Scientific Papers. Series D. Animal Science. Vol. LXV, No. 1, 2022
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

POSSIBILITIES TO REDUCE CO_2 EMISSIONS BY USING ELECTRIC MOTORS WITH HIGH ENERGY EFFICIENCY

Nicoleta-Alina UDROIU, Carmen Georgeta NICOLAE

University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: alina.udroiu@agro-bucuresti.ro

Abstract

The latest Intergovernmental Panel on Climate Change (IPCC) report said that without immediate and deep emissions reductions across all sectors, limiting global warming to 1.5°C is beyond reach. According to a new IEA (International Energy Agency) analysis, CO_2 emissions rose by 6% in 2021 to 36.3 billion tonnes, their highest ever level, as the world economy rebounded strongly from the Covid-19-pandemic crisis. The direct greenhouse gas emissions (CO_x, CH_4, NO_x) come mostly from agriculture (crops cultivation) and the livestock sector. Indirect reduction of CO_2 emissions in livestock farms and the food and beverage industry can involve using electric motors with high energetic efficiency. Electric motors represent worldwide, around 50% of electricity consumption. A recent study highlights that if the world's 300 million industrial motor-driven systems were replaced with optimized, high-efficiency equipment, global electricity consumption could be reduced by 10%. This paper analyses the International and European Commission Regulations for efficiency and the new Ecodesign measures for electric motors.

Key words: *carbon dioxide emissions, energy efficiency class, energy policies and regulation, induction motor.*

INTRODUCTION

The IEA (*International Energy Agency)* works with countries worldwide to shape energy policies for a secure and sustainable future (IEA, 2021). The burning of coal, natural gas, and oil for electricity and heat is the largest single source of global greenhouse gas emissions. In the last ten years, average annual global greenhouse gas emissions were at their highest in human history (IEA, 2021).

Approximately 45 % of the world's electricity is used for electric power motors in buildings and industrial applications. Many research suggests that if the 300 million electric motor-driven systems in active service worldwide were replaced with optimized, high-efficiency equipment, we could reduce global electricity consumption by up to 10%. (Floeck, 2021). In industrial applications, motors are used for pumping, fans, air, liquid compression, conveyance, and other mechanical handling and processing (Waide et al., 2011). The use of high-efficiency electric motors is a current goal in the global industry due to the need to reduce energy costs and not pollute the environment.

By the Kyoto Protocol, developed countries have committed to meet a target of a 20% reduction in carbon emissions by 2020, with an extra stipulation of minimum motor efficiency restrictions (Shyi-Min, 2016). A transition to energy-efficient motor systems would reduce the global electricity demand by motor systems by 20 to 30% in 2030, depending on the actual development and implementation of energy efficiency and environmental policies globally. Using more efficient motors, countries can save 300 TWh per annum of electricity in 2030, saving 200 Mt of CO_2 emissions (equivalent to the annual electricity generated by approximately 60 coal-fired power plants with a capacity of 1,000 MW) (U4E, 2017). For the carbon emissions of electricity use, there is no such thing as a default value. The CO_2 intensity of electricity production (kg CO_2/MWh electricity) depends on the fuel mix used for electricity generation and on the calculation method used. Moreover, different approaches – often related to the type of study carried out – exist to determine the CO_2 emission reduction from (future) electricity savings (Harmsen & Graus, 2013).

In livestock farms, most of the equipment is driven by electric motors: for the preparation and distribution of feed, manure evacuation systems, ventilation, milking installations, water pumps, etc. Also, the processing units of animal products use electricity as the main source of operation of mechanized or automated systems. Such motors are commonly used in pumps, fans, compressors, extruders, mixers, agitators, centrifuges, conveyors, etc. Thus, electric energy reductions can be made through process optimization and technological and manufacturing behavioral changes. Electric motor-driven systems (EMDS) are the most important type of electric load in the industry. In the food industry or livestock farms, EMDS plays an important role, the electric drives forming the link between the source of electricity and most mechanical processes that require a large amount of energy (Waide & Brunner, 2011). For example, in the European Union, they are estimated to account for about 70% of all industrial electricity consumption (Waide & Brunner, 2011). Thanks to the highly efficient motors, users also save energy, reduce their operating costs, and reduce their CO_2 emissions.

Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage, and describes how an electric motor converts electrical energy into mechanical energy. Not all electrical energy that goes into a motor is converted to usable mechanical energy. It is known that the efficiency of electric motors is over 95%, the percentage of 5% representing the losses (dissipated as heat) due to the thermal effect produced during operation. This loss is evidenced by a rise in motor temperature.

The electric motor market has witnessed a major change in the last decade in several aspects: in structure, with company mergers contributing to a more global market, in content with energy-efficiency policies, and in its economy due to increasing electricity prices, all aspects contributing to pushing the market towards more energy-efficient electric motors (De Almeida et Al., 2019)

The most used electric motors in the animal husbandry and food industry are the three-phase or single-phase asynchronous AC motors (Figure 1). The electric motor system includes equipment for supplying power, starting the motor and varying its speed, mechanically transmitting its motion to drive equipment (e.g., pumps, fans, compressors, production machines), and additional controls for subsequent parts of the process.

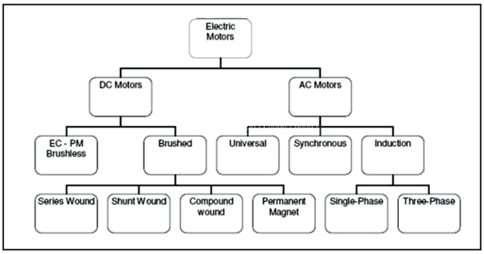

Figure 1. The application categories for the electric motors (Waide & Brunner, 2011)

Most developed countries have implemented energy efficiency regulations similar to that of the European Union. Several regions have adopted a minimum energy efficiency to restrict the sale and use of industrial motors.

MATERIALS AND METHODS

Energy efficiency label is one of the most important ways to implement the energy efficiency standard for electric motors. Label design should be based on the grade setting specified in the standard. However, various countries have different practices in numbering high and low-efficiency products (APEC, 2008). Ecodesign regulations require manufacturers to decrease the energy consumption of their products by establishing minimum energy-efficiency standards. Requirements for individual product groups are created under the EU's Ecodesign Directive (2009/125/EC). As an alternative, industry sectors may also sign voluntary agreements to reduce the energy consumption of their products (Monforti-Ferrari et al., 2015).

Since motors have long lifetimes, sometimes 20 years or more, the electricity waste is locked-in for decades. An Integrated Policy Approach to fully transforming a market includes Standards and Regulations, Supporting Policies, Finance and Financial Delivery Mechanisms, Monitoring, Verification, enforcement (MVE), Environmental Sustainability, and Health (U4E, 2017).

In 1998, in Europe, three-phase low-voltage electric motors were classified and marketed by the European Committee of Manufacturers of

Electrical Machines and Power Electronics (CEMEP) in three efficiency classes called EFF3, EFF2, and EFF1, based on a voluntary agreement between the motor manufacturers and the European Commission (IEC, 2008). This classification system has proven useful and was initially adopted by many countries around the world. Later, other countries developed their own national systems, different from the European system. Following international debates between electric motor manufacturers, a common international standard has been established to replace all (different) national systems. In order to harmonize the standards describing motor energy efficiency, the International Electrotechnical Commission has developed the International Efficiency (IE) classes through collaboration with the National Electrical Manufacturers Association (NEMA), CEMEP (Table 1), the Japan Electrical Manufacturers' Association (JEMA), the Institute of Electrical and Electronics Engineers (IEEE) and other international organizations **(**CSA in Canada, COPANT in South America, AS/NZS in Australia and New Zealand, JIS in Japan, GB in China etc.) (Fong et.al., 2020).

In October 2008, the old classification system of the three-phase AC motor was replaced with IEC 60034-30 into three commercially available energy-efficiency classes: *IE3 Premium Efficiency; IE2 High Efficiency* (similar to 50 Hz operation with Eff1), and *IE1 Standard Efficiency* (the lower class and similar in 50 Hz operation with Eff2).

The *IE4 Super Premium Efficiency* class is described in the actual IEC 60034-30-1 standard, published in 2014, for direct online operated AC motors and in the IEC TS 60034-30-2 for variable speed AC motors (Ferreira F et al., 2016). In IEC TS 60034-30-2, minimum efficiencies for the highest efficiency class IE5 or *Ultra Premium Efficiency* are also specified for the first time. An IE5 motor will have a 20% loss reduction with respect to an equivalent IE4 motor. (European Commission 2009, 2019, 2021).

Under the current regulation, motors must reach the IE2, IE3, or IE4 efficiency level depending on their rated power and other characteristics (Gavrilă et al., 2016).

For instance, three-phase motors with a rated output between 0.75kW and equal to or below 1000kW had to achieve the IE3 level by July 2021. Motors between 75kW and 200 kW must meet the IE4 level as of July 2023. The EU is the first place worldwide making the IE4 level mandatory for some categories of motors (Table 2). Thanks to highly efficient motors, users also save energy, reduce operating costs and reduce CO_2 emissions.

Table 3 specifies the start dates for implementing the new standards in other non-European countries. Around 50% of industrial energy demand in the European Union comes from electric motors. This represented 2020 some 578 million tons of CO_2 emissions. The extension of the efficient motors under the regulation will avoid an additional 40 million tonnes of CO_2 each year. With that, the annual energy bill of EU households and industry will be reduced by approximately €20 billion by 2030 (European Commission, 2019, 2021; Bauer Gear Motor, 2022).

The advantage of energy-efficient motors is that they are constructed with improved manufacturing techniques and superior materials and usually have higher service factors, longer insulation and bearing lives, lower waste heat output, and less vibration, increasing reliability. The previous Commission Regulation 640/2009/EG regarding electric motors' Ecodesign requirements were replaced by the new Commission Regulation (EU) 1781/2019 **(**European Commission, 2021). Several Ecodesign regulations focus on industrial components largely employed in the food sector, such as ventilation units (Reg. 1253/2014), power transformers (Reg. 548/2014), heaters and water heaters (Reg. 813/2013), hot water storage tanks (Reg. 814/2013), water pumps (Reg. 547/2012), industrial fans (Reg. 327/2011) and electric motors (Reg. 4/2014) (Monforti-Ferrario et al., 2015). In 2021 Regulation (EU) 2019/1781 was amended by the Commission Regulation (EU) 2021/341, which aims to clarify and improve some aspects of some of the ecodesign regulations adopted in 2019 **(**European Commission, 2021)**.**

Table 1. Energy efficiency standard of CEMEP, IEC and NEMA

Efficiency Class	IEC *(International Electrotechnical Commission)*	CEMEP *(European Committee of Manufacturers of Electrical Machines and Power Electronics)*	NEMA *(National Electrical Manufacturers Association- USA)*
Ultra Premium	IE5	-	
Super Premium	IE4	-	Super Premium
Premium	IE3	-	Premium
High	IE2	EFF1	High
Standard	IE1	EFF2	Standard
Below Standard	-	EFF3	

(Source: IEC)

Table 2. Overview of efficiency requirements from EU regulations from 2017

Three-phase motors for continuous operation up to 1000V 50/60Hz		Year of implementation of minimum efficiency requirements		
		from 01/01 2017	from 01/07 2021	2023
Power	Mode	2-; 4-; 6-pole	2-; 4-; 6-; 8-pole	
≥ 0.12 < 0.75 kW	Starter	-	IE2	
	FC	-		
≥ 0.75 < 75 kW	Starter	IE3	IE3	
	FC	IE2		
≥ 75 ≤ 200 kW	Starter	IE3	IE3	IE4 for 2-;4-;6- pole motors
	FC	IE2		
> 200kW < 375 kW	Starter	IE3	IE3	
	FC	IE2		
≥ 375 ≤ 1000kW	Starter	-	IE3	
	FC	-		

(Source: European Commission)

This will require minimum requirements for a wider scope of motors with a power range from 0.12 kW – 1000 kW relative to the previous 0.75 – 375 kW, and will also include 8-pole motors. Also, this new regulation will abolish the former requirement of an IE2 motor plus a converter instead of IE3 (De Almeida, 2017). Also, maximum losses for converters between 0.12 kW and 1000 kW at IE2 are requested. From 2023, IE4 will be required for motors between 75 kW and 200 kW (IEC 60034-1). Figure 2 illustrates IE motor efficiency for 50/60 Hz current frequency. For any mechanical system driven by an electric motor, very important it is also the operating mode. IEC uses ten duty cycle (S1 to S10) designations to describe electrical motor operating conditions. These cycles refer to the sequence and duration in time of all aspects of a typical operation, including starting, running with no load, running with a full load, electric braking, and rest. On the motor's nameplate, it is important to be specify the efficiency class and the operating mode (duty cycle) (Figure 3).

RESULTS AND DISCUSSIONS

According to ANRE *(Romanian Energy Regulatory Authority)* data, at the level of the year 2020 of the total electricity produced in Romania 16.51% came from coal 15.92% from natural gas (ANRE, 2020). Many consumers on livestock farms still use electricity from these conventional sources. This means an indirect increase in CO_2 emissions through electric motors with low energy efficiency.

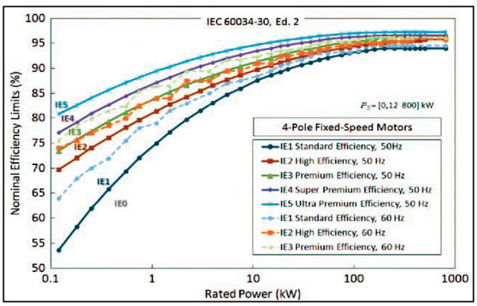

Figure 2. IEC 60034-30 efficiency classification standard, representing classes from IE1 to IE5 for 4-pole electric motors

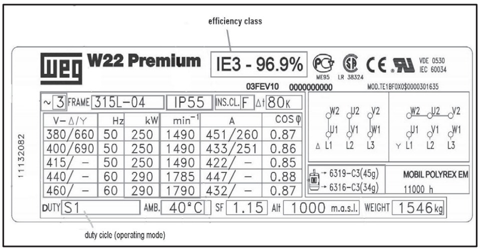

Figure 3. Example of an electrical motor nameplate

Promoting market uptake of efficient motors and drives is an important contribution to the fight against climate change. The EU supports the Super-Efficient Equipment and Appliances Deployment (SEAD) Initiative bringing together countries worldwide to cooperate in promoting efficient appliances (European Commission, 2021).

AC induction motors are a cheap and cost-effective means of converting electrical energy *(P_{input})* into rotational mechanical power *(P_{output})*. They are an effective way to continuously operate pumps, fans, compressors, conveyors, etc., at a fixed speed. These motors are mass-produced by many manufacturers around the globe and sold in standard catalog types and sizes (Waide et al., 2011).

The efficiency *(η)* of a 3-phase induction motor can be calculated with the formula:

$$\eta = \frac{P_{output}}{P_{input}} \cdot 100\%$$

this means:

$$\eta = \frac{P_{ouput}}{P_{output} + P_{losses}} = \frac{P_{output}}{P_{output} + P_{fixed} + P_{var}} \cdot 100\%$$

The relative importance of the different kinds of IM losses *(P_{losses})* depends on motor size.

The *motor losses* (fixed or variable) can be split into five major areas (Table 4) (IEC 60034-31):

· *copper losses* (determined from input power, voltage, current, rotational speed, and torque);

· *iron losses* (determined from input power, voltage, current, rotational speed and torque);

· *rotor losses* (determined from input power, voltage, current, rotational speed and torque);

· *friction and windage losses* (determined from input power, voltage, current, rotational speed and torque);

· *additional load losses* (PLL) (much more difficult to determine, IEC/EN 60034-2-1 specifies different methods of determining PLL which involve low, medium or high uncertainty) (Saidur, 2010).

In spite of the wide sort of electric motors available in the market, three-phase squirrel-cage induction motors (SCIMs) represent by far the vast majority of the market of electric motors (Ferreira F et al., 2016). However, there are some relatively recent entrances in the marketplace, such as the line-start permanent magnet motors (LSPMs) and the synchronous reluctance motors (SynRMs), the latter requiring a variable-speed drive (VSD) or electronic controller. Consequently, the evaluation of direct-on-line (DOL) performance only makes sense for SCIMs and LSPMs (Ferreira et al., 2016). The Synchronous reluctance motor (SynRM) has become commercially viable as a high-efficiency alternative to the induction motor (Ozcelik et.al., 2019).

The core idea of a SynRM motor is that the rotor has no windings or magnets, just electric steel plates stacked together to form a rotor package. However, synchronous reluctance motors require electronic control to produce the rotating magnetic field compared to induction motors. Rotor position feedback is used to control phase energization in an optimal way (De Almeida et al., 2004, 2017).

Unlike in an induction motor, a SynRM rotor has no induced current and thus no losses. This makes SynRM the perfect combination of simplicity and efficiency (Figure 4) (Fereira et al., 2016). A Motor-Driven Unit (MDU) consists of the core components of a motor system: electric motor, variable speed drive (VSD), mechanical transmission, and end-use application, like a pump or fan (Figure 5) (De Almeida et al., 2019; Kulterer, 2021).

Table 3. Legal starting dates for energy efficiency standards

Country	Efficiency Class	Power Range	Start Date
Canada	NEMA Premium	0,75 kW ... 375 kW	28. June 2017
USA	NEMA Premium	0,75 kW ... 375 kW	01. June 2016
Mexico	NEMA Premium	0,75 kW ... 375 kW	13. January 2017
Columbia	IE2	0,12 kW ... 370 kW	31. August 2018
Brazil	IR3 (IE3)	0,12 kW ... 370 kW	01. August 2019
Switzerland	IE3 + IE2 for inverter duty IE2 for VSD IE2 (3 phase) IE3 (3 phase) IE2 (1 phase) IE4 (3 phase)	0,75 kW ... 375 kW 0,12 kW ... 1.000 kW 0,12 kW ... <0,75 kW 0,75 kW ... 1.000 kW >= 0,12 kW 75 kW ... 200 kW	01. January 2017 01. July 2021 01. July 2021 01. July 2021 01. July 2023 01. July 2023
Europe	IE3 IE2 inverter-driven IE2 for VSD IE2 (3 phase) IE3 (3 phase) IE2 (1 phase) IE4 (3 phase)	0,75 kW ... 375 kW 0,75 kW ... 375 kW 0,12 kW ... 1.000 kW 0,12 kW ... <0,75 kW 0,75 kW ... 1.000 kW >= 0,12 kW 75 kW ... 200 kW	01. January 2017 01. January 2017 01. July 2021 01. July 2021 01. July 2021 01. July 2023 01. July 2023
Turkey	IE3 + IE2 inverter-driven IE2 for VSD IE2 (3 phase) IE3 (3 phase) IE2 (1 phase) IE4 (3 phase)	0,75 kW ... 375 kW 0,12 kW ... 1.000 kW 0,12 kW ... <0,75 kW 0,75 kW ... 1.000 kW >= 0,12 kW 75 kW ... 200 kW	01. January 2017 01. July 2021 01. July 2021 01. July 2021 01. July 2023 01. July 2023
Saudi Arabia	IE3	0,75 kW ... 375 kW	16. August 2018
India	IE2	0,12 kW ... 1.000 kW	04. August 2018
China	IE3	3-phase: 0,12 kW ... 1000 kW 1-phase: 0,12kW … 3,7kW with starting capacitor 0,12kW … 2,2kW with running capacitor 0,25kW … 3,7kW with starting + running capacitor	01. June 2021
South Korea	IE3	0,75 kW ... 200 kW 0,75 kW ... 375 kW (4 and 6 pole)	01. October 2018
Japan	IE3	0,75 kW ... 375 kW	01. April 2015
Taiwan	IE3	0,75 kW ... 200 kW	01. July 2016
Singapore	IE3	0,75 kW ... 375 kW	01. October 2018
Australia New Zealand	IE2	0,73 kW ... 185 kW	15. May 2019

Source: https://www.bauergears.com/energy-efficiency/energy-regulations-standards

Table 4. Typical losses in an AC induction motor

Typical losses in 4-pole motors		Factors affecting these losses
Stator losses	30-50%	Stator conductor size and material
Rotor losses	20-25 %	Rotor conductor size and material
Core losses	20-25%	Type and quantity of magnetic material
Additional load losses	5-15%	Primarily manufacturing and design methods
Friction and windage	5-10%	Selection/design of fan and bearings

Source: IEC 60034-31

Regulating the entire Motor-Driven Unit (MDU) would translate into 1400 TWh of cost-effective electricity savings (7% of the World motor systems electricity consumption), with a corresponding reduction in emissions of 469 Mton of CO_2 eq by 2040 (De Almeida et al., 2019).

The productivity premium resulting from intelligent speed control can be utilized in two ways: to increase productivity and keep production stable while reducing energy consumption. For example, pump and fan applications can cut energy consumption by two-thirds (ABB, 2004). The relationship between centrifugal pump or fan speed and its energy demand is known as the cube law because the demand for power increases with the cube of the speed.

This means that a small increase in speed requires a lot more power, but also that a modest speed reduction can give significant energy savings. A pump or a fan running at half speed consumes only one-eighth of the power compared to one running at full speed (ABB, 2016).

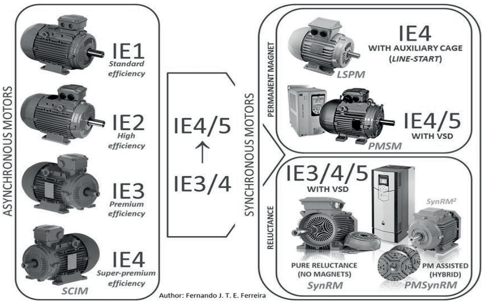

Figure 4. Examples of commercial three-phase motor technologies with high-efficiency class. (Ferreira et al., 2016)

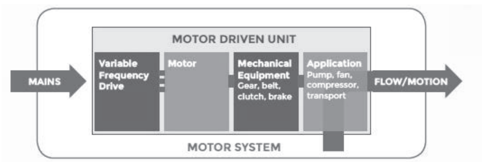

Figure 5 Motor-driven unit (Kulterer, 2021)

A centrifugal pump delivers maximum output, and the excess is reduced at the valve, where the surplus energy is wasted through friction (Falkner, 2008).
Reducing motor speed to meet the actual demand of the process often means substantial energy savings and reduced operating costs. An electric drive enables a process to achieve the right speed and torque while maintaining its accuracy the ability to bring a process up to speed slowly prevents the sudden shock loading that can damage the motor and the driven machine over time (Ahonen et al. 2016).
An example of saving energy is given by De Almeida (2004), who shows that in the case of using pumps with variable speed drive, and efficiency of almost 72% can be obtained compared to a classic system where the efficiency is only 31%. Figure 6 exemplifies the possibility of increasing the energy efficiency of the pumps provided with variable speed drive (U4E, 2017).
Many studies have discussed energy efficiency standards for electric motors in the industry and compared different countries in terms of technology, regulatory, and trend aspects regarding motor systems. For example, to reduce energy consumption and carbon emissions at a food processing units, if is it replaced all the old inefficient motors in compressors and cooling systems with modern IE5 motor and drive packages, it is possible to reduce the energy consumption of the unit by 14% and the carbon dioxide emissions by 131 tonnes per year. (IEA,2021).

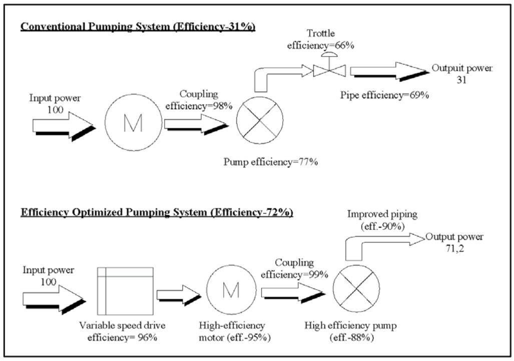

Figure 6. The efficiency of an electric motor pumping system, showing the energy-saving potential (U4E, 2017)

CONCLUSIONS

Many countries' regulatory agencies have introduced and implemented regulations to encourage the development and use of higher-efficiency electric motors.
According to the European Commission Regulations from 1 January 2017, all line-start motors with a rated output of 0.75–375 kW should not be less efficient than the IE3 efficiency level. VSD motors should not be less efficient than the IE2 level. There are about 8 billion electric motors in use in the EU, consuming nearly 50% of the electricity the EU produces. Upgrading to IE5 SynRM motor, we can reduce energy losses by 40% compared to IE3 and save electricity 18 TWh in a year. All measures aim to reduce carbon dioxide (CO_2) emissions by 6 million tonnes over the motor lifetime (ABB, 2016). Besides energy saving on the consumer side, using sources with high energy conversion efficiency and renewable energy sources is also important. It results in a significant reduction in greenhouse gas emissions.
The most common barriers to applying energy-efficient technologies identified in the field include split budgets (different capital and operations budgets), risk of failure, lack of internal incentives, and market structure.

REFERENCES

ABB (2004). Motor and drives, *ABB Review, Special Report*

ABB (2016). Boosting industrial profitability with energy-efficient drives and motors, *Brochure*

Ahonen, T., Martinez Orozco, S., & Tolvanen, J. (2016). Effect of electric motor efficiency and sizing on the energy efficiency in pumping systems. *18th European Conference on Power Electronics and Applications*

ANRE (2020): Rapport annual ANRE (National Energy Regulatory Authority) *https://www.anre.ro/ro/despre-anre/rapoarte-anuale*

APEC (2008). Electric Motors−Alignment of Standards and Best Practice Programmes within APEC. Final Report APEC*, Energy Working Group*

Bauer Gear Motor (2022). Guide to Energy efficiency, *https://www.bauergears.com/energy-efficiency/energy-efficiency-resources*

De Almeida, A., Ferreira, F., & Both, D (2004). Technical and Economic Considerations to Improve the Penetration of Variable-Speed Drives for Electric Motor Systems, *IEEE Industrial and Commercial Power Systems Technical Conf. (ICPS'04), Conf. Rec., 136-144.*

De Almeida, A., Fong, J., Falknerb, H., & Bertoldi, P. (2017). Policy options to promote energy efficient electric motors and drives in the EU, *Renewable and Sustainable Energy Reviews 74 1275–1286,* http://dx.doi.org/10.1016/j.rser.2017.01.112

De Almeida, A., Fong, J., Brunner, C.U., Werle, R., & Van Werkhoven, M. (2019). New technology trends and policy needs in an energy-efficient motor system- A major opportunity for energy and carbon savings, *Renewable and Sustainable Energy Reviews,* 115, https://doi.org/10.1016/j.rser.2019.109384

European Commission (2021). New EU rules to boost the energy efficiency of electric motors. *(https://ec.europa.eu/info/news/new-eu-rules-boost-energy-efficiency-electric-motors-2021-jun-30_en)*

European Commission (2019). Regulation (EU) 2019/1781 on Ecodesign requirements for electric motors and variable speed drivers, *Official Journal of the European Union.*

European Commission (2021). Regulation (EU) 2021/341 amending Regulations (EU) 2019/424, 1781 and 2020 to 2024, *Official Journal of the European Union.*

Falkner, H. (2008). EuP Lot 11 Pumps (In Commercial Buildings, Drinking Water pumping, Food Industry, Agriculture); *Ecodesign Assessment of Energy Using Products; DG-TREN*; AEA Energy Environment: Brussels, Belgium

Ferreira, F., de Almeida, A., & Leprettre, B. (2016): Comparison of Protection Requirements in IE2-, IE3- and IE4-Class Motors, *IEEE Transactions on Industry Applications,* 52(4), 1.

Floeck, S. (2021): How can energy-efficient electric motors combat climate change? *https://eandt.theiet.org/content/sponsored/abb-how-can-energy-efficient-electric-motors-combat-climate-change/*

Fong, J., Ferreira, J.T.E.F., Silva, A., & Aníbal de Almeida, A. (2020): IEC61800-9 System Standards as a Tool to Boost the Efficiency of Electric Motor Driven Systems Worldwide, *Inventions, 5, 20.*

Gavrilă, H., Mănescu Păltânea, V., et al. (2017). New Trends in Energy Efficient Electrical Machines. *10th International Conference Interdisciplinary in Engineering INTER-ENG 2016, Procedia Engineering 181, 568-574*

Harmsen, R. & Graus, W. (2013). How much CO_2 emissions do we reduce by saving electricity? *Energy Policy, 60,* 803–812.

IEA (2021). Net Zero by 2050 A Roadmap for the Global Energy Sector. *International Energy Agency Special Report*

IEC 60034-30:2008 Rotating electrical machines - Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors, *International Electrotechnical Commission* Geneva, Switzerland

IEC 60034-31:2021 International Standard Rotating electrical machines – Part 1: Rating and performance, *International Electrotechnical Commission:* Geneva, Switzerland

Kulterer, K. (2021): Report on the EMSA Survey on digitalization in electric motor driven systems. *IEA 4EElectric Motor Systems Annex*

Monforti-Ferrario, F., Dallemand, J.F. et al. (2015). Energy use in the EU food sector. *Science for Policy Report by the Joint Research Centre, European Commission*

Ozcelik, N.G., Dogru, U.E., Imeryuz, M., & Ergene, L.T.(2019): Synchronous Reluctance Motor vs. Induction Motor at Low-Power. *Industrial Applications: Design and Comparison, Energies, 12*(11), 1-20.

Saidur, R. (2010). A review on electrical motors energy use and energy savings, *Renewable and Sustainable Energy Reviews,* 14, 877–898.

Shyi-Min, L. (2016): A review of high-efficiency motors: Specification, policy, and technology - *Renewable and Sustainable Energy Reviews,* 59, 1-12.

U4E-United for Efficiency (2017). Accelerating the Global Adoption of energy-efficient electric motors and motor systems-UN Environment – Global Environment Facility (U4E), *Policy guide series.*

Waide, P., & Brunner, C. (2011): Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems. *International Energy Agency-Working Paper.*