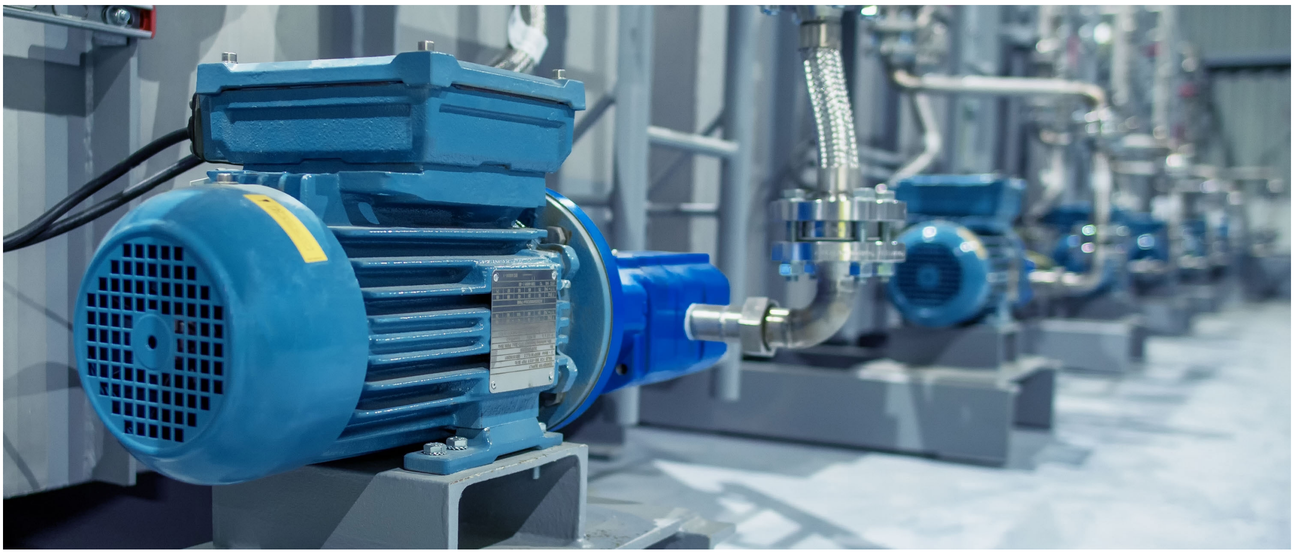
In addition to incentive schemes, larger programs such as Indonesia's Just Energy Transition Partnership (JETP) can help mobilize substantial financing for energy transition efforts. JETP aims to secure international support and investments, including the promotion of energy-efficient technologies in the industrial sector. Such programmes align with Indonesia's commitment to achieving net-zero emissions and improving energy security.

1.3 CBAM

The EU's Carbon Border Adjustment Mechanism (CBAM) is the EU's tool to put a fair price on the carbon emitted during the production of carbon intensive goods[6] that are entering the EU, and to encourage cleaner industrial production in non-EU countries.

The objective is for the carbon intensive industry in both the EU and outside to reduce their emissions, both direct and indirect emissions. The less companies do to reduce CO2 emissions, the more must be paid to export goods into EU.

High efficiency for motor systems can be part of the mitigation actions for the carbon intensive industries.



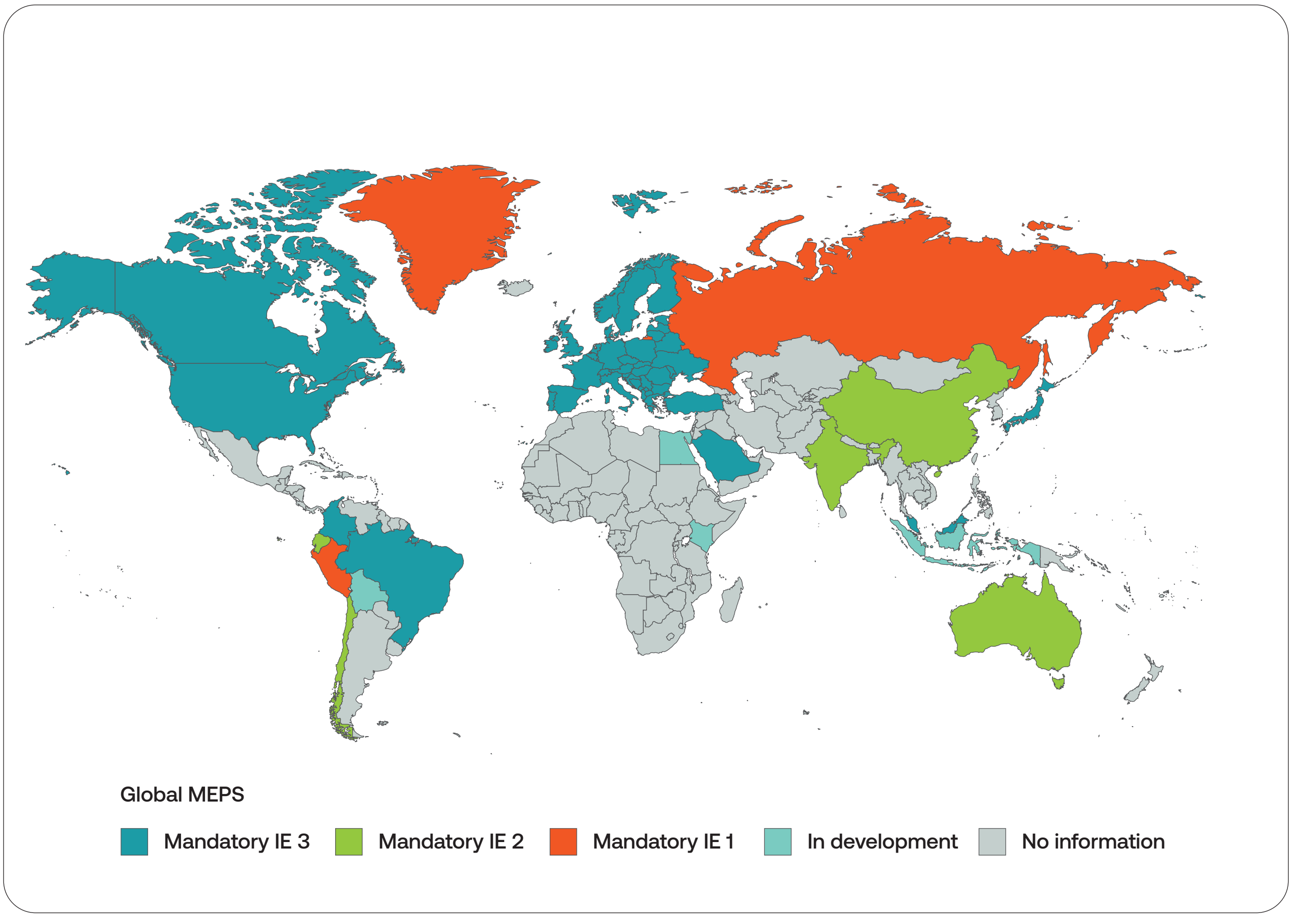
6 https://monitor-industrial-ecosystems.ec.europa.eu/industrial-ecosystems/energy-intensive-industries

2. National perspectives in Indonesia

2.1 The current status

While draft for regulation is currently being treated, and has been planned for many years, Indonesia has not yet introduced MEPS, as done in for example EU and other countries, as described in section 1 of this guideline. The map on Figure 6. illustrates the level of introduction of MEPS across the world for various motor classes.

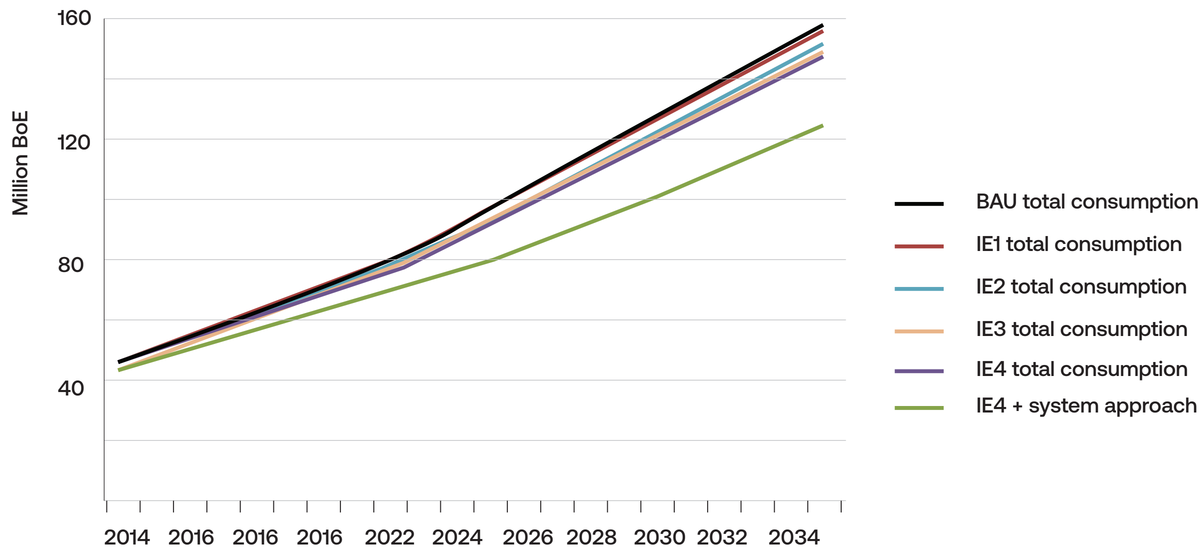
Figure 6 Countries with MEPS (Minimum for electric motors.



Source: Motor MEPS around the World (Source: ISR-UC, 2018)

According to a study conducted in 2015 by Energy research Centre of the Netherlands (ENC) on the motor market in Indonesia, the impact of introducing MEPS at the first level of IE1, would be modest with expected electricity savings being only 0.7% compared to business as usual. Expanding this requirement to level IE4 would increase the energy saving to 5.1% but could only be implemented over a longer period. Expanding this requirement further into looking at a full system approach, which also considers using VSDs, better couplings, more efficient equipment such as pump attached to motor, this potential can be increased by a factor 25 compared to only making IE1 motors mandatory. The impact of these at various levels of IE-classes in units million BOE equivalent are seen on Figure 7.

Figure 7 Effect of introducing MEPS at several IE-classes, followed by the system approach.



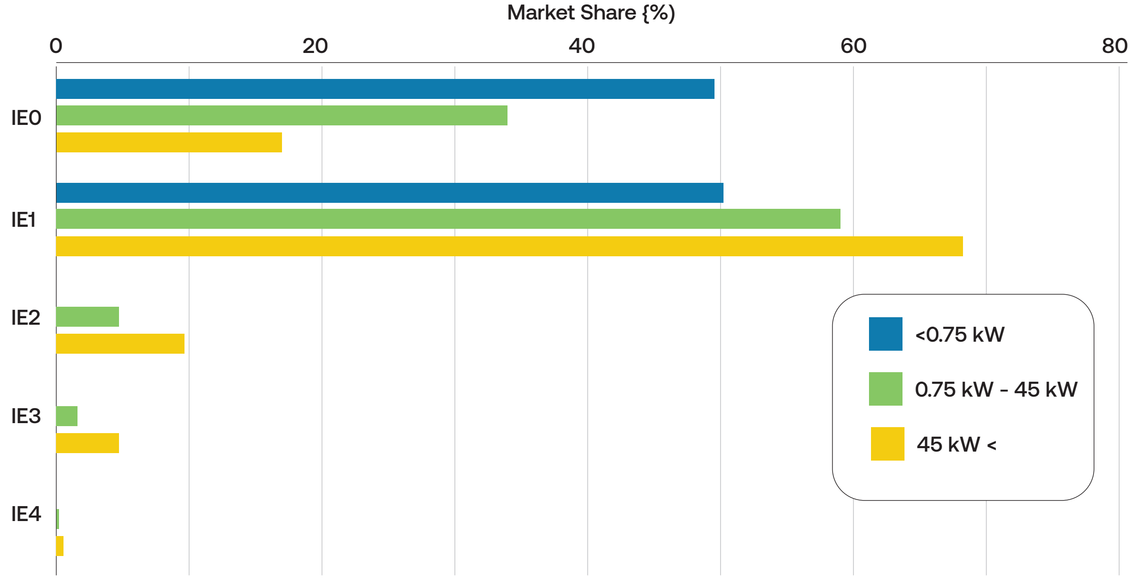
Source: Optimizing Electric Motor-Driven Systems. ECN (2016

When the study was conducted in 2015 recent studies had found that around 22-50% of motors could be classified as high efficiency, depending on the group of motors evaluated. Motors bought from other than the biggest vendors were anecdotally often heard to be supplied mainly by China, which at the time were mostly standard or below standard motors [7].

The results from the study are summarized in Figure 8. which show, that by the time of the study, the average motor class was IE1.

Anecdotal data from local consultants and motor manufacturers on the current Indonesian motor market states, that since 2015 the average motor class market share has shifted from primarily IE0 and IE1 to now being dominated by classes IE1 and IE2.

Figure 8 Market share of electric motors in Indonesia by IE-class in 2014



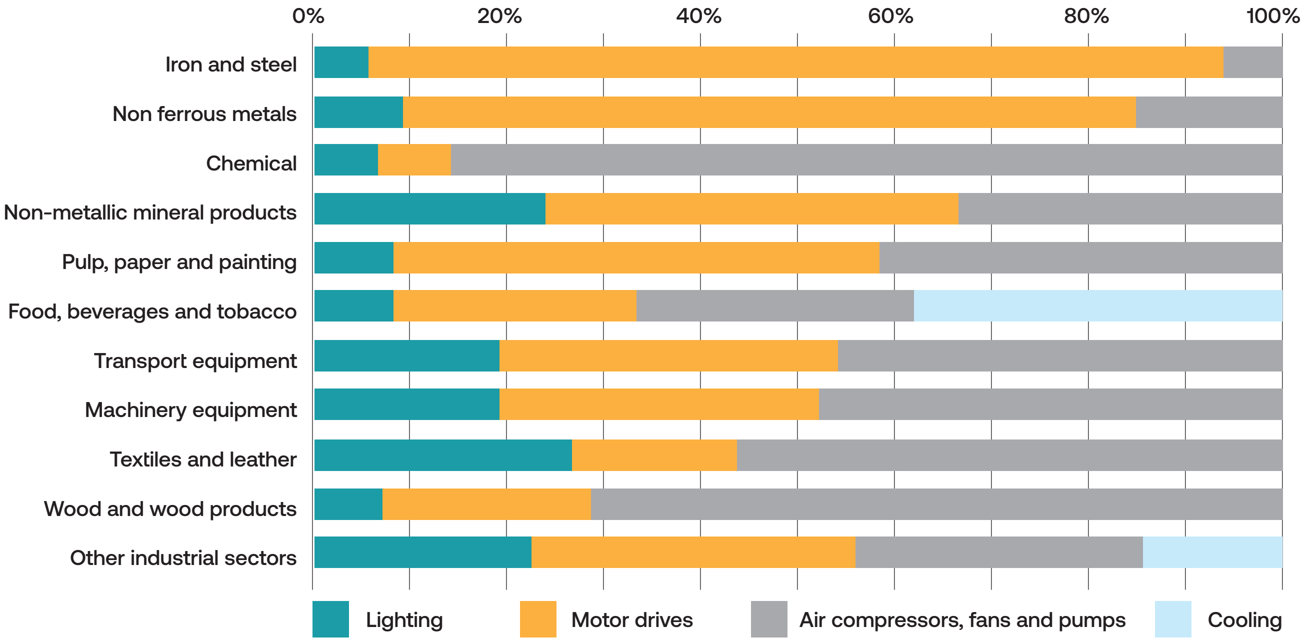
The above quoted study by ECN is the newest most comprehensive study on the topic, that was available at the time this guideline was made. A new study will be conducted in 2025 which will seek to update the results from the study by ECN and provide a fresh view on the Indonesian motor market.

7 Energy Efficient Electric Motors in Indonesia, Policy brief (ECN 2015)

2.2 Impact of minimum requirements

Understanding the importance of introducing Minimum Energy Performance Standards (MEPS) for electric motors is key to achieving long-term energy savings. Since electric motors are widely used in industries and represent a significant share of electricity consumption, as seen on Figure 9, MEPS help ensure that motors meet higher efficiency standards. This leads to lower energy consumption, reduced operational costs, and a decrease in carbon emissions, aligning with global climate goals.

Figure 9 Share of electricity demand by industrial sector in Indonesia



An analysis of electric motors in Indonesia was conducted using the Low Emission Analysis Platform (LEAP) model to assess the long-term energy-saving potential. The data, sourced from the 2015 ECN study [8], categorized electric motors into three capacity groups: low capacity (up to 0.75 kW), medium capacity (0.75 to 45 kW), and high capacity (above 45 kW). Motor efficiencies were organized into five classifications: IE1, IE2, IE3, IE4, and IE5 (IE5 being the most energy efficient). An average efficiency was calculated for each classification within each capacity group, resulting in five distinct averages per capacity category, as seen on Figure 10. Furthermore, the current distribution of electric motors has been taken from ECN document that can be seen on Figure 7.

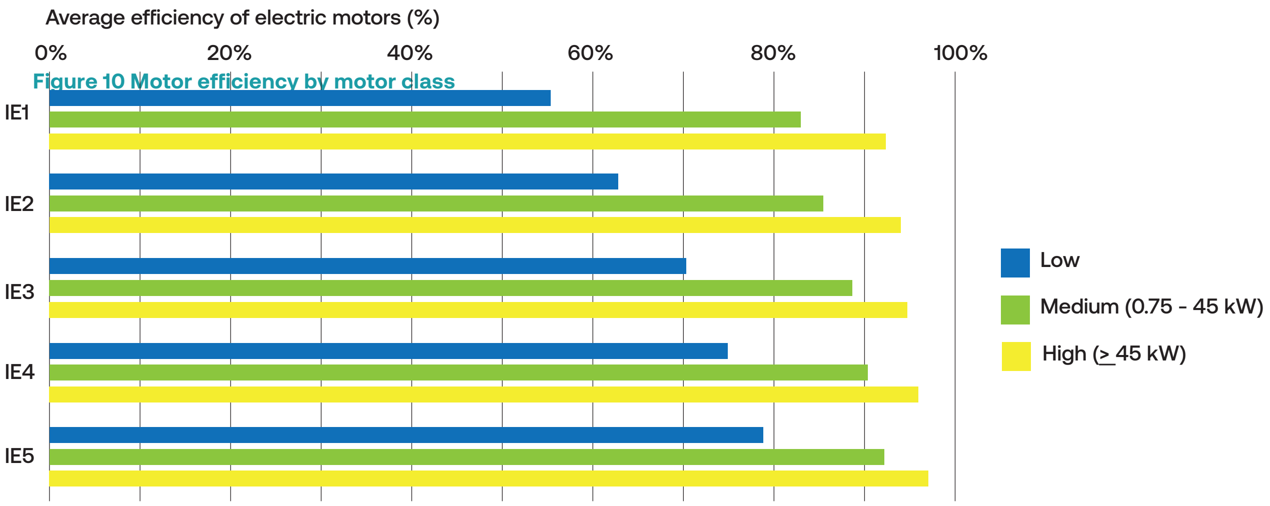


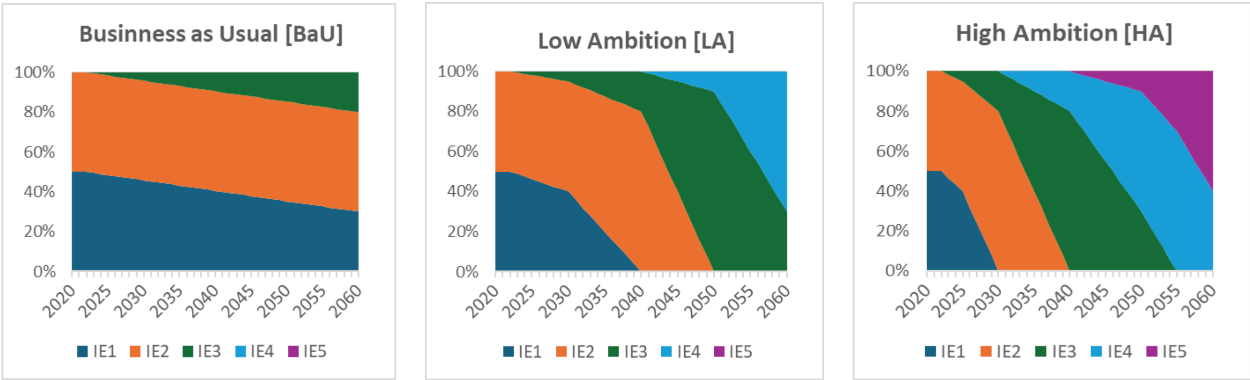
Figure 10 Motor efficiency by motor class

8 Source: 'Energy Efficient Electric Motors in Indonesia, Mid-term report: quantifying the project, stakeholders feedback and preparing the next phase' (ECN 2015)

2.2.1 Scenarios

To assess the impact of energy performance standards on motor efficiency and energy savings in Indonesia, three distinct scenarios have been developed: Business-as-Usual (BaU), Low Ambition MEPS, and High Ambition MEPS, as illustrated on Figure 11. The BaU scenario serves as a baseline to illustrate the trajectory of motor efficiency in the absence of formal regulations, providing insight into how market dynamics, such as electricity prices and motor costs, can drive changes in motor efficiency over time.

Figure 11 Scenarios for BaU and MEPS-ambition levels



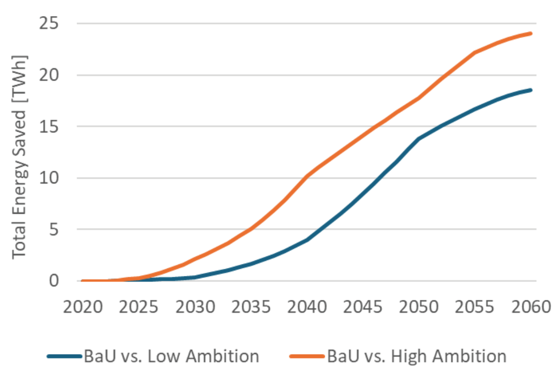
The Low Ambition MEPS scenario introduces gradual improvements in energy performance standards, with IE2 motors mandated by 2030, followed by IE3 in 2040 and IE4 in 2050. This approach reflects a more conservative pathway for efficiency improvements, allowing for gradual market adaptation. In contrast, the High Ambition MEPS scenario accelerates the implementation of standards, requiring IE2 motors by 2025, IE3 by 2030, IE4 by 2040, and ultimately promoting the adoption of IE5 motors by 2050. This scenario represents a more aggressive strategy aimed at maximizing energy savings and advancing motor efficiency at a faster pace.

2.2.2 Results

The differences between the BaU and the Low Ambition scenario rise to 18.6 TWh of energy savings by 2060, while the difference with the High Ambition scenario grows to 24.0 TWh by 2060. This indicates that high ambition measures lead to more significant reductions in demand or improvements in efficiency.

To achieve these benefits, it is crucial to implement Minimum Energy Performance Standards (MEPS) as soon as possible. Establishing MEPS sets a baseline for motor efficiency, ensuring that only motors that meet or exceed specific efficiency criteria are available in the market. Initiating MEPS with standards such as IE2 and IE3 is essential because these levels represent significant improvements over older, less efficient motor designs. By gradually introducing these standards, we can facilitate a smoother transition for manufacturers and users alike.

Figure 12 Impact of the level of ambition of MEPS



By prioritizing the implementation of MEPS in this structured manner, it is necessary to create a market environment that not only promotes energy-efficient practices but also supports the adoption of VSD technology and increases the efficiencies of Fans and Pumps. Ultimately, this strategy will lead to greater overall energy savings, enhanced performance of electric motors, and a significant contribution to sustainability efforts in the industrial sector.

3. Motor technology in brief

All electric motors convert electricity into mechanical energy. They operate using principles of electromagnetism. Introducing an electric current in a magnetic field with bundle of wires creates a torque which causes the motor shaft to rotate. An electric motor has a stationary part – the stator, and a rotating part – the rotor. The magnetic field can be created by permanent magnets or by electric current in a winding.

3.1 Asynchronous motors (AC)

Asynchronous (induction) three-phase AC motors are the most widely used motor type in the industry and are used in all kinds of machinery and equipment. The construction can apply 2, 4, 6 or 8 poles. The number of poles of a motor determines its output power, rated speed, maximum speed, torque fluctuation, noise, and vibration characteristics. Motors with different numbers of poles are suitable for different application. For heavy duty (more than 1 MW power) the motors are normally constructed for high voltage (like 10 kV).

Another special construction is motors for ATEX applications. These motors are equipped with pressurized equipment; fire and explosion proof external structure; increased security; anti spark protection to eliminate the risk of explosion.Single-phase motors are mostly used in households or smaller equipment.

3.2 Synchronous motors (AC)

In synchronous motors, the rotor and the supply frequency are synchronized. The current and speed remain constant even when loads vary. Synchronous motors are therefore ideal for use in machines and robotic arms.

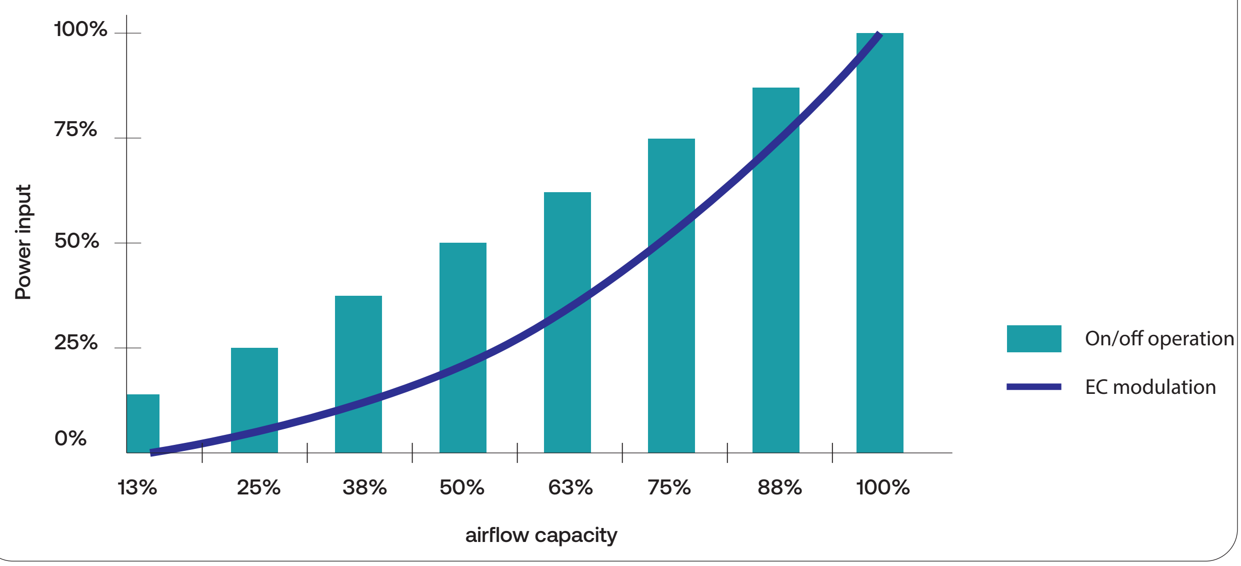
3.3 DC motors

DC motors have a high starting torque and fast response times during start/stop and acceleration phases. DC motors are used in sectors like portable and medical equipment automotive applications. Fans with DC motors and VSD can achieve high energy efficiency.

3.4 EC motors

EC (*electronically commutated*) motors are brushless DC motors, which are controlled by external electronics such as a variable speed drive. Compared to AC motors, in which the direction of the electric current is done mechanically which causes losses, this is done electronically in EC motors, which eliminates these losses and results in higher efficiency. Besides having higher efficiency due to less losses, the frequency control also permits a variable load on the motors, meaning that for example the air flow of a fan can be reduced by adjusting the speed of the motors down instead of using dampers or multiple fans with AC motors. The difference in operation is illustrated on Figure 13.

Figure 13 Example of power input versus air flow capacity of fan using either AC motors with On/Off operation or EC modulation. Source: https://hvacglobal.org/ac-dc-and-ec-motor-definitions-and-comparisons/



3.5 Energy efficiency of motors

The energy efficiency of an electric motor is calculated as

the ratio of the mechanical output power to the electrical input power.

$$\left(\eta_{motor} [\%] = \frac{P_{mechanical\ output} [kW]}{P_{electrical\ input} [kW]} \times 100 \right)$$

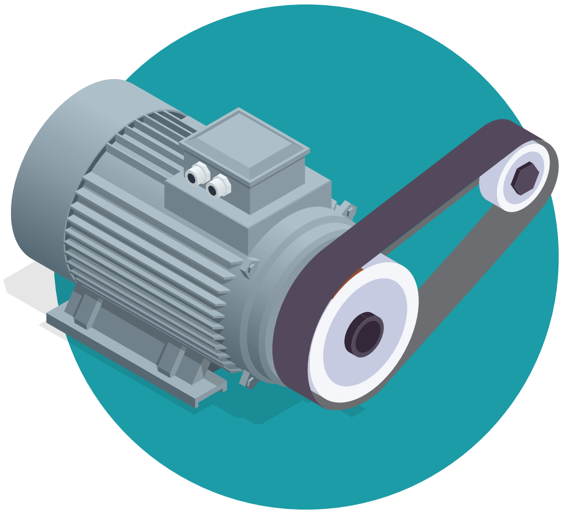
The same definition applies for electric motor-driven systems.

The efficiency of a motor is determined by the quantity of the different losses:
- mechanical losses are friction losses that occur between the stationary and moving parts
- electrical losses are the losses that occur in the copper windings due to the current and winding resistance.
- magnetic losses are losses that occur in the core or the iron parts due to the demagnetization of the ferromagnetic core and to current induced in the core

The manufactures must innovate and improve on all details for increasing the total energy efficiency of motors. To improve energy efficiency of motor systems the optimisation of the system around the motor is more important than the motor itself.

3.6.1 Belt drivers

From an economical perspective, belt drive systems are the cheapest, and will operate reliably up to around 50 kW, from which gear or direct drive systems are recommended.

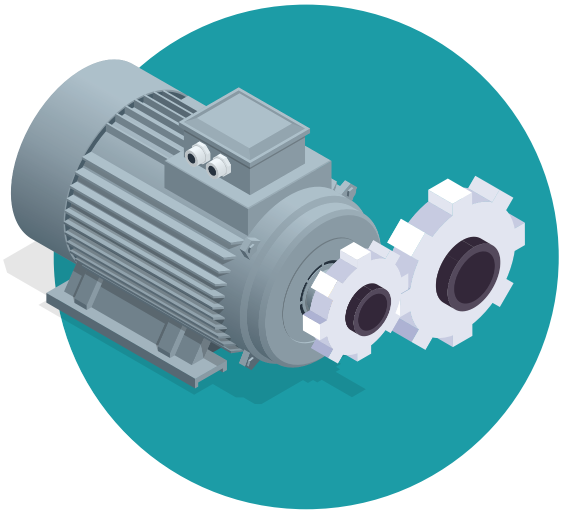


Belt drives require low maintenance with only belt tension and alignment having to be routinely checked. If a belt is worn out it can easily be replaced with a spare belt, which is typically kept as spare parts.

Depending on belt type and condition, belt drives can result in high efficiency losses due to poor power transfer, which will become worse if the belt is not maintained or replaced.

3.6.2 Gear drivers

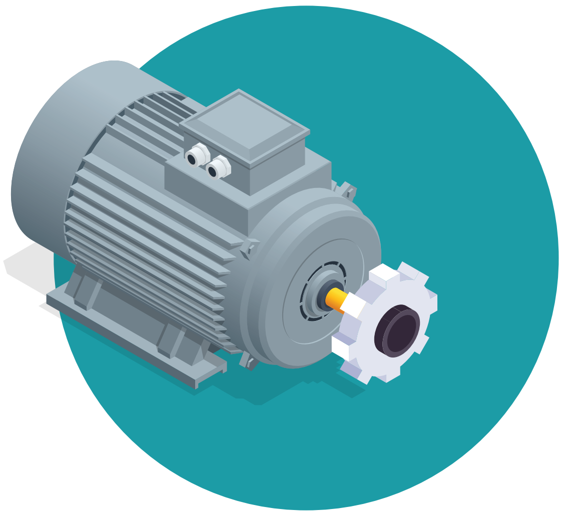
Gear drives are suited for applications with motors larger than 50 kW and have higher initial cost than belt drives and can have higher maintenance cost if not properly lubricated and gears are to be replaced. If properly maintained, gears and gearbox can last as long as the motor.



Gear drives should be periodically checked for sufficient lubrication or unwanted vibrations due to poor alignment of gears, which can cause damaging shocks between parts. Compared to belt drives, gear drives are noisier in operation which may be a determining factor for chosen solution depending on the location of the motor.

3.6.3 Direct drivers

Motors with direct drives offer both higher efficiency and lower maintenance due to fewer moving parts than both belt- and gear drives while also offering better precision control. The trade-off is, that belts and gears offer more flexibility in terms of load speed, where the speed for a direct drive will have to be directly controlled on the motor, which will result in higher initial costs, due to the need of a dedicated drive controller. Installation and maintenance of motors



3.7 Installation and maintenance of motors

The motors should be installed according to guidelines by the manufacturer and only be done by skilled personnel to follow proper safety requirements. Decisions should be made regarding type of mounting and whether the motor should be mounted with a flange or on a foot. Improper mounting and alignment of motor could lead to both loss of efficiency and unnecessary damage from unwanted vibrations.

Precise alignment is a prerequisite of optimal motor operation and lifespan and should be done by trained personnel to ensure perfect co-linearity between shafts. Measurement of vibration levels, check and adjustment of alignment should be done during routine maintenance. For larger foot-mounted motors e.g. for compressors it is especially important to ensure, that the foundation on which the motor block is placed, e.g. a concrete slab, is levelled and sized for sufficient damping of vibrations, and that the footing of the motor is fully connected to the foundation without any gaps. The foundation may also have to be separated from the rest of the floor to ensure that the vibrations do not propagate to walls or other machinery.

Electrical installation should only be done by authorized electrical installers to ensure proper connection and correct insulation of cables, and that all electrical work is in compliance with local electrical codes and standards.

The motor should be placed in a properly ventilated and cooled environment will minimize risk of overheating and ensure longest lifetime of electrical components. The environment temperature and degree of ventilation and working state of the fans and sinks should be checked as part of routine maintenance to ensure optimal heat dissipation.

As part of regular maintenance, a register should be kept of all the motors at the enterprise, which should include service intervals, brand, IE-class (if relevant), application, installation year, log of repairs and rewinding's etc. Companies with an ERP system (like SAP, Oracle EBS etc.) can with advantage use the tools included in the ERP system for both technical documentation maintenance log.

4. Energy efficiency of electrical motors

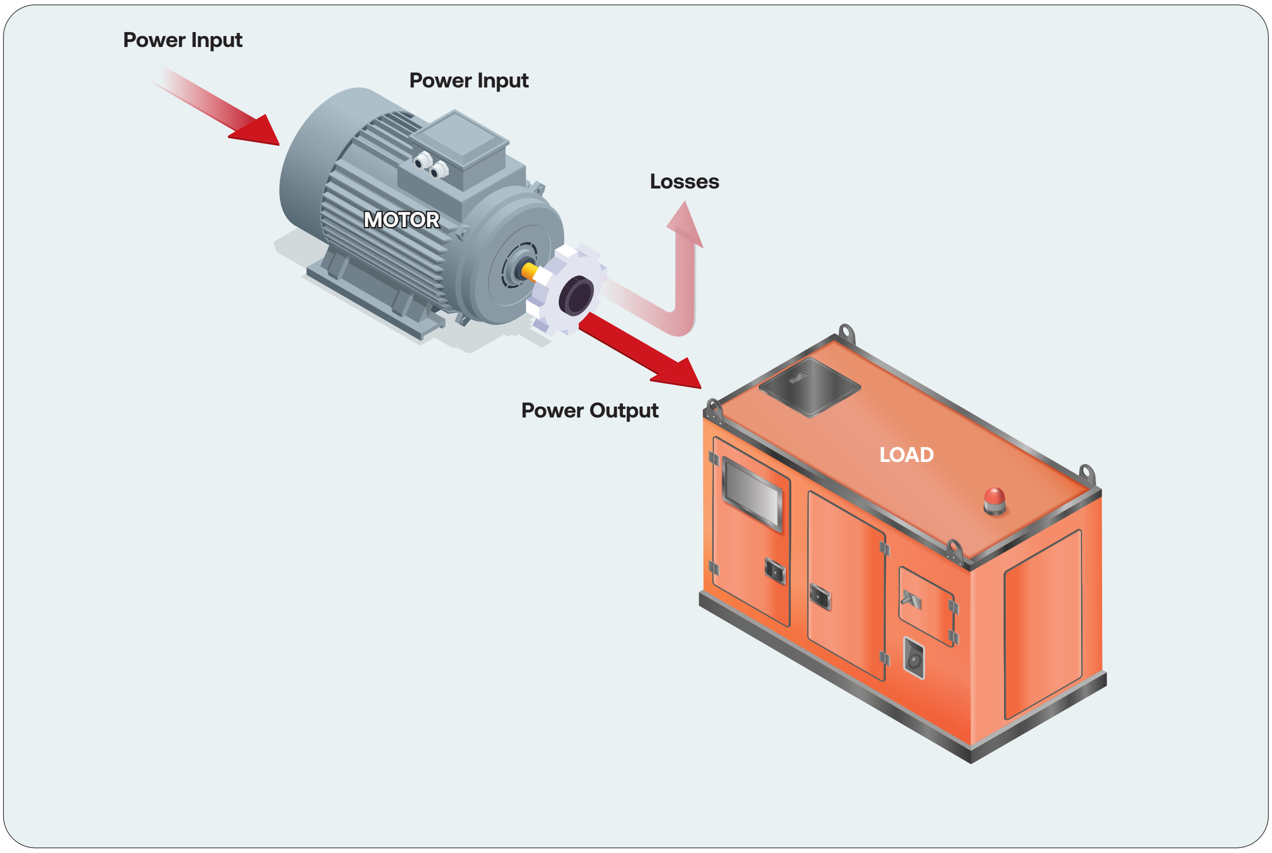
4.1 Different classes of electrical motors

When categorizing the motors into different degrees of efficiency, a commonly used system is the International Energy (IE) efficiency classes, which is defined by the International Electrotechnical Commission (IEC) 60034-30 standard for rotating electrical machines.

In order to obtain an IE rating, manufacturers must document, that their motors have been tested within the requirements of the standard.

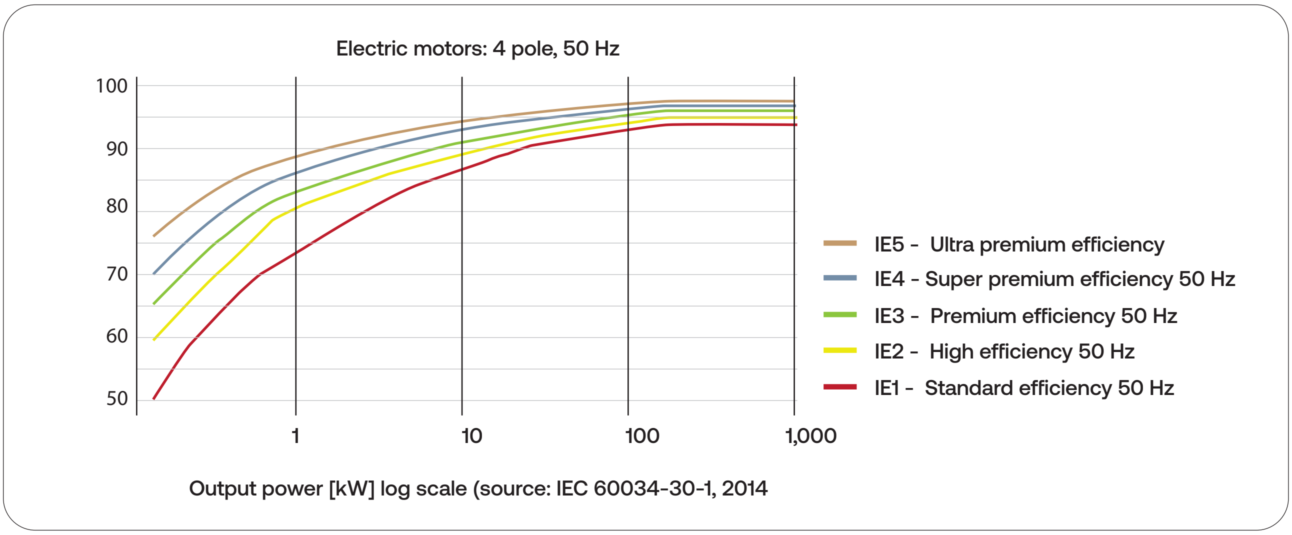
Currently the IE efficiency classes consist of five levels with IE1 being the least efficient (Standard efficiency) and IE5 being the most efficient (ultra-premium efficiency) and most recently added class. The efficiency, represented as the ratio between motor output power and electrical motor input power, meaning a measure of the motors effectiveness at which it converts electrical energy to mechanical energy, as illustrated on **Figure 14.**

Figure 14 Graphic illustration of motor loss Source: United States of America Department of Energy



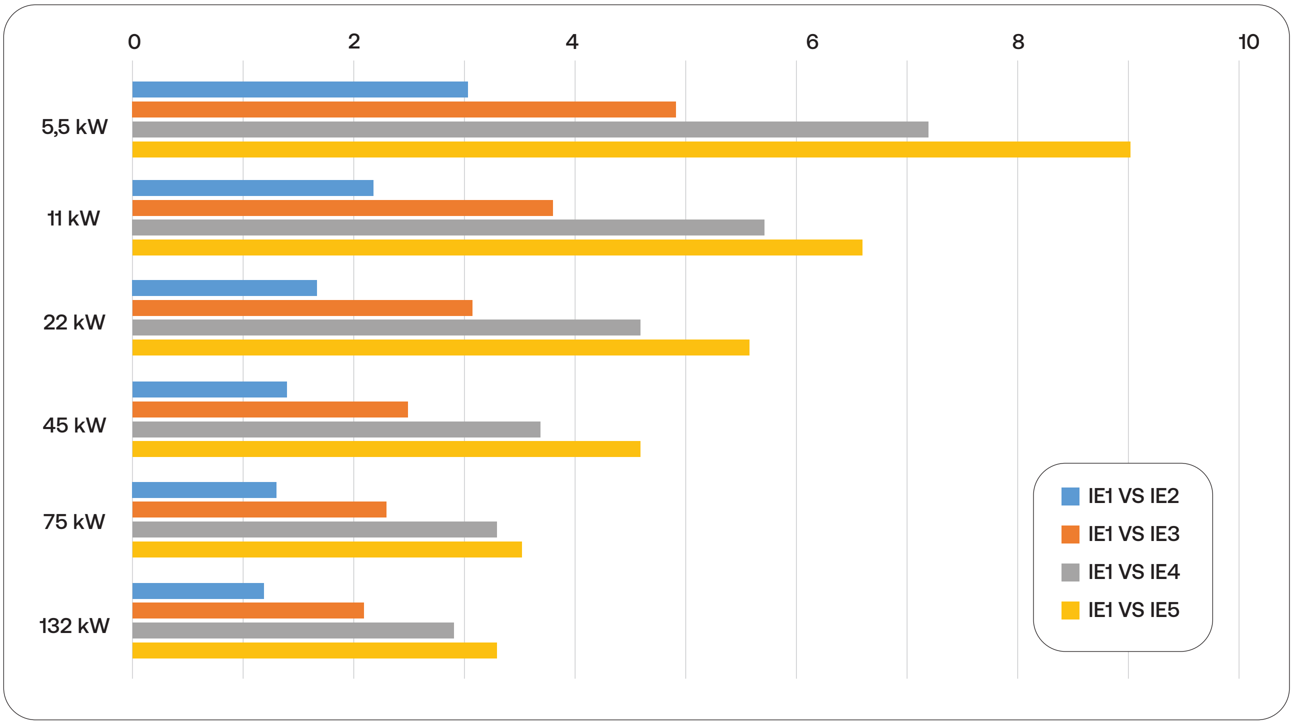
Motor efficiency varies with both motor class and output power with the gaps between efficiency classes being smaller for larger motors, as seen on **Figure 15.**

Figure 15 Motor efficiency in percentage versus motor output power in kilowatt. Source: IEC 60034-30-1, 2024



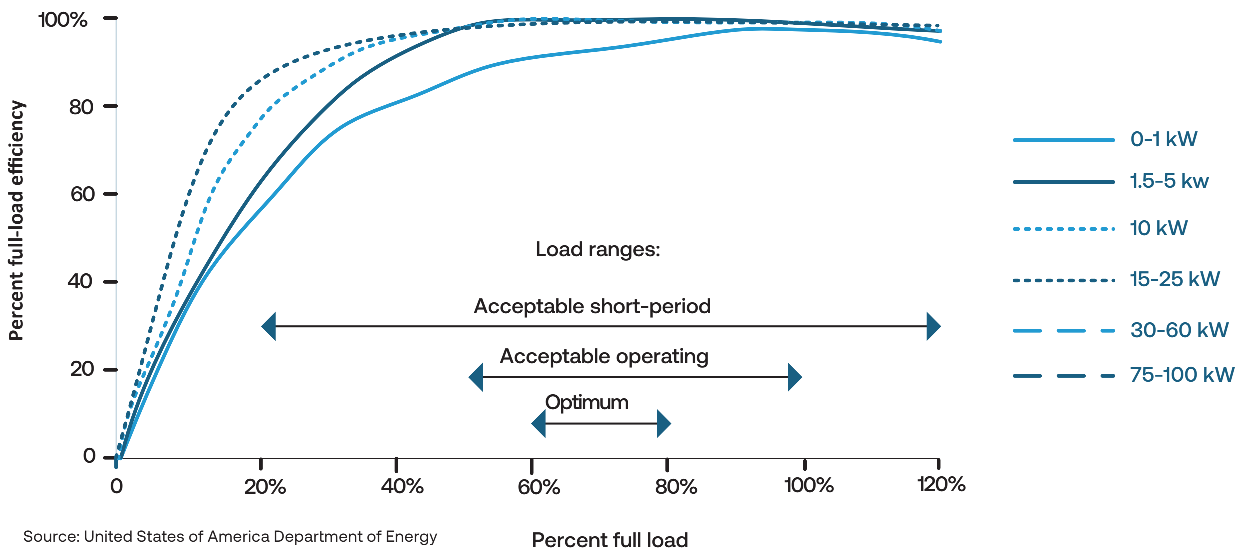
The difference in efficiency between IE1 and the higher motor classes is also illustrated on Figure 12 for selected motor sizes, which further shows that the efficiency difference is higher between classes of smaller motors compared to larger motors.

Figure 16 Difference in efficiency between IE1 and higher motor classes for 4 pole motors.



The efficiency of the motor is not constant during operation and as shown on Figure 12 the efficiency motors also depends on the amount of loading a motor is subjected to, with the motor being most efficient at a load percentage of around 75% of full load, with lower or higher loadings only being recommended momentarily for highest average efficiency.

Figure 17 Motor percentage of full load efficiency versus percent of full load.



Source: United States of America Department of Energy

The motor size also has an impact on the load/efficiency curve, meaning that larger motors operate at higher average efficiency on a broader load scale. The load profile of a motor is especially important to consider when sizing new systems and when determining the average load of a motor with frequency control. Besides efficiency, the loading also has impact on the life expectancy of the motor, with frequent overloading reducing both efficiency and motor life.

4.2 Variable speed drives

4.2.1 Advantages of VSD

The motor load can be controlled by using a Variable Speed Drive (VSD), which regulates the power from the electrical supply provided to the motor itself by adjusting the frequency and voltage based on the process demand. Reducing the motor load with a VSD can therefore not only increase the efficiency of the motor but also reduce the electricity consumed by the motor to match only what is needed[9].

Other benefits of a VSD include:

- **Reducing starting current Without VSD,** the starting current of AC motors without variable speed drives may be many times higher than the normal full load current, which can both lead to tear of the motor, higher than needed electricity consumption and overload of the power line and transformer. Using a VSD can reduce these issues by permitting a controlled start.
- **Energy savings** Due to the affinity laws governing the relationship between motor speed and motor energy consumption, the electricity needed to run the motor will be reduced by a factor 1/8 of full load power, if the motor speed is halved, leading to exponential reduction in energy consumption with reduced speed.
- **Extended motor life** Minimizing start-up current and average motor load leads to less tear on the motor components which increases the lifetime of the motor and reduced expenses for maintenance. The possibility of a controlled stopping of the motor also reduces wear and tear and risk of mechanical shocks.

9 https://new.abb.com/drives/what-is-a-variable-speed-drive

- **Reducing excess power** Using a VSD can put a limit to excessive torque, so that the motor never exceeds a certain threshold, which can increase safety and protect machinery.

- **Increasing frequency** A frequency converter may be able to increase the frequency above 60 Hz for greater motor speed to increase capacity of undersize equipment.

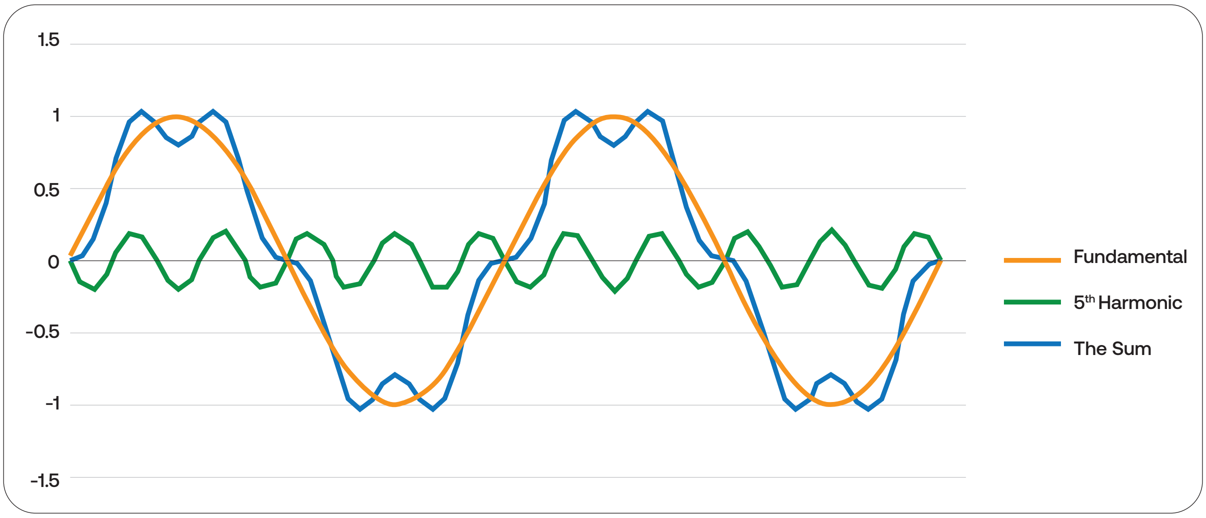
4.2.2 Disadvantages of VSD

- **Higher investment and more complex system** When choosing to include a VSD on a new motor or retrofitting an existing one, the potential electricity saving should be considered against the increased investment- and maintenance cost. According to motor suppliers, the additional price of the VSD can roughly be estimated as +50% of the cost of the motor itself and will also come with an increased cost of installation due to higher complexity. The enterprise should also make sure that it has the relevant competences for regular maintenance of the VSD.

- **Harmonic distortion** A VSD can introduce harmonics in electrical networks, which can cause disturbances and reduce the quality of the electricity, as illustrated on Figure 18, and these harmonic distortions can lead to malfunctions of electrical equipment connected to the network.

  While filters can remove these disturbances, they can also be reduced through optimization of the VSD setup. In many cases with the right setup of the VSD's filters can be avoided, but it must be evaluated in the specific case.

Figure 18 The distorted current or voltage waveform is the sum of the fundamental (e.g. 50 Hz) wave and harmonic (250 Hz in this example) wave.



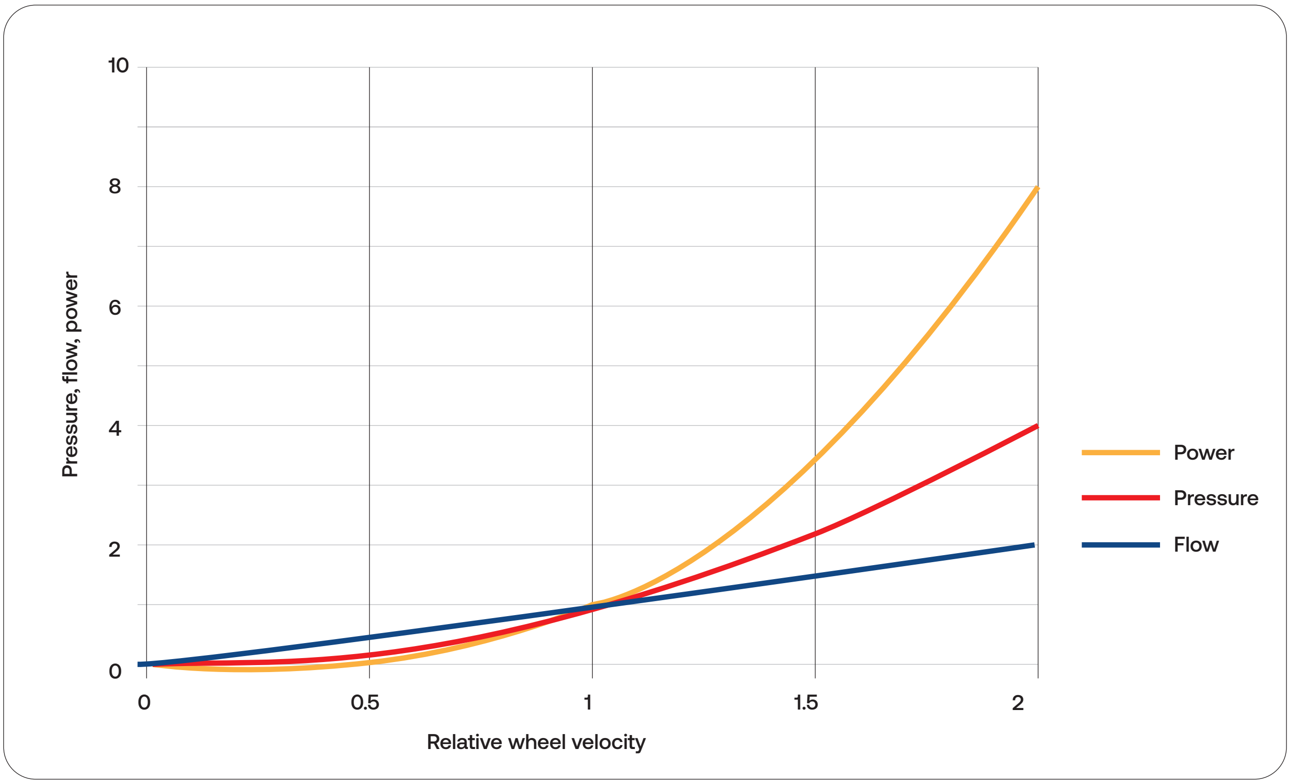
Source (illustration and text): Harmonics – The unwanted ingredient in your supply, ABB.

- **Overheating Motor**s running at reduced speeds through the use of VSDs can have insufficient cooling and may be liable to overheat, unless proper ventilation and cooling is installed.

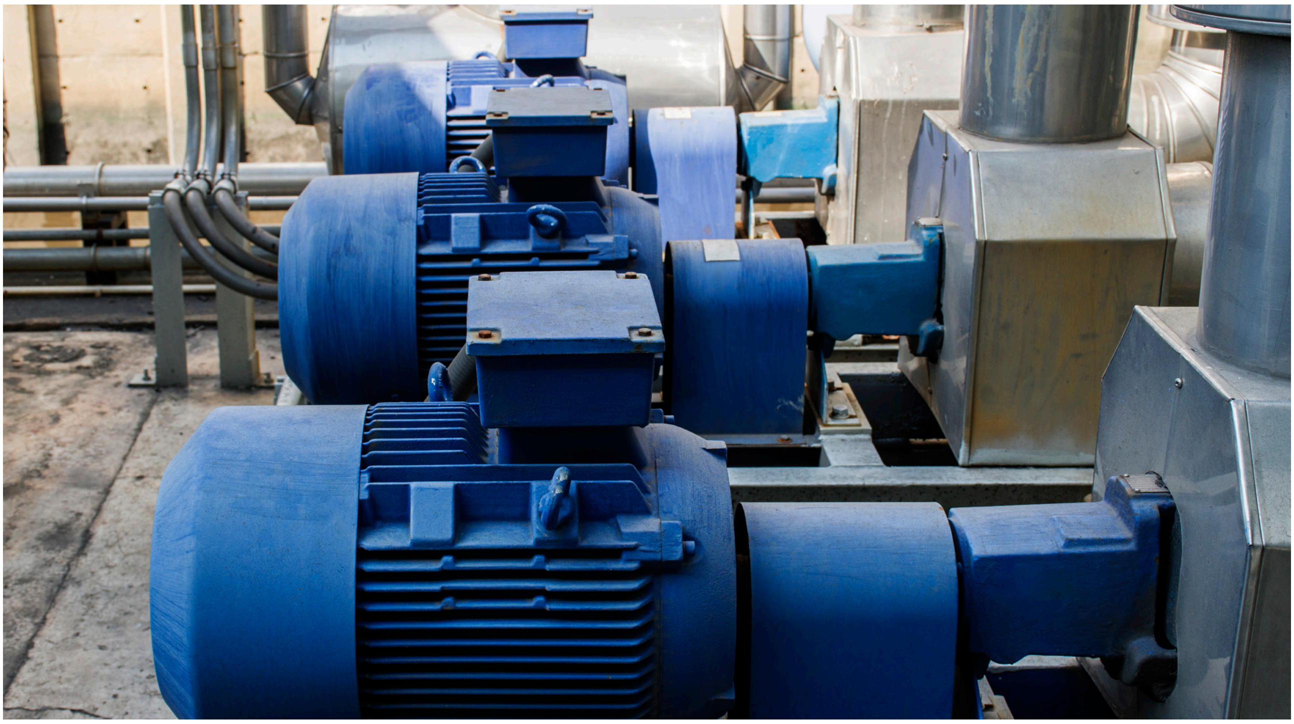
- **Power losses** Installing a VSD will result in additional power losses of around 2% and up to 5%. Therefore, if a motor is running at constant load there is no benefit in installing a VSD. If, however, the process for which the motor supplies a load could be running below 100%, there could be energy savings involved in using a VSD.

An example in which it makes good sense to install a VSD, is on a fan or centrifugal pump. The electricity consumption of the motor on a fan or centrifugal pump varies cubed to the speed of the impeller. Therefore, as seen on Figure 13, if the speed of the wheel is doubled this results in an 8-fold increase in power consumption. Conversely if the speed is halved, the power consumption is only 1/8th.

Figure 19 Graph showing pressure, flow and power relative to wheel velocity for a fan. Source: The Engineering ToolBox.



Depending on the operational pattern of the equipment and the motor this can result in very large savings. A simple example could be cooling provided by a fan of constant speed. If the cooling requirement is lower during winter, the fan can be regulated down to perhaps a fraction of the speed during summertime, which will result in relatively large energy savings compared to if the fan was running at full speed all year round. This will have the upside of also providing a more constant temperature but also reduce wear and tear on the equipment.



5. Energy efficiency of electrical motor systems

Systems utilizing motors for e.g. controlling air or water flow to a process can be controlled in more ways than one, with different solutions being suited for different applications. When looking at the efficiency of a process using an electric motor, the motor itself should not be the only focus area. While replacing a low-efficiency class motor with one of higher efficiency class will reduce the electricity consumption, significantly higher energy savings can be achieved by installing a variable speed drive and controlling the load of the motor to match the requirements of the process, instead of doing this with valves.

According to data from Industrial Efficiency Technology database from 2015, energy savings of around 5% can be achieved when looking only at the motor. When looking at the full system, savings of >30% can be achieved. However, if the process requires the motor to yield a more or less constant load, installing a variable speed drive will only introduce an additional efficiency loss if the possibility of varying the motor load is not utilized.

The general focus points of the solution should be:

- **Minimizing idling consumption of motor**
- **Correct sizing of motor to fit application**
- **Motor with or without frequency converter**
- **Using valves or dampers to control flow**
- **Usage of VSDs only where it makes sense**

This section covers examples and recommendations regarding the design of the system around the motor itself, and in which cases it is recommended to use variable speed drives, and in which cases it is not.

5.1 Systems using both motors with and without VSDs

Since VSD introduce a small efficiency loss they should only be installed on motors where the benefit of variable load and lower electricity consumption can be utilized. For processes requiring a constant load, where soft starts or variable loads are not relevant, a fixed speed motor is the recommended solution.

An example of an application where a combination of motors with and without VSD are relevant is a cooling central or a compressed air central. The demand of cooling or compressed air will often vary with the operation of individual processes and can give sudden spikes or drops in load demands. While this can usually be somewhat managed with storage capacity such as an ice water buffer tank or a compressed air vessel, it might be necessary to install multiple air- or cooling compressors to cover the varying demand. One solution for this is installing multiple compressors running at On/Off mode to provide a somewhat smooth load. This is illustrated on Figure 14. The downside of this is, that one of the compressors may have multiple starts and stops during the day to run at either no load or full load, which can both increase wear on motor and compressor and electricity consumption.

Figure 20 Example operation of one motor running at On/Off mode and the other at fixed speed.

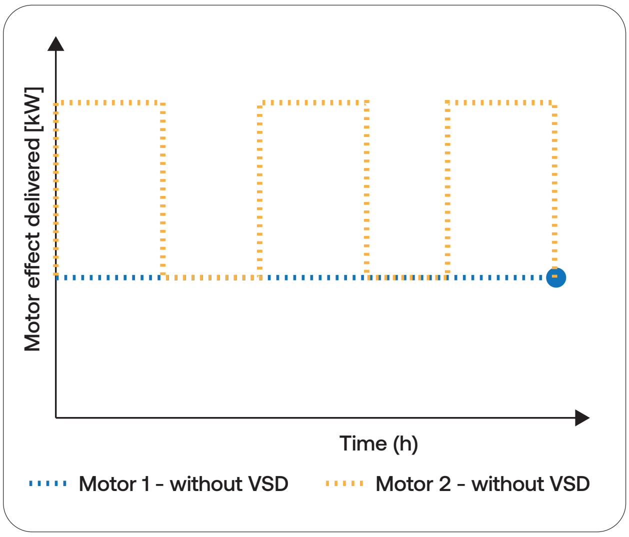
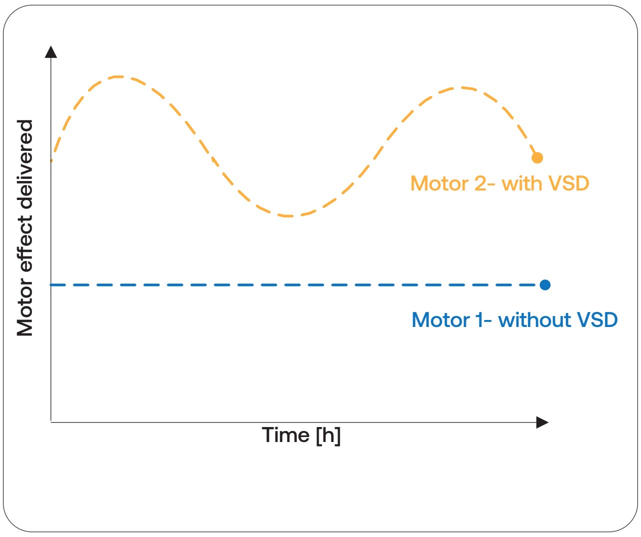


Figure 21 Example operation of one motor running at variable speed and the other at fixed speed.



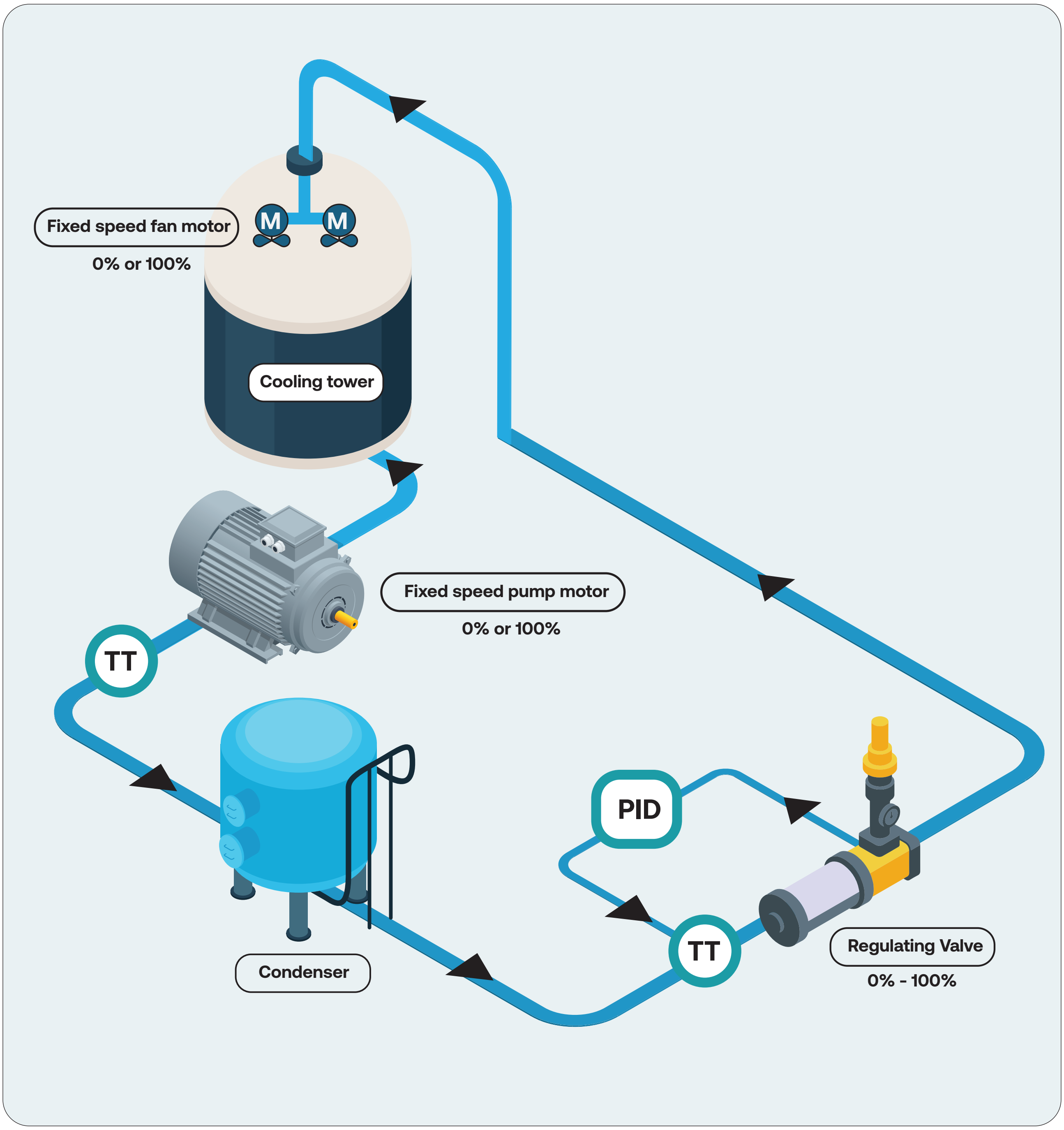
An optimized alternative solution can be to install one compressor with VSD on the motor and one without, as illustrated on Figure 15. This way Motor 1 without VSD can cover the base load most efficiently without any loss in a VSD, and Motor 2 with VSD can cover the variations in load demand without any unwanted On/Off operation, which will also reduce electricity consumption.

5.2 Regulation with valves or dampers versus using frequency control

Processes requiring a flow of liquid or air may require a motor on a pump or fan to move the medium. Adjusting the flowrate of the medium can generally be done directly at the pump or fan by varying the motor speed, for example with a variable speed drive, or in the flow stream itself using a valve or a damper.

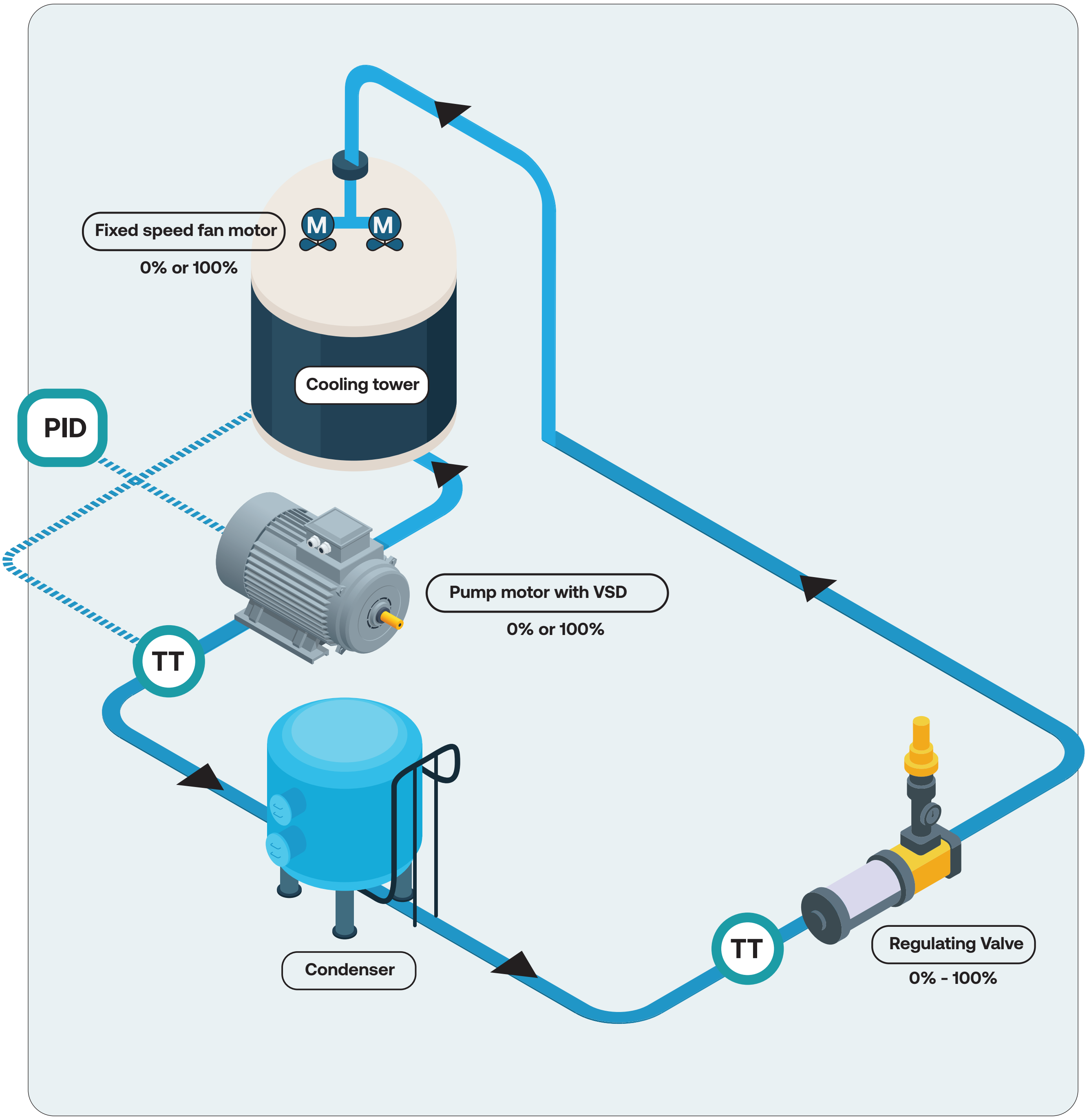
A typical example can be a cooling tower providing cooling water for a given process. In the example illustrated on Figure 16 the cooling water flow to the condenser of a falling film evaporator is provided with a fixed speed pump with the flow regulated by a valve controlled by the outlet temperature of the condenser. Depending on the ambient temperature and the product- type and flow through the evaporator, the cooling water flow demand varies.

Figure 22 Illustration of condenser cooled with cooling water from a cooling tower with fixed speed pump motor with the flow regulated with a valve.



An optimized version of the system is shown on Figure 17, in which the pump is replaced with a new pump with VSD, and the fans on the cooling tower also having VSDs. This way both the fan and pump speed can be reduced, to ensure a fixed outlet temperature if the ambient temperatures are sufficiently low to provide enough cooling without forced draft, and if the cooling water flow requirement is lowered due to lower cooling demand in the condenser. With the reduced speed of the pump and fans, the electricity consumption is also lowered.

Figure *23* Illustration of condenser cooled with cooling water from a cooling tower provided with a variable speed pump.



6. Motor review

When investigating the opportunity of replacing existing motors or installing new motors there is a series of considerations, which should be taken to ensure the best solution is chosen. This section covers a series of recommendations when reviewing existing motors for replacement or when sizing and choosing motors for new installations. Replacement can be both due to failure of existing motor, or because it is economically feasible due to potential electricity savings from a new more effective motor.

The section also covers recommendations when looking to optimize more than the motor itself for example by installing a VSD for more energy efficient control of the process.

6.1 Replacement by failure

An enterprise can be forced to replace an existing motor if it breaks down, and is a necessity to keep the production running, and no redundant capacity is installed. It can also choose to replace the motor, if it is nearing the end of its life and is deemed at risk for breaking down soon. In any case the motor will have to be replaced and the investment in a new motor will have to be made no matter what. In this case, the investment cost used for calculating the payback time should only be the additional price of investing in a more energy efficient motor compared to investing in a similar model with similar efficiency as the existing. This is due to price of installation being close to the same in both cases. If a VSD is also installed on the replacement motor as a new addition, the price of this including installation will also have to be considered. Alternately the enterprise can choose to repair the motor through rewinding, which typically costs only 10-20%[10] of the motors value. However, this can lead to decreased motor efficiency and may only increase the lifetime of the motor by few years. According to motor manufacturers, the decrease in efficiency may be between 5-10% if not done properly. So, it should be seen as a short-term solution before investing in a new motor and will also not result in a positive payback time, since the expenses for electricity in the best case will be the same as before. While the initial cost in repairing the motor may be relatively low, investing in a new and more energy efficient motor will reduce electricity expenses and can, depending on the annual operating hours of the motor, be a lower investment when considering the full life cycle of the motor.

6.2 Replacement due to need for energy reduction

If an enterprise has a desire to reduce its energy consumption due to financial reasons, limits in electrical supply or for reducing CO_2-emissions, it may want to invest in more energy efficient motors. The need can also come from wanting to install VSDs for better control of certain processes. In any case if the motor is replaced due to any of these reasons, and not because replacement is needed to keep the production running, the payback time should be calculated using the full price of both motor and installation, since this will be an additional cost on top of regular maintenance.

6.3 How to conduct a motor review

When reviewing a production facility or any other enterprise for potential energy savings related to usage of electric motors, it is important to take a systematic approach.

The following procedure is suited for a screening involving constant speed motors which are replaced with new constant speed motors with higher efficiency. If the screening has motors for which it is advantageous to also install a VSD for better control, these should be handled separately.

10 Estimate by pump manufacturer Grundfos

6.3.1 Constant speed motors

The recommended procedure for reviewing constant speed motors is describe below, which is related to the attached spreadsheet to be filled out when performing the review:

- **Tag name and application area If the enterprise has its own tag name for the specific motor**, this should be used in order to ensure an easy overview of the motors investigated, along with motor location and application. Here application should describe if the motor is used on a pump

- **Existing motors If available the following information should be noted from the nameplate of the existing motors:**
  - Brand of motor and specific model
  - Number of motors (if several identical motors are used for identical applications)
  - Rated effect on the nameplate in [kW]
  - Motor class and efficiency in [%]
  - Annual operating hours
  - Average load on the motors (by measurements or estimation from scada information)

  While this procedure focuses only on the motor itself, other factors such as power transfer technology between motor and driven machinery should be noted, since a belt or gear drive may have efficiency losses which can be eliminated by converting to a direct drive. Depending on the application of the motor, for example if it is attached to a pump or fan, more info is necessary such as:
  - Max. pump liquid flow in [l/s]
  - Max. pump head in [m] or [bar]
  - Max. fan air flow in [m^3/h]
  - Max. fan static pressure in [Pa]

  This info is required to determine the correctly sized replacement models, if entire pumps and/or fans plus motors are replaced. If this info is not available from the nameplate, the brand and motor type should be looked up online or it may be necessary to reach out to the supplier for a datasheet. Unless annual operating time or electricity consumption is measured the annual operating hours may have to be a best estimate from the enterprise based on a typical operation pattern.

- **Replacement motors**
  - Brief description of scope of replacement for example if only motor itself is replaced or if replacement motor is also fitted with VSD.
  - Brand of motor and specific model
  - Rated effect in [kW]
  - Motor class and efficiency [%]

- **Savings**
  The business case in replacing the motor(s) will depend on the electricity and financial savings due to increased efficiency, and the investment cost.

  - **Electricity saving**
    The annual electricity saving is determined as:

$$\text{Electricity saving (kWh)} = \text{Annual operating hours [h/y]} \cdot \left(\frac{P_{\text{Existing [kW]}}}{\eta_{\text{Existing [\%]}}} - \frac{P_{\text{Replacement [kW]}}}{\eta_{\text{Replacement [\%]}}} \right)$$

Annual operating hours [h/y]	– Equivalent annual full load operating hours
$P_{\text{Existing [kW]}}$	– Power output of the existing motor
$P_{\text{Replacement [kW]}}$	– Power output of the replacement motor
$\eta_{\text{Existing [\%]}}$	– Efficiency of existing motor
$\eta_{\text{Replacement [\%]}}$	– Efficiency of replacement motor

- **Financial saving**
  The annual financial saving from reduced electricity consumption due to the motor replacement is calculated as:

$$\text{Financial saving}\left[\frac{IDR}{Y}\right] = \text{Electricity saving}\left[\frac{kWh}{Y}\right] - \text{Electricity saving}\left[\frac{IDR}{kWh}\right]$$

  Other savings might include reduced maintenance due to higher quality motor, more optimal operation causing less wear and tear. However, if the motor is placed in an ideal environment close to room temperature and low humidity, e.g. under a cover if placed outside, the expenses for motor maintenance during its lifetime are generally negligible, unless the motor breaks down[11]. Therefore, expenses for continuous motor maintenance are negligible and will in any case not be higher, if the motor is replaced with a more efficient model.

- **Investment cost**
  When determining the investment cost of more energy efficient equipment it will depend on the specific situation:

  - **Replacement due to failure** –The payback time is calculated using the additional price of investing in a more energy efficient motor, since the price of installation is the same in any case.

$$\text{Financial saving}\left[\frac{IDR}{Y}\right] = \text{Electricity saving}\left[\frac{kWh}{Y}\right] - \text{Electricity saving}\left[\frac{IDR}{kWh}\right]$$

  If the new motor is also fitted with a VSD, this should also be factored into the additional cost.

  - **Replacement due to need for energy reduction** – The payback time is calculated using the full price of both new motor and installation, since this will be an additional cost on top of regular maintenance.

- **Payback time (simple)**
  The simple payback time in years is calculated as the investment cost divided by the annual financial savings.

$$\text{Financial saving}\left[\frac{IDR}{Y}\right] = \text{Electricity saving}\left[\frac{kWh}{Y}\right] - \text{Electricity saving}\left[\frac{IDR}{kWh}\right]$$

The motor review will result in key energy and financial figures for each individual motor, which the enterprise can use for determining which motors to replace.

6.3.2 Motor policy

It is recommended to formulate a policy for the procurement of motors. In this way the people handling motors have a guideline for the procurement and don't need to make calculations when a new motor is needed.

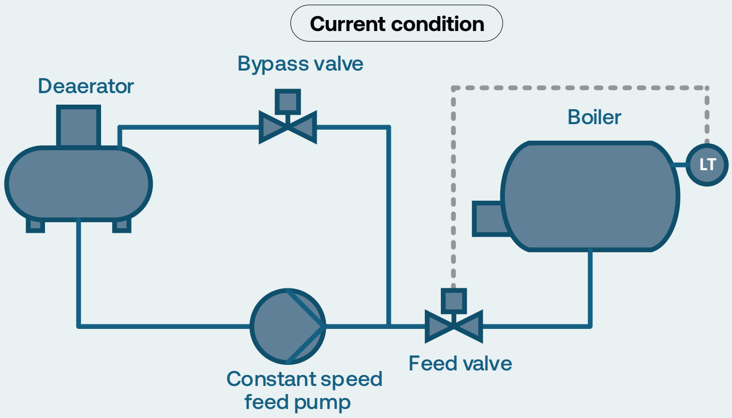
Example of a motor policy:
- Motors with VSD must as minimum be IE3
- Motors without VSD must as minimum be IE4

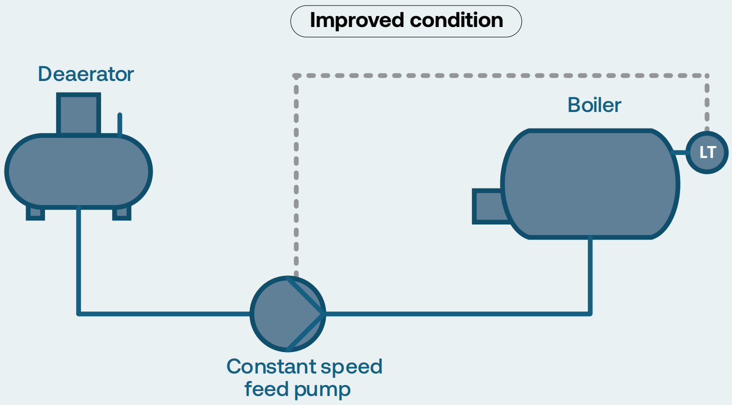
11 Grundfos

7. Examples from energy auditing

More detailed examples of motor replacements or motor system optimizations with CAPEX, OPEX savings, energy savings, system descriptions etc.

7.1 Replacement of boiler feed water pump



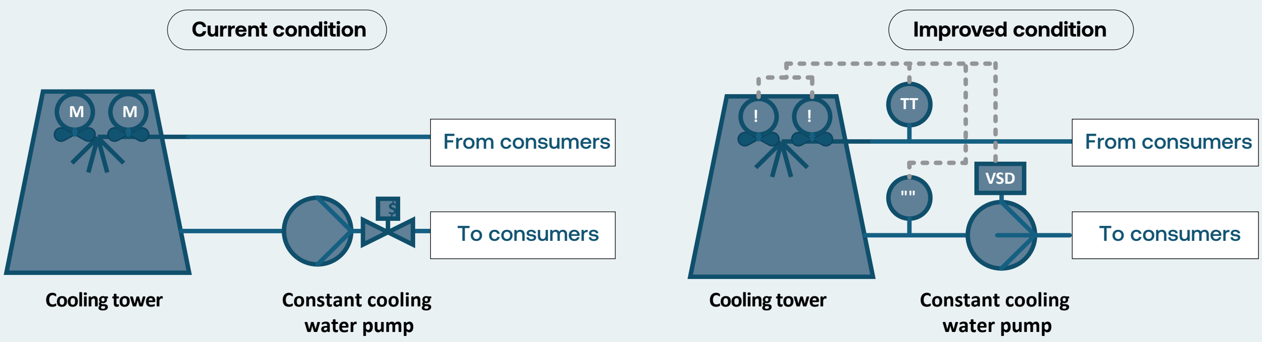


At a food and beverage production site, the feed water to the boiler from the deaerator is supplied with a constant speed pump, and the flow is regulated with a feed valve which receives signal from a feed water level transmitter in the boiler. A bypass valve ensures, that excess feed water is returned to the deaerator. The 11 kW pump is always operated at a full load on fixed duty point.

In the improved situation, the feed pump is replaced with a new, smaller more efficient pump with built-in VSD, which is controlled with the feed water level transmitter in the boiler to ensure, that the pump is only loaded to the required pump capacity and motor electricity consumption is kept at a minimum. The new pump is on average run at 65% load and 2,4 kW, meaning that the energy saving is a result of the motor both being more efficient and run at lower effect.

	Current motor	Improved motor
Installed motor size [kW]	11	7,5
Motor duty point [kW]	8,0	2,4
VSD	No	Built-in
IE Efficiency class	IE3	IE5
Motor efficiency [%]	91,2	92,5
Key figures		
Energy savings	kWh/year	50.000
Financial savings	Mio. IDR/year	57
Investment	Mio. IDR	171
Payback time	Years	3

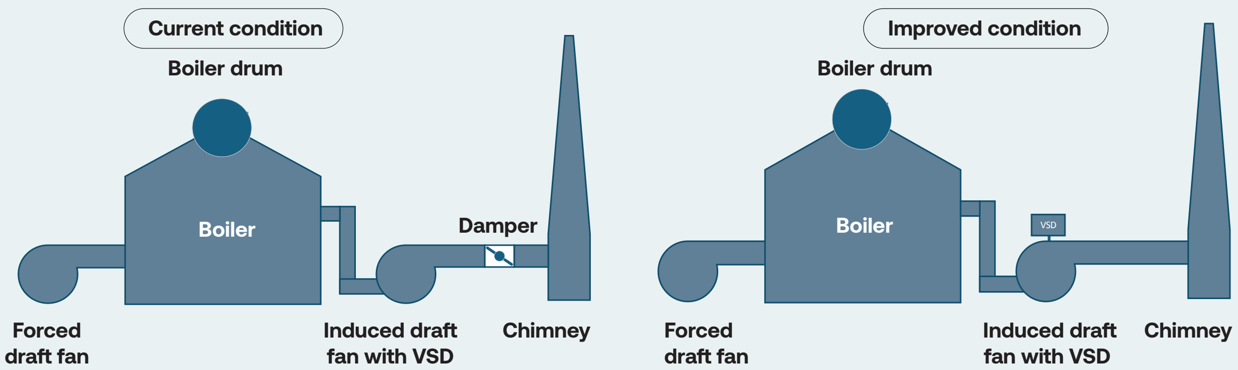
7.2 Replacement of cooling tower water pumps



	Current motor	Improved motor
Installed motor size [kW]	30	30
Motor duty point [kW]	30	19,5
VSD	No	Built-in
IE Efficiency class	IE1	IE3
Motor efficiency	90,7	93,6
Key figures		
Energy savings	kWh/year	150.000
Financial savings	Mio. IDR/year	150
Investment	Mio. IDR	400
Payback time	Years	2,7

At a food and beverage production site, the cooling water is provided with a constant speed pump and the flow controlled with a regulating valve. In the improved situation, the cooling water pump is replaced with a new, smaller more efficient pump with VSD, which is controlled with temperature transmitters measuring the temperature difference of the in- and outlet flow of the cooling tower to ensure optimal temperature difference and reduce pump load. The cooling tower fan is also controlled with the temperature difference.

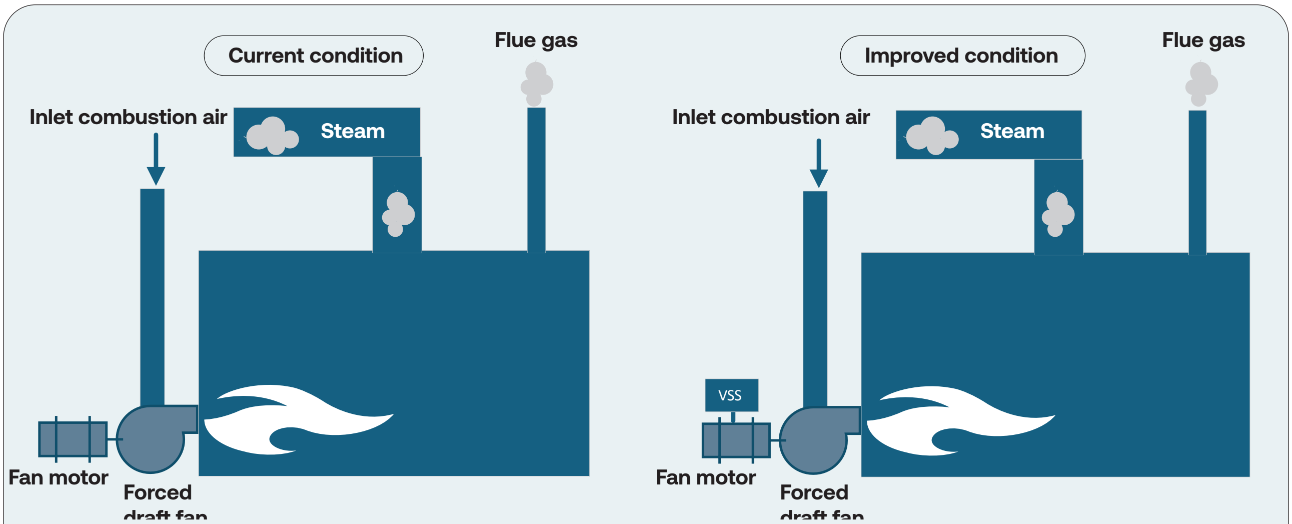
7.3 Replacement of induced draft fan motor for boiler



	Current motor	Improved motor
Installed motor size [kW]	315	315
Motor duty point [kW]	188,4	43
VSD	No	Retrofitted
Key figures		
Energy savings	kWh/year	628.000
Financial savings	Mio. IDR/year	690
Investment	Mio. IDR	693
Payback time	Years	~1

At a paper mill, the air flow from the boiler is sent to the chimney with an induced draft fan, which is controlled with dampers in the air channel. The 315 kW motor on the fan is running at constant speed with only the damper controlling the air flow In the improved situation, the constant speed motor on the induced draft fan is fitted with a VSD, which ensures sufficient draft and reduced electricity consumption. The motor will remain the same in both cases, so efficiency remains the same.

7.4 Replacement of boiler burner inlet fan



	Current motor	Improved motor
Installed motor size [kW]	18,5	18,5
Motor duty point [kW]	22	13
VSD	No	Yes
IE Efficiency class	IE3	IE3
Key figures		
Gas savings	% of total consumption	3,5
Gas savings	kWh/year	704.000
Electricity savings	kWh/year	65.000
Financial savings	Mio. IDR/year	350
Investment	Mio. IDR	950
Payback time	Years	2,7

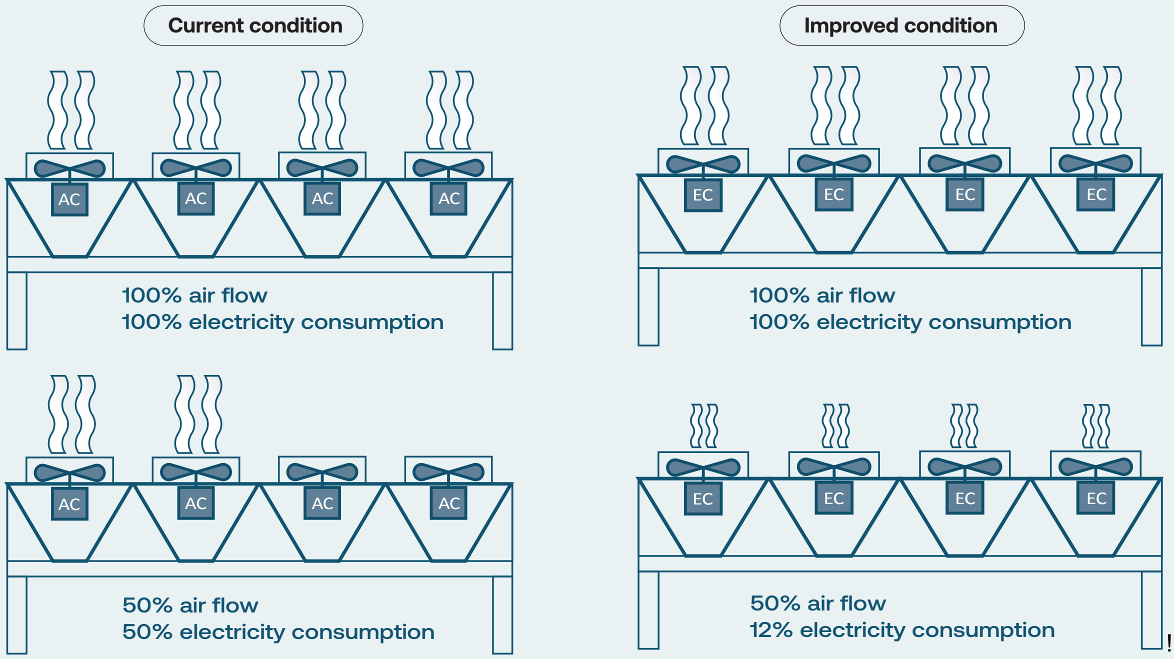
At a company the boiler forced draft fan is driven by a constant speed electric motor with the air flow being controlled with manually adjusted dampers. The system permitted very limited control over the fuel to air ratio meaning that it was not possible to optimize the amount of oxygen to the burner, which led to an ineffective combustion.

In the improved situation, the controls of the fan motor are optimized and retrofitted with a VSD to both ensure optimal fuel to air ratio and oxygen content, but also lower the electricity consumption for the fan motor. So, the project both increased the efficiency of the boiler by 3,5 % and almost halved the electricity consumption of the fan motor. The motor will remain the same in both cases, so efficiency remains the same.

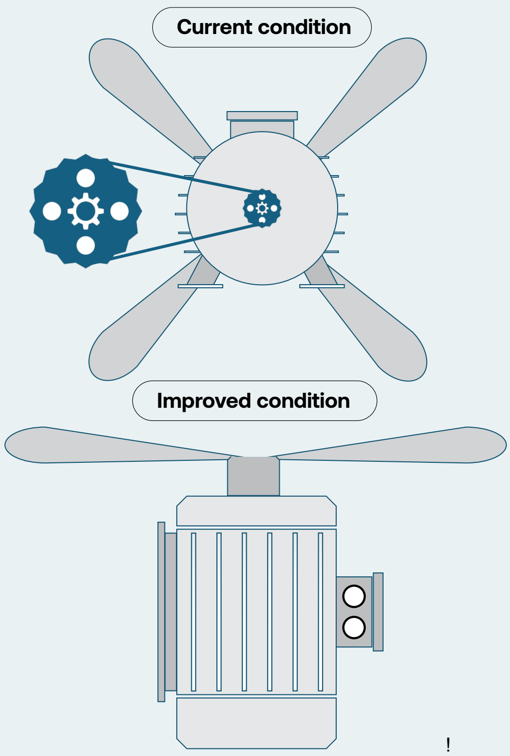
7.5 EC motor instead of AC motor on fan

	Current motors (9 fans)	Improved motors (9 fans)
Installed motor size [kW]	1,80	1,55
VSD	No	Yes
IE Efficiency class	IE1	IE3
Motor efficiency [%]	56,0	69,9
Key figures		
Energy savings	kWh/year	90.000
Financial savings	Mio. IDR/year	23
Investment	Mio. IDR	112
Payback time	Years	4,5

At a food and beverage company the fans of a cooling tower were driven by AC motors. When regulating the air flow, the only way to do so is turning of individual motors, meaning that the electricity consumption scales directly with the number of fans turned on. In the improved situation the AC motors are replaced with EC (electronically commutated) motors with higher efficiency. EC motors are brushless DC motors, which are controlled by external electronics such as a variable speed drive. Compared to AC motors, in which the direction of the electric current is done mechanically which causes losses, this is done electronically in EC motors, which eliminates these losses and results in higher efficiency. Besides having higher efficiency due to less losses, the frequency control also permits a variable load on the motors, meaning that the air flow can be reduced by adjusting the speed of the motors down. Since the fans consume exponentially more electricity with higher loads, the electricity consumption can be reduced significantly by reducing the air flow to for example half of full load. The project resulted in an electricity saving of almost 50%.



7.6 Direct drive instead of belt drive for fan motor



At a factory multiple fans for a water treatment plant were installed with belt drives.

The fans were retrofitted to be directly driven by the motors, which led to an estimated energy saving of 8,3%. In total 11 motors with motor powers ranging from 7,5 kW to 51 kW.

Solutions with gear drives or belt drives may be chosen due to spatial issues but will generally have higher losses than direct drive solutions and will also require more maintenance.

Key figures		
Energy savings	kWh/year	235.000
Financial savings	Mio. IDR/year	290
Investment	Mio. IDR	1.900
Payback time	Years	6,5

8. The procurement process for motors

The procurement process for motors and motor systems is both related to new investments and to the maintenance and replacement of worn-out equipment. In both cases it should still be investigated whether a more optimized solution exist and if it is feasible under the present conditions.

The following cases are considered:

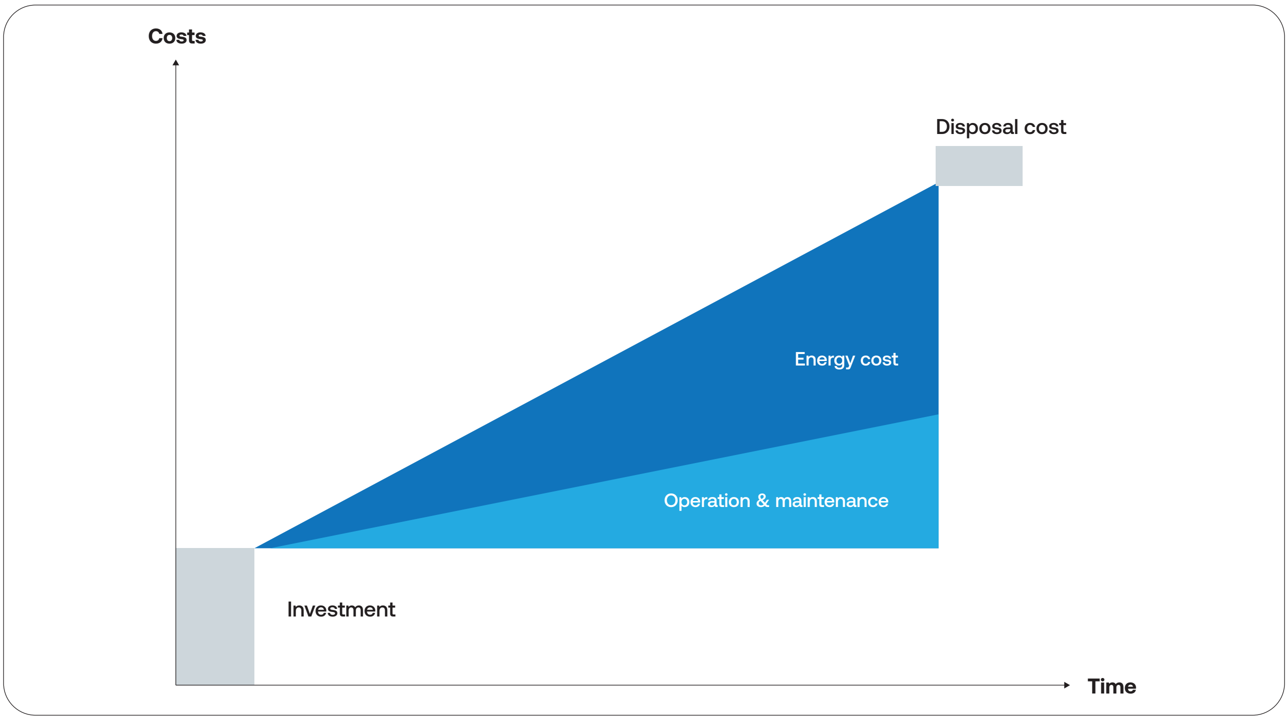
- Replacing a motor due to energy efficiency (motor review)
- Replacing a motor due to break down or failure
- Buying a new motor
- Buying new equipment or plant including motors
- The procurement process should include mechanisms that ensure both energy efficiency and low total costs.

8.1 Total cost of ownership (TCO)

Total cost of ownership (TCO) is an estimate of the expenses associated with the purchase, implementation, use and scrapping of a piece of equipment, machine or plant.

There is a tendency to focus a lot on the investment when the decision to purchase a motor or other equipment must be made, this despite the fact that the total costs over the lifetime are often much greater than the investment cost. For a business, the cost of purchase and the costs of operations and maintenance are often itemized separately on financial statements. A comprehensive analysis of the cost of ownership is a common practice for companies to achieve a cost-optimal solution.

Figure 24 General illustration of how costs are distributed over the life of a new piece of equipment



When choosing which period of time as basis for calculating the TCO, emphasis must be placed on the lifetime of the equipment. Many motors have a long life and for example 15 years will be relevant in many cases. If there are no special circumstances, the time period should not be less than 10 years.

In order to evaluate a purchase of motors, it is not always necessary to evaluate all costs. If some costs are the same in the two situations, they can be omitted in the TCO calculation. Thus, the TCO calculation when purchasing motors can in many cases be made relatively simple.

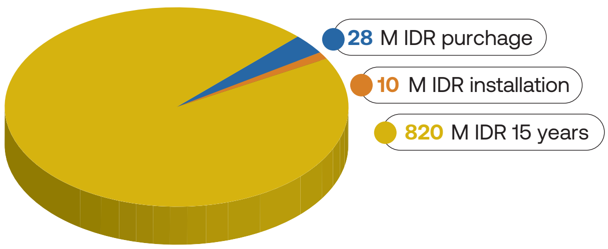
Figure 25 General ratio between purchase price and other costs in a TCO calculation

The total cost of ownership is illustrated in the figure below which shows an example of procurement of a 5,5 kW IE4 4-pole motor running at 80% load on average 8.000 hours per year over a lifetime of 15 years.

The price of the motor itself is assumed to cost 28 mio. IDR with installation being 10 mio. IDR. The electricity price is assumed 1.330 IDR/kWh.

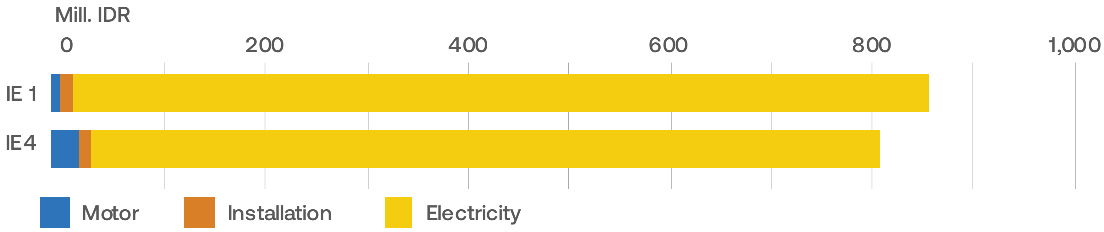
It can be seen that the price of the motor and installation only makes up about 6% of the total cost of ownership, assuming that the motor will have to be replaced after 15 years.

Figure 26 Illustration of expenses making up the total cost of ownership for a 5,5 kW IE4 motor during a lifetime of 15 years with 8.000 annual operating hours and 1.330 IDR/kWh.



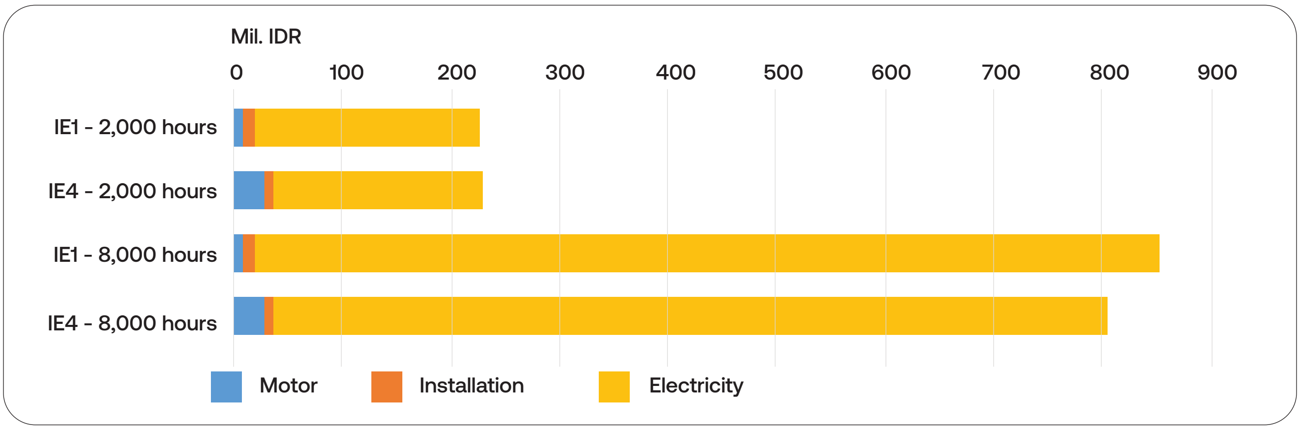
Expanding this example with a comparison between the IE4 motor and an IE1 motor of same size it can be seen on Figure 27, that the IE1 motor is 9% more expensive when taking into consideration total cost of ownership, meaning that the price of the IE4 motor will be paid back three times with the electricity saving.

Figure 27 Comparison between total cost of ownership of a 5,5 kW IE1 and an IE4 motor, with the IE4 motor being slightly cheaper over the assumed 15-year lifetime with 8.000 annual operating hours and *1.330 IDR/kWh*



If the example assumes only 2.000 annual operating hours, the energy saving is outweighed by the increased cost of the more efficient motor. The difference can be seen on Figure 24, where the TCO for the examples with 2.000 annual operating hours are almost the identical in TCO through the lifetime.

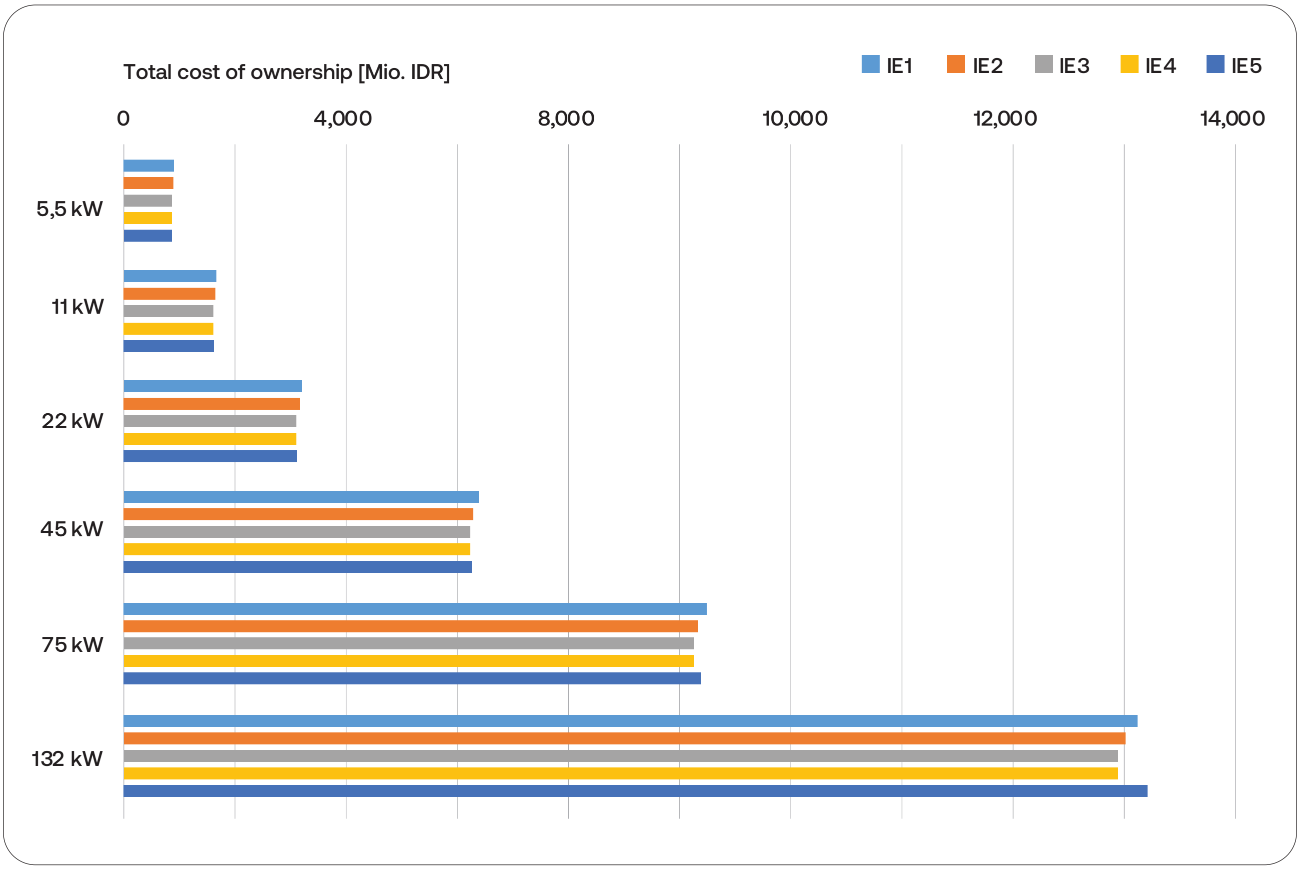
Figure 28 Comparison between total cost of ownership of a 5,5 kW IE1 and an IE4 motor, with the IE4 motor being slightly cheaper over the assumed 15-year lifetime with 2.000 and 8.000 annual operating hours.



The example is expanded further on Figure 30 by including larger motors up to size 132 kW and all classes in the IE-classification system. For all motor sizes the TCO decreases with increasing IE-class until IE5 at which the TCO increases due to the increased motor price outweighing the reduced electricity expense resulting from increased motor efficiency.

The example assumes 8.000 annual operating hours, at with motors at 80% of full load.

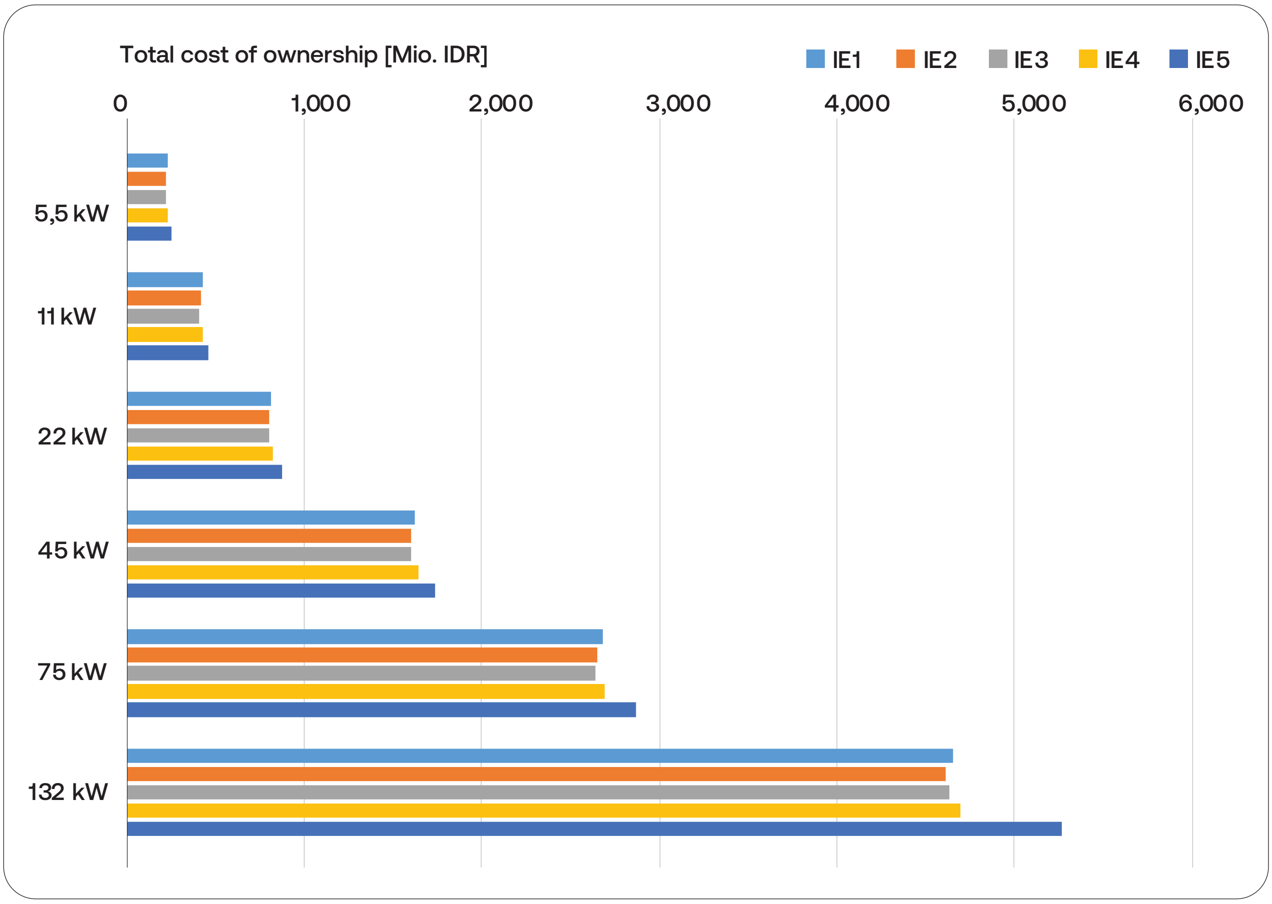
Figure 29 Comparison between total cost of ownership of a various motor sizes and motor classes IE1 to IE5 assuming 8.000 annual operating hours over 15 years.



As a general recommendation; for small and medium size motors (up to 45 kW) it is advisable to purchase IE5 motors, if possible, under the given prerequisites and IE4 for bigger motors. This is only a general rule, and the actual case must always be calculated.

If the example in Figure 31 assumes only 2.000 annual operating hours, the cases look different. As a general recommendation of good energy efficiency practice, it is not recommended to purchase motors lower than IE3.

Figure 30 Comparison between total cost of ownership of a various motor sizes and motor classes IE1 to IE5 assuming 2.000 annual operating hours over 15 years



8.1.1 Discounted cashflow analysis

In simple cases, where conditions are steady over the coming years, a calculation of the payback period can be sufficient.

However, it is more illustrative to use a discounted cashflow analysis that will reveal the cumulative impact of the project over the timespan chosen, as shown the example in Figure 32. The example is from Figure 28 with the following assumptions:

- Different in purchase and installation cost between IE4 and IE1: 38,0 – 19,3 = 18,7 mills. IDR
- Different in annual cost of electricity IE4 and IE1: -52,1+ 56,5 = 4,4 mills. IDR
- Maintenance costs – the same for the two motors
- Lifetime: 15 years
- Write-off period: 10 years
- IRR: 5%
- Taxation not included

The result of the analysis is:

- Cumulative cash flow over the lifetime: 29 mills. IDR
- NPV: 12,8 mills. IDR

Figure 31 The discounted cashflow analysis of an investment in a higher motor class, see Figure 28

	2024	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Electricity IE4	0.0	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1	-52.1
Electricity IE1	0.0	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5
Maintenance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EBITDA	0.0	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Depreciation	0.0	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	0.0	0.0	0.0	0.0	0.0
IE4 investment	-38.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IE1 investment	19.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cashflow	-18.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	4.4	4.4	4.4	4.4	4.4
Cumulative cash flow	-18.7	-16.1	-13.6	-11.0	-8.5	-5.9	-3.3	-0.8	1.8	4.3	6.9	11.3	15.7	20.2	24.6	29.0
NPV	-18.7	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.6	2.6	2.5	2.3	2.2	2.1
Cumulative NPV	-18.7	-16.3	-13.9	-11.7	-9.6	-7.6	-5.7	-3.9	-2.2	-0.5	1.1	3.6	6.1	8.5	10.7	12.8

8.1.2 TCO replacing a motor due to energy efficiency

The cost of the new motor includes:

- Purchase (price for delivery of the new motor)
- Installation (dismantling of the old motor and installation of the new motor)
- Electricity consumption (using working hours per year and estimated load)

Maintenance (often only cleaning) can in many cases be neglected as it will be the same for both the new and the old motor. If the old motor has a limited remaining lifetime this can also be taken into account.

Scrapping cost can normally be set to zero as the materials in the motor have a value that can cover the cost.

If the total cost for the current motor exceeds the costs for the new motor replacement it is economically feasible and a saving in electricity consumption and indirect CO_2 emissions are reduced.

8.1.3 TCO replacing a motor due to break down or failure

In this case a replacement one to one is compared with the best available motor. As IE5 is on the market this should be the first option. If no vendors can deliver a IE5 motor, then ask for a IE4.

The cost of the best available motor includes:

- Additional purchase price (only the price difference between the two motors)
- Reduced electricity consumption (difference between the two motors in the electricity consumption)

Installation cost will normally be the same for the two motors.

If the calculation of the additional purchase price and reduced electricity consumption results in a saving the best available motor should be purchased.

A policy of always buying motors in the highest IE class can be recommended as the actual lifetime in many cases are longer than the one used in the TCO calculation. It also makes it simpler only to have the highest IE class in the spare parts stock.

8.1.4 TCO buying a new motor

The TCO calculation will be the same as for replacing a motor due to break down or failure.

8.1.5 TCO buying new equipment or plant including motors

In case of buying new equipment or a new plant including motors a different approach is recommended. Instead of looking at the price difference for the individual motor, it is advisable to define the energy requirements in the tender documents. If no energy requirements are set, the vendor will choose a solution with components that will result in a low and competitive price for the equipment or plant.

The tender documents can encompass the following energy requirements:
- The thermal energy consumption of the equipment / plant must not exceed xx MWh per ton product.
- The electricity consumption of the equipment / plant must not exceed xx MWh per ton product.
- All motor shall be in IE5 class and if IE5 not can be obtained a least IE4.
- Flow regulation shall be performed with VSD's and regulation with valves / dampers cannot be accepted.

By including these kinds of requirements in the tender documents, it gives a clear signal to the vendor that TCO is important and not only the quote price and what it takes to make the quotation conditional.

When evaluating the quotations it is important that the energy requirements are taken seriously and not only focusing on the price and production performance. If the quotation includes motors with a lower IE class than required a TCO calculation can be made on the specific motors and in many cases, this will show that it is feasible to upgrade the motor.

8.2 Energy Efficient Design

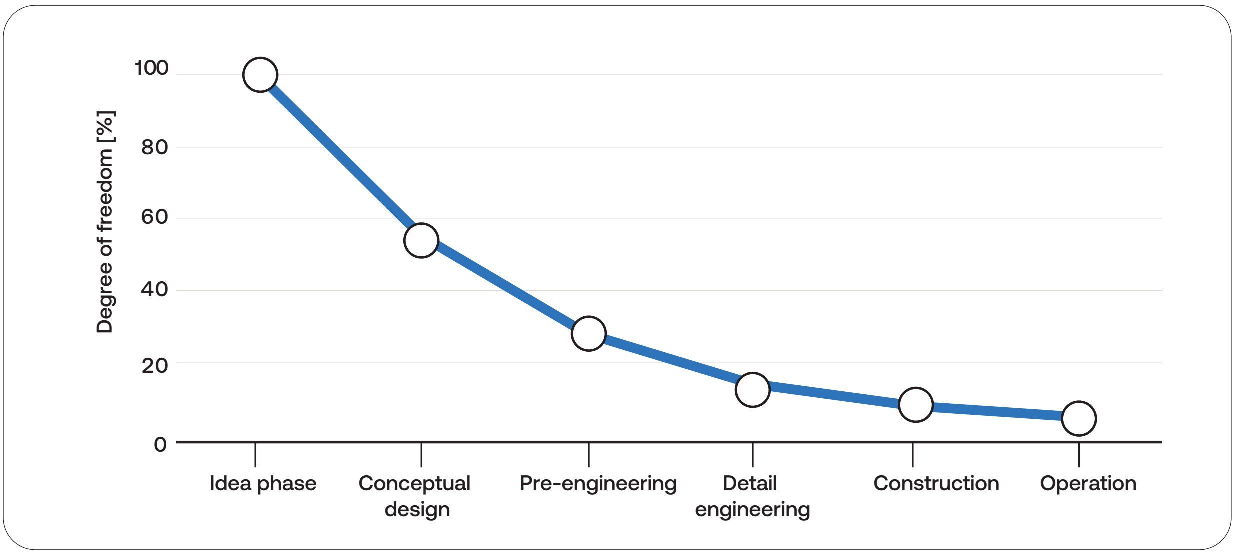
It is expensive to design with a low energy efficiency for reducing the investment and hoping to be able to improve the energy efficiency later. To avoid this, the principle of "Design with energy awareness" is the best way to include a good energy efficiency from the beginning of the project development.

Get it right the first time!

8.2.1 The degree of freedom in shaping the energy profile

When a project is the Idea phase the degree of freedom in shaping the energy profile is 100%. As the project development moves to later phases the degree of freedom will become narrower. Ultimately when the equipment / plant commences operation, the possibility for influencing the energy consumption is limited without a new investment.

Figure 32 The degree of freedom in shaping the energy profile



8.2.2 Idea phase and conceptual design

In the early stage of a project motors are not much in focus. Deciding which technology to use and correct sizing of equipment capacity override decisions such as which specific motor types to select.

8.2.3 Pre-engineering

The aim of the pre-engineering or feasibility study phase is to define the project to carry out and evaluate alternative overall solutions, so as it can be concluded what the most attractive way forward will be.

New motors or optimization of current systems can however also offer a range of benefits, such as:

- Reduced operational costs including energy
- Improved regulation (VSD's instead of valves / dampers)
- Compliance with current regulation if relevant
- Reduced carbon footprint
- Increased market value of the product as a result of lower environmental impacts.

For main equipment / plant the tender documents are developed in this phase. It is important that the energy efficiency requirements are defined as described in 8.1.5.

For the pre-engineering as a whole, it is important to make an energy review before moving to the next phase.

An energy review is a systematic evaluation on the energy efficiency in projects and suggestions for improvement. For having a fresh view on the project, it is important that the energy auditor has not taken part in the pre-engineering work and have the right qualifications for evaluation the energy efficiency in different solutions. The energy auditor can for example be the energy manager of the company or an external energy consultant.

8.2.4 Detail engineering

In the detailed engineering phase, an approved pre-engineered project will be designed into detail, all components specified, the final tender documents submitted, and contracts closed.

Consequently, motors that are not part of a more comprehensive equipment, machinery or plant will be specified at this stage. Oversizing of the motors should be avoided, and the chosen type of motor must be fit to the work they shall conduct.

The ambient conditions for the motors shall also considered. The design around the motor shall ensure that motor temperature does not exceed manufacturer recommendations, like protecting the motor from getting covered with dust and still allowing the heat to escape.

It is recommended to generally chose motors with the highest available IE classification. If not a TCO calculation according to 8.1.4 must clarify that a motor with lower energy efficiency has a lower TCO.

Before signing contracts with a vendor regarding equipment, machinery or plant, it is important to examine the quotation in detail to ensure that all motors fulfil the requirements set in the energy requirements, 8.1.5.

For the detailed engineering, it is important to make a second energy review before moving to the next phase. The approach is the same as described for pre-engineering, 8.2.3.

8.2.5 Constructing

In construction phase the most important activity is to ensure that delivery and installation is as described in the detailed engineering, and all regulations and control systems are trimmed according to the production process before handover.

8.2.6 Operation

In operation the motors will be part of the energy management system. As the conditions can change over time, the energy performance needs continuous attention. The production can also change from time to time and motors and the equipment must be evaluated with a view to the applicability for the new production. The ambient conditions for the motors must also be attended in the daily operation.

In case of motor failure rewinding can be an option, but it is not recommended. A rewinded motor will have a lower energy efficiency than before maintained. It is neither advisable as a temporary solution. A temporary solution tends to last longer than expected and the additional electricity consumption in this period can be substantial compared with replacing it with a high classified motor immediately. For high classified motors like IE5 rewinding is not an option technically.

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