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Master thesis

Energy efficiency movement, policy impact and market transformation in electrical motor industry: Empirical study on Ecodesign regulation adoption in ABB IEC Low Voltage Motor

School of Technology and Innovation, Production
Master of Science in Economics & Business Administration

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ABSTRACT:

Energy intensity has been improved on average by 1.3% a year and is aimed to be below 4% as described in the Net Zero Emission by 2050 Scenario over 2020-2030. Energy efficiency has been the essential strategy to achieve this goal. Governments and public decision makers around the world are looking for the most promising ways to reduce energy consumption and emissions in order to achieve sustainability targets. Businesses, companies, and appliance manufacturers hold the keys to produce the applications necessary to effect energy-efficient use. Particularly in the industrial sectors, efficiency policies play a vital role in enabling development and driving the market towards the energy efficient products which are required by the legislative policies in specific industries.

This thesis studies the electrical motor in terms of energy efficiency, the most relevant electrical motor efficiency policies, and market transformation. The study employs an empirical case to a) describe the role of the electrical motor in energy efficiency; b) to review electrical motor efficiency policies and efficiency calcification standards; c) to focus in particular on European energy efficiency framework and Ecodesign directives; d) to observe and review business implementation such as product portfolio development in the adoption of Ecodesgin regulation; e) to collect quantitative data on past market deliverables and conduct a future market demand survey within the case company. The findings are summarized in terms of the impact of energy efficiency policies, the transformation of the electrical motor market and trends driven by efficiency policies and existing optimized technical solutions and products beyond existing standards that are available on the market. Moreover, at the end, the author discusses and recommends energy savings which are achievable and potentially much higher by addressing energy efficiency improvements on total motor driven systems instead of individual components. Further efforts to develop standards and policies in this regard are crucial. In addition, obstacles in today's global energy market such as the impact of COVID-19 and political issues, must be looked at and taken into consideration in further studies.

KEYWORDS: Energy efficiency, Ecodesign, MEPS, product portfolio management, electrical motors, market transformation

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ABBREVIATIONS

EE1st – Energy Efficiency First
NECPs – National Energy and Climate Plans (NECPs)
IEC – International Electrotechnical Commission
MEPS – Minimum energy performance standard
PFE - Program for improving energy efficiency in energy intensive industries
EEM - Energy efficiency measure
CEMEP - European Committee of Manufacturers of Electrical Machines and Power Electronics
VSD – Variable speed drive
MEErP - Methodology for the ecodesign of energy-related products
NPD – New product development
CDM - Complete drive modules
PDS - Power drive systems

1 Introduction

1.1 Background

Many of the core dilemmas in sustainable development are seen to be long-standing including the resource-dependent nature of development, the persistence of poverty and rising inequality in terms of access to development opportunities and environmental improvements (Elliot, Jennifer, 2012). In general, the challenges are easily understood from the definition of sustainable development itself: "development that meets the needs of the pre-sent without compromising the ability of future generations to meet their own needs" (Our common Future, 1987). In other words, the challenges are managing human, natural, and financial resources, and the need for long-lasting quality in our lives and the state of the environment.

The first key challenge is resource scarcity such as future energy sources and low-carbon development. There are two key issues presented by energy in sustainable development. One is the concern for the adequacy and security of affordable supplies in the future, and another crucial challenge is the environmental damage caused by the consumption of energy. Globally, cumulative energy consumption grew by nearly 5588 exajoules and carbon dioxide emission by 332175 million tones in the last ten years. Whilst over 40 percent of consumption came from the Asia Pacific area, the more economically advanced regions such as North America and Europe counted for over 30%. In terms of world electricity generation during 1995 to 2012, the absolute share of fossil fuels increased from 62% to 67.8%. Despite declining since 2015, fossil fuel consumption is as high as 61.3% today, and 35% source comes from coal. (BP, 2021)

The implications for sustainable development of these two issues of future energy supply and current patterns of consumption are extremely wide-ranging. The demand for electricity will grow faster than for any other form of final energy; thus, emissions will keep rising. Despite the patterns of production and consumption having undergone significant changes over recent decades (Pinheiro, Jugend, Filho, Armellini, 2018), the pressures to reduce energy consumption and lower carbon dioxide emissions come from everywhere. One of the solutions to this challenge is to seize the opportunities to use energy more efficiently.

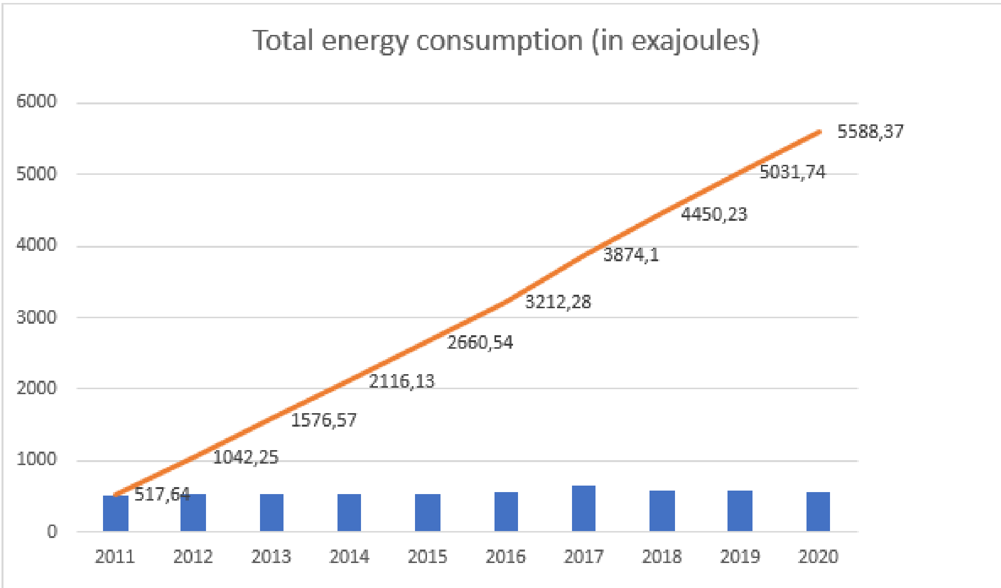

Figure 1.1.1 – Total energy consumption 2011-2020 (Calculated from source: BP Statistical Review of World Energy, 2021)

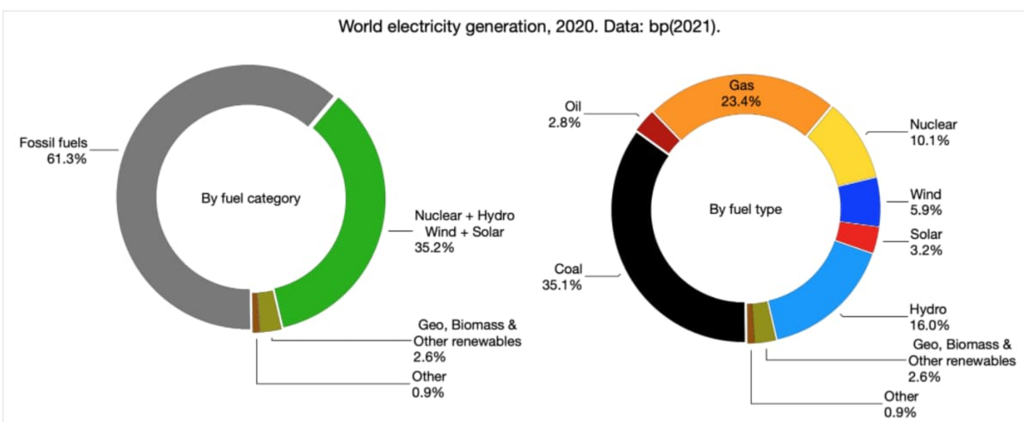

Chart 1. World electricity generation by share in 2020.
Data: bp Statistical Review of World Energy 2021[1 4].

Figure 1.1.2 – World electricity generation (BP Statistical Review of World Energy, 2021)

By 2050, global energy usage is projected to increase by almost 50% compared to 2020. This includes an increase in energy consumption in the industrial sector. (U.S Energy Information Administration, 2021). The realization that energy usage must become more sustainable and efficient is not new in the EU either. “Over the years, the European Parliament has been setting the agenda,” says Morten Helveg Petersen, Vice-President of the European Parliament Committee on Industry, Research and Energy, and a member of the Renew Europe Group, “and, when I speak to my colleagues from different parliamentary groups, I see that the principle of ‘energy efficiency first’ has a key role to play in realizing our objectives.”

At the time of writing, in the first quarter of 2022, the cost of energy – oil, gas and electricity – is particularly high, which has led to significant extra energy costs for companies.

1.2 Research objectives and questions

Modern technologies hold the key to enabling applications to provide energy-efficient use, and businesses, companies, and manufacturers are continuously investing and providing the necessary technologies and driving the innovation that improves energy efficiency. However, it raises the question of what pressurizes and drives such development towards an energy-efficient world? In the industrial sectors, the author considers the answer is efficiency policies such as standards, legislation, and regulations, which are rapidly adopted by governments and public decision makers around the world who are looking for the most promising ways to reduce energy consumption and emissions to achieve sustainability targets.

The energy efficiency report from IEA (2021) highlighted that government policies are expected to help energy efficiency investment rise by 10% to almost 300 million USD. Figure 1.2.1 shows that, in particular, Europe has outstandingly the largest investment growth concentration, while policies in other regions needed to be incentivized. The European Union has no less than 40 laws, 11 policies, and 31 climate targets set to implement mandatory regulations for key appliances (European Parliament, 2021).

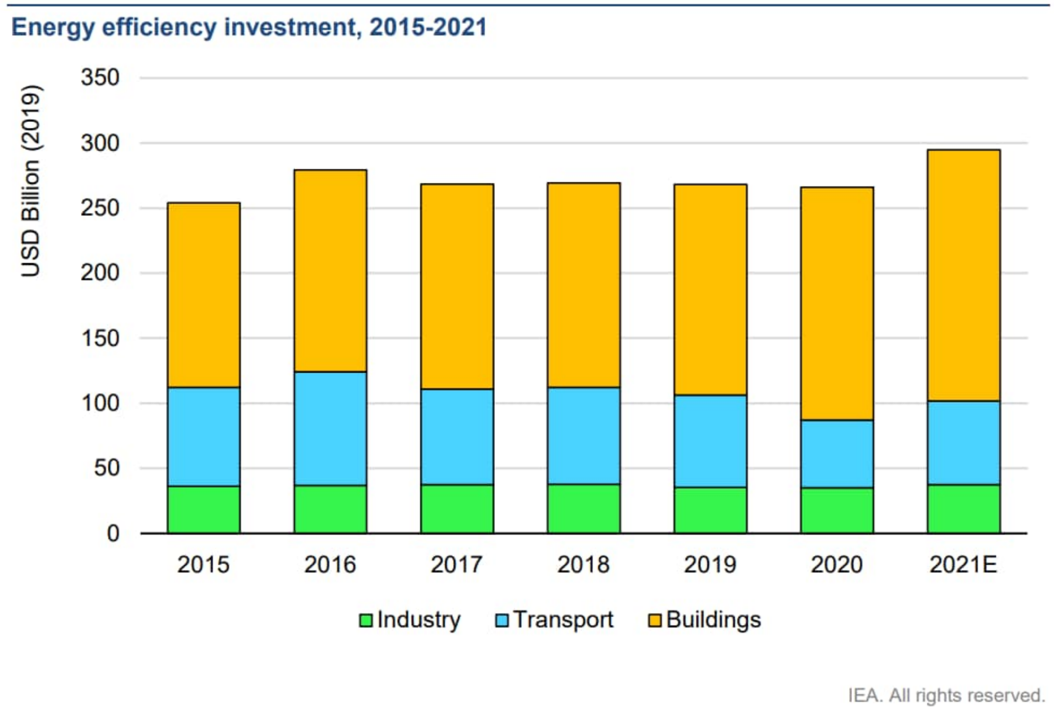

Figure 1.2.1 – World energy efficiency investment (source: IEA 2021)

The effect is large and widespread to enable energy saving through appliance programs, which include, for example, the energy efficiency first (EE1st) principle as defined in Article 2(18) of the Regulation on the Governance of the Energy Union and Climate Action (European Union, 2018), and regulations such as Ecodesign, complemented by energy labelling rules, which drive market investment and technology innovation in a sustainable manner while reducing energy consumption and CO2 emissions. For example, the EU legislation for energy labels and ecodesign has been estimated to produce energy savings of approximately 230 million tons of oil equivalent (Mtoe) by 2030. For consumers, this means an average saving of up to €285 per year on their household energy. When looking at these impressive numbers and results, there is no doubt that energy efficiency policies are the key enabler to incentivizing energy saving. But what are these policies specifically? How do they work? How do those policies apply to business practice?

Although there is a large amount of research on energy efficiency, there are still not sufficient empirical studies on the integration of research into business practice and we cannot explain more than 50 % of the impact of energy efficiency policies (Labandeira et al. 2020). The gaps between abstract theories, and their impacts on industry sectors and concrete actions, have been problematic in identifying the energy efficiency policies significantly contributing to energy consumption, and supporting industrial competitiveness and innovation by promoting better environmental performance of products throughout the market. On the other hand, despite the intensification of industrial actions within sustainable development which have been significantly intertwined with society and environmentally on a global scale, public education will be still required to explain and promote the value of energy efficiency. In reviewing existing research and studies, there is a realization of a gap in results, found already some years ago and when compared to today's trends, it is increasing all the time. For example, one research item found that the market share of electrical motors was dominated by IE2 efficiency class motors, but such a conclusion is far behind the times. The present author has been working in industrial sectors and has particularly witnessed the evolution of the energy efficiency movement in the electrical motor industry in the past decade and found strong interests and values to share expertise and further explore the field of enhancing energy efficiency through empirical studies.

Through an empirical study in the electrical motor industry, this research aims to reveal the critical role of efficiency policies in enhancing energy efficiency as the key enabler to achieve energy reduction and emission saving, and how energy efficiency policies drive market transformation in energy-use products. The research explores electrical motor efficiency policies on a global scale, but focuses particularly on European Ecodesign directives and regulations, and IEC standards which have most effect in electrical motor technology trends and market shift. The diffusion of effects is not limited to Europe, but also influences the defining of efficiency policies in other regions and countries, for example China GB standards and energy labeling. In this thesis, the aim is to find answers to the following research questions:

1) What kinds of impacts do existing electrical motor efficiency policies have on ABB?

2) How have policies, especially European Ecodesign regulation, impacted on the electrical motor market transformation?

1.3 Research design

To address the research objectives and questions, we conducted the study in two parts, consisting of a theoretical literature review and an empirical investigation which reflects the findings in business practice (Figure 1.3.1).

Part I Theoretical literature review.

The aim of this part is to identify 1) the role of the electrical motor in energy efficiency; 2) energy efficiency vision and efficiency policies in the electrical motor; 3) Europe ecodesign requirements. The outcome of the literature review provides a descriptive overview of the importance of enhancing energy efficiency and Ecodesign directive development, which are the foundations for empirical study on how Ecodesign and energy efficiency policies drive industrial sustainable development and provides the framework for the development of business practices. This part of the study goes through the latest public research results reported by major energy agencies and governments such as IEA and Europe Commission, and furthermore studies existing public policies on energy efficiency related to electrical motors which include voluntary agreements, standards, and regulations.

Part II Empirical study

Both qualitative and qualitative approaches are carried out. Qualitative studies consist of observations, business process review, case company internal research review and interactive data collection from experts. The objectives of this part are to explain the business case in terms of efficiency policy impact, describe the crucial role of energy efficiency in the electrical motor industry and how it shapes the strategic planning and decision-making in the case company. A quantitative approach is conducted with deep analysis based on numerical data collection from business results, market survey, and third-party consultant analysis in terms of global electrical motor trends. The results from this part are presented in terms of the assessment and evaluation of theoretical findings which are applied in the case company in their business practice.

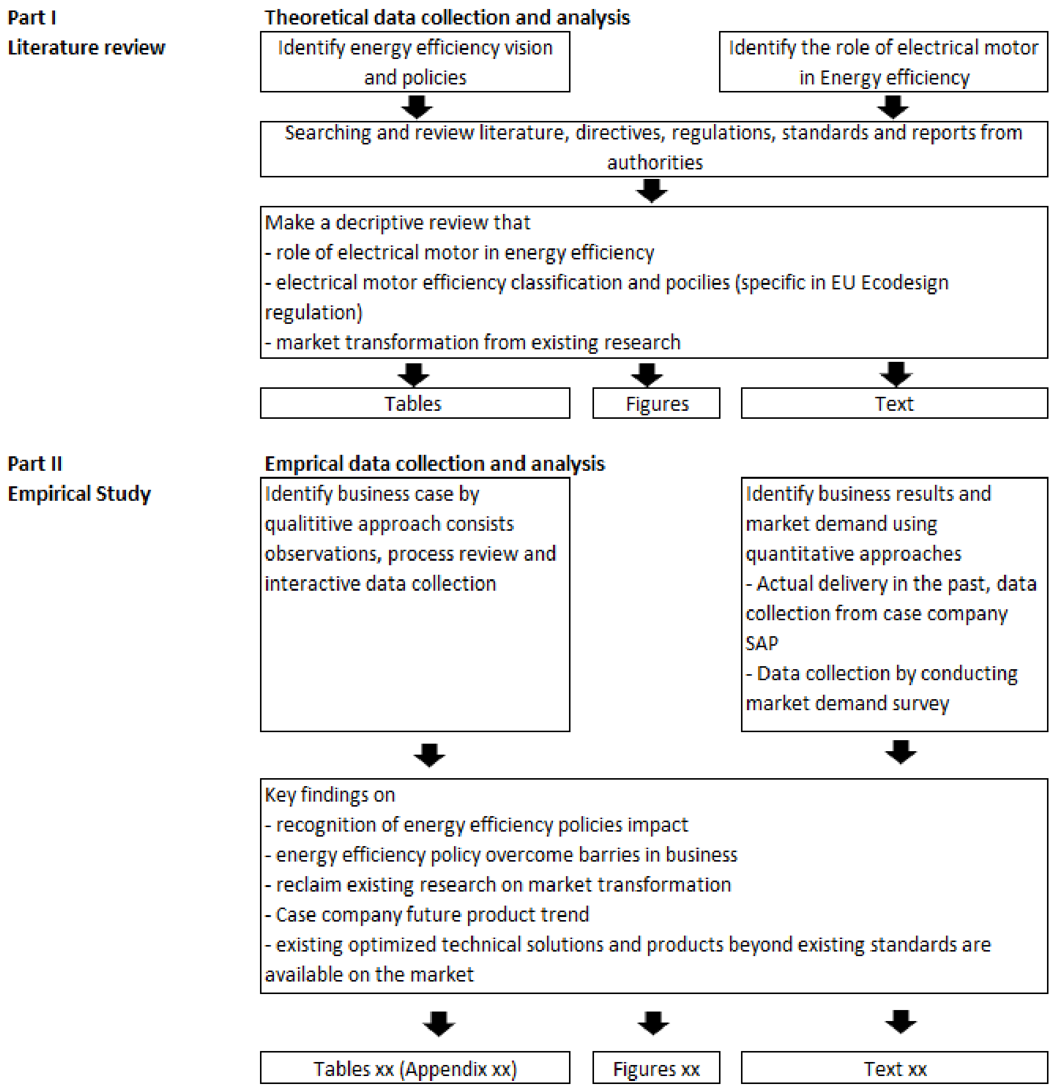

Figure 1.3.1 – Research design

1.4 Definition, delimitations and limitations

1.4.1 Energy efficiency policies

Energy efficiency is one of the pillars of the EU's Energy Union strategy, which has been proposed as an effective way to improve the economic competitiveness and sustainability of the European economy, lower emissions, reduce energy dependency, and increase security of supply, and create jobs (Malinauskaite et al. 2019). Energy efficiency policies strongly support the achieving of sustainability goals and reducing energy and climate mitigation costs (Labandeira et al. 2020).

Today, energy efficiency policies are not new around the world. Many regions and countries have set up or are currently developing energy efficiency policies in different appliances. This research involves examining policies in the major markets of electrical motors in. Europe to fully depict understanding of the energy efficiency vision in the electrical motor industry as selected. The empirical case company mergers contributing to the global market, therefore, are needed to study the impact of global policies on electrical motors. However, the concentration is on the European Ecodesign directives and regulation of energy-using products developed by the European Commission, due to the selection of the case company and most essentially because Ecodesign regulations have been most effectively adopted by electrical motor manufacturers and have impacted the market transition. By purposely focusing on identifying the trend of market driven by efficiency policies instead of explaining the policy details, the detailed requirements, and exemptions of noted energy efficiency policies, for example, motors operating at abnormal conditions such as an ambient temperature above 60°C, will not be in the scope of discussion in this thesis.

1.4.2 Ecodesign

(ISO 14006, 2020) defined Ecodesign as a “systematic approach that considers environmental aspects in design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product”. The theoretical concept of Ecodesign can be found in numbers of studies which aim to design products where minimizing their environmental impact throughout their life cycle is considered (Karlsson and Luttropp, 2006). In an ecodesign-based product, design, quality, and customer satisfaction requirements must be integrated with environmental requirements, so that solutions consider their impact during all stages of the product life cycle, from raw material extraction through to manufacturing, packaging, use, recycling, and re-use (Bovea and Perez-Belis, 2012). The ecodesign requirements for individual product groups are created under the EU's ecodesign directive in a process coordinated by the European Commission. The EU legislation on ecodesign is applicable in 31 product groups. The word Ecodesign is widely used in different sectors where different products and services are provided.

Nevertheless, in this research, Ecodesign is distinguished as the ecodesign of energy-using products. The methodology for the ecodesign of energy-using products was developed for European Commission (VhK, 2005). The methodology of ecodesign of energy-using products is common to all preparatory studies and identified as: a)Existing relevant standards and legislation; b) Market characteristics for the products under consideration; c) Relevant environmental aspects of the products and their technical/economic potential for improvement; d) Technical analysis of the best available technologies (BAT) and the best not available technologies (BNAT); e) LCC assessment; f) Scenario, policy, impact, and sensitivity analysis. (Anibal T. de Almeidaa, Joao Fonga, Hugh Falknerb, Paolo Bertoldic, 2017). This is a well-known and applied tool in other research, for example, figure 1.4.2

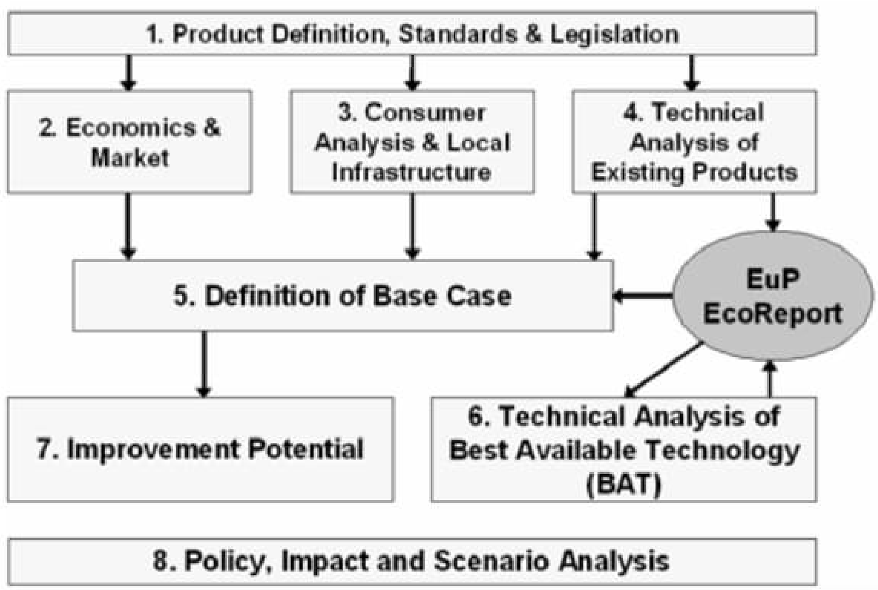

Figure 1.4.2 – Methodology study for ecodesign of energy-using products (Anibal T. de Almeida, Fernando J.T.E. Ferreira, Joao Fong, Conrad U. Brunner, 2008)

By utilizing a part of this tool, preliminary assumptions were defined in this research for the particular case of electrical motors. The author focuses on the analysis and findings on a) EU Ecodesign regulation 2019/1781 adoption; b) market analysis from existing research and relevant empirical study from the case company; c) the impact on energy consumption improvement; d) the trend of best available products.

1.4.3 Electrical motor driven system

An electrical motor driven system includes all the intermediate components from the main motor unit to its output power load drives, for example the transformers, frequency converters, gear boxes and mechanical transmission units between the motor and load. Previous research has concentrated on the technical potential for energy efficiency improvement in electrical motor driven systems. Waide and Brunner have defined three levels of motor system to improve the energy efficiency. Figure 1.4.3. Program for improving energy efficiency in energy intensive industries (PFE) lists the categorization of energy efficiency measure (EEM) examples according to Waide and Brunner (Waide,P., Brunner, C., 2011) Table 1.4.3. is adapted from Svetlana, Therese and Patrick (Svetlana Paramonova, Therese Nehler, Patrik Thollander, 2021)

This study is focused on the case company business in low voltage motors, and related energy policy such as the European Ecodesign directive, which defines electrical motors as one of the product groups. Further discussion is explored at the end of study, for example, the potential energy saving from the variable speed driven motor system.

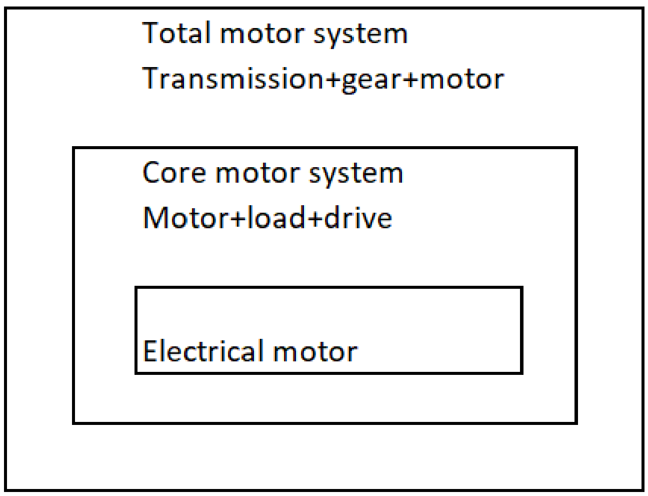

Figure 1.4.3. Motor system levels

Level	Definition of the components	Example of EEM from PFE
Electrical motor	**Standard motors** - High power factor - Correct sizing	Removal of motors
	New motors - New energy efficiency - Alternative motors (e.g., variable speed motors, synchronous reluctance motors)	Replace motor with more energy-efficiency ones

Core motor system	**Loading units** **Pump** - Correct sizing - High-efficiency pumps (Dynamic pressure compensation) **Fan** - Correct sizing - High-efficiency fans - Effective blades **Compressor** - Energy-efficient systems (Electric servo and linear - motors)	Switching off a refiner; replacement of a backwater pump; sizing of pumps; reducing diameter of impeller on a condensate pump
	Interconnection **Gear box** - Decrease gear losses - Direct coupling to a piece of - equipment (e.g. pump, fan) **Mechanical power transmission** - Flat belts - New materials of belts - Direct coupling to a piece of - equipment (e.g. pump, fan)	
	VFD and VSD system	Frequency control of vacuum pump
Total motor system	**Piping system** - Optimum operational point - Correct sizing (valves) - Downsizing	Bypass-damper on grinder; replacement of chip transporter; purchase of new frequency-controlled refrigerating machines; reduction of pressure in hydrogen peroxide unit; change from hydraulic to electric drive
	Ducting system - Optimum operational point - Correct sizing - Optimal air flow	
	Eliminate mechanical reduction of flow	

Table 1.4.3 Motor system levels (adapted from Svetlana, Therese and Patrick, 2021)

1.4.4 Declaration of competing interest

The author declare that she has no known competing financial interest or personal relationships that could have appeared to influence the research reported in this thesis. The empirical data and information are only allowed to be used for future research purposes.

2 Literature review

2.1 Energy consumption of electrical motor and potential savings

The central aim of the 2015 Paris Agreement was to strengthen the global response to the threat of climate change by keeping the global temperature rise within this century well below 2 ◦C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 ◦C (United Nations, 2015). To reach this ambitious goal, two central strategies are pursued by the European Union and its member states concerning energy systems: (1) enhancing energy efficiency, and (2) decarbonizing the energy supply.

In many industrial sectors, the policies and consumer awareness play a major role in shaping energy efficiency impacts. One of the most promising ways to achieve the goals is through the adoption of energy-efficient technologies – reducing energy consumption will benefit companies in terms of profitability and sustainability. Moreover, current research also emphasizes the energy efficiency contribution in GHG emission reduction. Despite the IEA estimating that industry currently accounts for more than 37% of global greenhouse gas emissions, by improving energy efficiency (IEA, 2020), Brugger, Eichhammer, Mikova and Donitz have found that by 2025, the overall contribution from energy efficiency measures, including low-carbon generation technologies and conversion saving, can be translated into a 79% emission reduction compared to the 2010 level, and an 81% emission reduction compared to the 1990 level. (Heike Brugger a, Wolfgang Eichhammer, Nadezhda Mikova, Ewa Donitz, 2021)

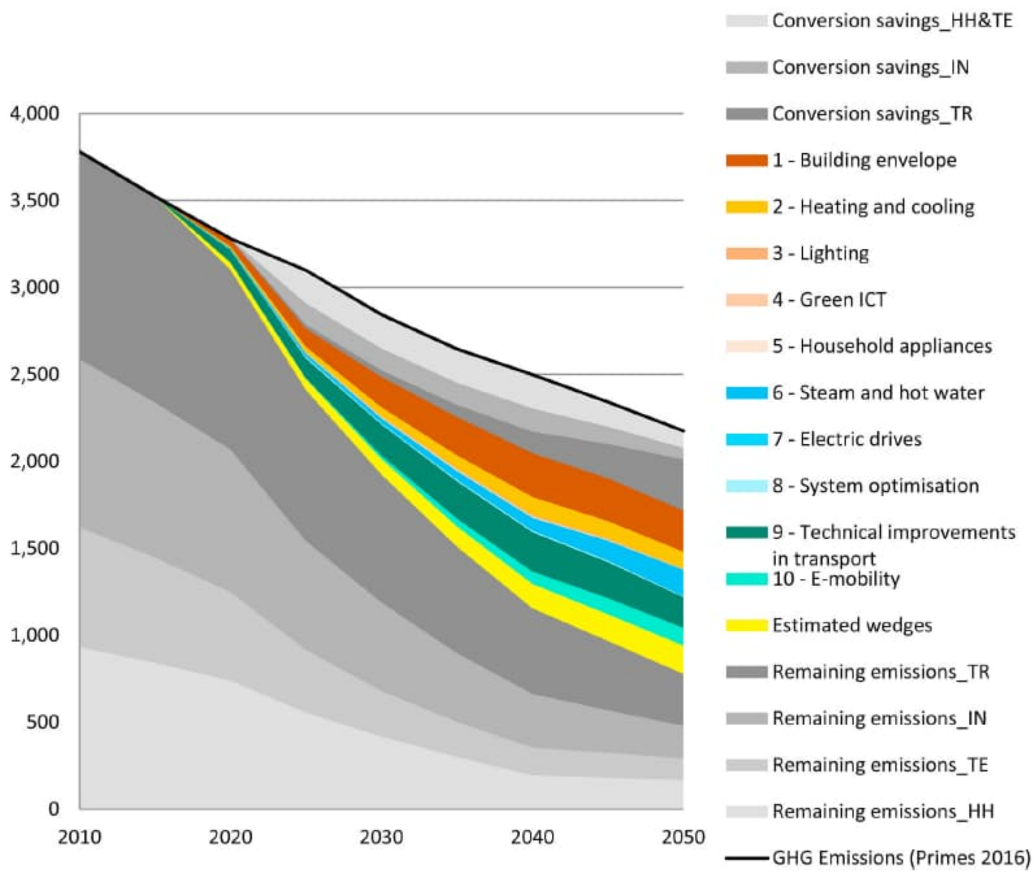

Figure 2.1.1. Energy-related GHG emissions resulting from final energy savings in Mt CO2 equivalent (Heike Brugger a, Wolfgang Eichhammer, Nadezhda Mikova, Ewa Donitz, 2021)

Motor systems are a major electricity consumer in global electricity, using 46 percent (4E, 2014), counting total electricity consumption in the world as around 7100 TWh/year (Svetlana Paramonova, Therese Nehler, Patrik Thollander, 2021), and being mainly in industry, infrastructure systems, buildings and the transportation of goods and people.

About 70 percent of the electricity is consumed by industries using over 300 million industrial motor-driven systems in operation (Fong, J.; F. Ferreira; A.M. Silva; and A.T. De Almeida, 2020), and about 35 percent in the non-residential buildings sector (Anibal T. de Almeidaa, Joao Fonga, Hugh Falknerb, Paolo Bertoldi, 2017). IEA also reported 37 percent (157 EJ) (IEA, 2020) of total energy demand was from industrial manufacturing, and about 53 percent of electricity worldwide was used in electric motor systems (10 700 TWh), representing emissions of 5,5 Gton CO2eq, of which over 60% is used in industrial electric motor-driven systems (A. De Almeidaa, J. Fonga, C.U. Brunnerb, R. Werleb, M. Van Werkhovenc, 2019), as shown in Fig. 2.1.2

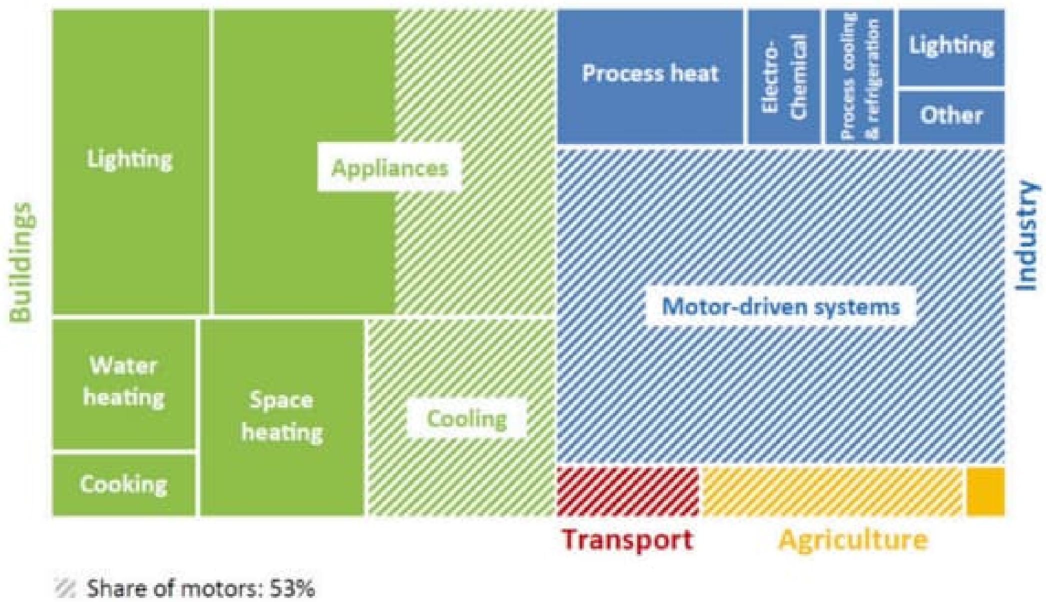

Figure 2.1.2 – Global total final electricity consumption by end-users, 2014 (source: IEA 2017)

From the existing research statement, in comparison, the number of percentages of world total electricity consumption from motor driven systems reduced by about 10% from 2018 to 2021. For instance, Waide, P. and C.U. Brunner's research (2011) estimated that global electricity consumption would reduce by 10%, by replacing the current 300 million motor systems with higher efficiency equipment (Waide,P., Brunner, C., 2011). 300 TWh of energy and 200 Mt of CO2 emissions could be saved per year by 2030. (UN Environment, 2017). The technology exists to reduce motor system energy demand by 20% to 30% (EMSA, 2021).

Therefore, improving the efficiency of electrical motors plays a significant role in energy consumption. Tying energy efficiency development into solid business considerations and grounded in objectives and operations is essential in order to fulfil the market demand and achieve a positive impact on society and the environment in accordance with the sustainable goals set. The recognition of motors as a major energy consumer has led to extensive studies by businesses and governments which are looking for ways to achieve and enable sustainable growth.

Industries and regions which have a large and aging installed base clearly present good opportunities to improve energy efficiency by modernizing existing electric motor systems. In the industrial sectors, the largest potential for reduction in electricity consumption and corresponding emissions comes from improving the efficiency of electric motors and end-use devices (Fong, J.; F. Ferreira; A.M. Silva; and A.T. De Almeida, 2020). Such is the case in the US, for example, where over 60% of industrial motors are over 10 years old (Lawrence Berkeley National Laboratory, 2021). The developments in energy efficiency in electrical motors are usually driven through directives, regulations, and standards.

2.2 Electrical motor component vS power drive system

Although the energy saving from the electrical motor as a core part of a motor driven system is important, it is an integrated process design offering the largest energy saving potential from the total system which also includes all components. Figure 2.2.1. shows optimum sytem design delivering maximum efficiency. The largest part of the potential energy saving is made available by the optimization of the entire motor system, which typically is in the range of 20–30% (A. De Almeidaa, J. Fonga, C.U. Brunnerb, R. Werleb, M. Van Werkhoven, 2019). In this study, the focus is on the electrical motor itself; however, a variable-speed drive serves to control an electric motor in such a way as to optimize its operation. It accomplishes this by adjusting the speed and torque of a motor as it operates to match the system's load requirements. With the right drive, an electric motor will run only as fast as is called for by the underlying load, leading to significant power savings such as in the application case comparison from the empirical study (see figure 2.2.2)

In practice, the electrical motor does not stand alone and policies increasingly have been taking variable speed drive efficiency into the measurement as an essential part of the motor driven system. IEC 61800-9-2 defines efficiency classes for AC drives, which are also referred to as complete drive modules (CDM). The efficiency classes range (low to high) from IE0 to IE2. These classes apply to AC drives rated 100 to 1000 V and 0.12 to 1000 kW. In addition, IEC 61800-9-2 also defines the efficiency classes for AC drives and motors in combination, which are also called power drive systems or PDS. Efficiency classes range from IES0 to IES2. The classes are valid for motors and AC drives rated 100 to 1000 V, and 0.12 to 1000 kW.

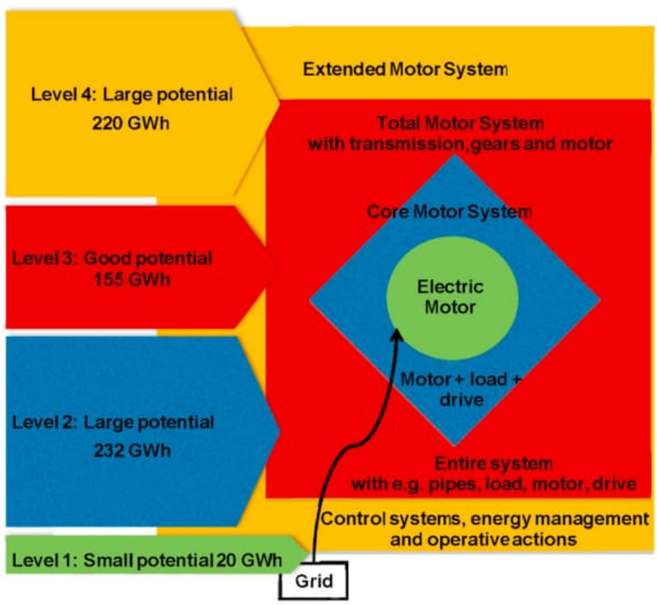

Figure 2.2.1 – Energy efficiency saving for different motor system levels. (Source: Svetlana Paramonova , Therese Nehler, Patrik Thollander, 2021)

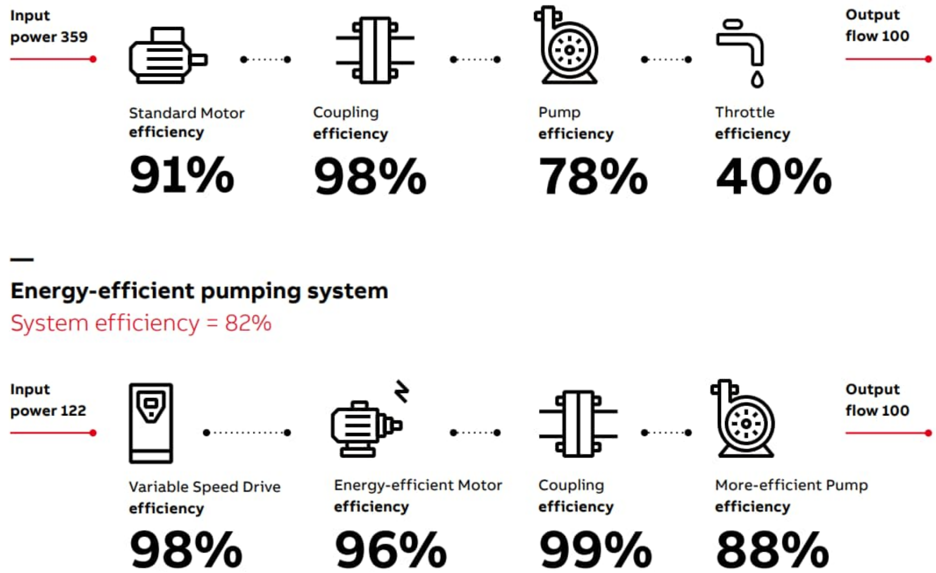

Figure 2.2.2 – Conventional pumping system (source: ABB)

It is to be clarified that this thesis will focus on efficiency policy on the electrical motor as an individual component, and the Ecodesign regulation 2019/1781 will be studied in the following sections set at the mandatory minimum efficiency level not only for electrical motors but also drives. However, it must be noted that it does not set minimum efficiency requirements for PDS (power drive systems).

2.3 Electrical motor efficiency classification and policies

In this section, an overview on electric motor efficiency standards and relevant issues are pointed out. 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, and in content with energy-efficiency policies (A. De Almeidaa, J. Fonga, C.U. Brunnerb, R. Werleb, M. Van Werkhoven, 2019). The International Energy Agency works with countries around the world to shape energy policies for a secure and sustainable future. The recognition of motors as a major energy consumer has led to widescale studies by businesses and governments, which are looking for ways to achieve and enable sustainable growth. The most major economies have intended to capture the identical potential saving from energy consumption and havelegislated energy efficiency policies based on international standards. By 2014, 4E, Electrical Motor System Annex published Policy Guidelines for Electric Motor Systems (4E, 2014) to introduce the most detailed overview of policies for electrical motor systems. The aims of the policies are presented below as revised by Svetlana Paramonova, Therese Nehler, Patrik Thollander (2021), Table 2.3.1

MEPS	Remove the worst performing components and systems from the market
Labels	Provide information on the energy performance of components and systems, identify the best available options
Voluntary Agreements	Non-regulatory mechanisms for improving the efficiency of major sectors or companies
Energy Management	Help to maximize energy savings within companies
Energy Audit	Find cost-effective energy savings within companies
Motor Policy	Install the most efficient cost-effective motors
Financial Incentives	Increase awareness of opportunities among end-users and contribute to long-term improvements in the market
Incentives for increased awareness and information	Overcome informational barriers

Table 2.3.1, Existing public policies to overcome barriers to energy efficiency related to electrical motor driven systems (source: Svetlana Paramonova, Therese Nehler, Patrik Thollander, 2021)

Among the policies, the mandatory minimum efficiency level was introduced as Minimum Energy Performance Standards (MEPS), which are set as the requirement for motors sold in individual countries for the promotion of higher efficiency motors entering the market. They areusually implemented through national or regional regulations; for example, the focus in this study is on European Ecodesign regulations 2019/1781, which is also well-known as EU MEPS regulation.

The developments in energy efficiency in electrical motors are usually driven through directives, regulations, and standards. Directives and regulations are national, country-specific, or regional since they are created by governing bodies and there is no true alignment and standardization when it comes to the trademarking, registration and validation of products. (Table 2.3.2).

Region	**Power range**	**Min. Eff. requried**	**Mandatory agreement (regulation)**	**Trade marking**
Europe	0,12-1000kW	IE2 (<0,75kW) IE3	EU 2019/1781 (Ecodesign regulation)	CE
USA	1-500HP	IE3	10 CFR Subpart B – Electric Motors Integral Horsepower Motor Final Rule (IHP) NEMA MG 1 Table 12-12	NEMA Nom. Eff. and the CC number
Canada	1-500HP	IE3	Energy Efficiency Act and Energy Efficiency Regulations	NEMA Nom.Eff and ENERGY
Mexico	0,746-373kW	IE3	NORMA OFICAL MEXICANA, NOM-016- ENER-2016	NOM certification
Brazil	0,12-370kW 0,16-500HP	IR3	Portaria Interministerial No. 533 ABNT NBR 17094-1:2018	PROCEL sticker
China	0,75-375kW	Grade 3	GB18613-2020	China Energy Label 007-2021
India	0,12-1000kW	IE2	IS 12615:2018	ISI

Saudi Arabia	0,75-375kW	IE3	Certificate of Conformity by third party	Not applicable
Japan	0,75-375kW	IE3	Top Runner Program introduced by Ministry of Economy, Trade and Industry (METI)	Not applicable
Singapore	0,75-375kW	IE3	National Environment Agency	Not applicable
South Korea	0,75-375kW	IE3	KEMCO	KEMCO
Australia, New Zealand, Fiji	0,73-185kW (not including 185kW)	IE2 or IE3	The Greenhouse and Energy Minimum Standards Determination 2019	IE

Table 2.3.2 – Overview of motor efficiency mandatory agreements around the world

Governments issue MEPS usually based on international standards. In the case of electric motors, they are based on efficiency classes (A. De Almeidaa, J. Fonga, C.U. Brunnerb, R. Werleb, M. Van Werkhoven, 2019), which are defined by many different standards, for instance NEMA in United Sates, AS/NZ in Australia and New Zealand, JIS in Japan, GB in China, ABNT in Brazil, MON in Mexico, and so on. This produces more challenges not only for motor manufacturers, but all equipment manufacturers delivering their incorporated motor products or spare parts around the world. In order to overcome these undesirable situations, a new international standard is being developed by the International Electrotechnical Commission, IEC 60034-30, which is intended to globally harmonize motor energy-efficiency classes for general purposes (Aníbal T. de Almeida, Fernando J. T. E. Ferreira, João A. C. Fong, Conrad U. Brunner, 2015).

The designation of the energy efficiency class consists of the letter “IE” (short for international energy efficiency class), directly followed by a numeral representing the qualification according to the definition in IEC 60034-30, Table 2.3.3. Four efficiency classes are proposed, namely Standard Efficiency (IE1), High Efficiency (IE2) equivalent to EPAct, Premium Efficiency (IE3), and Super-Premium Efficiency (IE4). (Aníbal T. de Almeida, Fernando J. T. E. Ferreira, João A. C. Fong, Conrad U. Brunner, 2015). IE5 was not yet defined, but according to IEC standard, it is envisaged for potential products in a future edition of IEC 60034-30.

Efficiency levels	**Designation**	**Definition**
Standard efficiency	IE1	Motors with a rated full-load efficiency equal to or exceeding the limits listed in IEC 60034-30-1, table 5.4.1
High efficiency	IE2	Motors with a rated full-load efficiency equal to or exceeding the limits listed in IEC 60034-30-1, table 5.4.2
Premium efficiency	IE3	Motors with a rated full-load efficiency equal to or exceeding the limits listed in IEC 60034-30-1, table 5.4.3
Super-Premium efficiency	IE4	Motors with a rated full-load efficiency equal to or exceeding the limits listed in IEC 60034-30-1, table 5.4.4
Ultra-Premium efficiency	IE5	Envisaged for a future edition of standard IEC 60034-30-1, Annex A

Table 2.3.3 IE efficiency classification (Source: IEC)

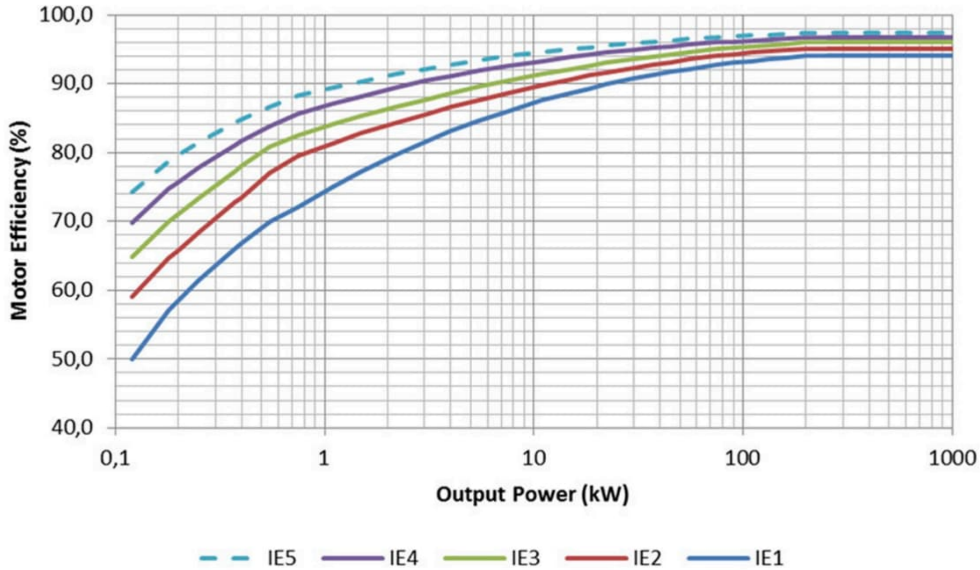

Figure 2.3.4 – Efficiency level in the IEC 60034-30-1:2014 Classification standard, 50Hz, 4 poled motor (source: IEC 60034-30-1:2014)

Directives and regulations are national, country-specific, or regional. MEPS (Minimum Energy Performance Standards) for electrical motors have played an essential role in helping countries to meet their energy efficiency and carbon dioxide emissions targets. For motor users, MEPS have led to an overall increase in motor efficiency and made it easier to compare efficiency levels between manufacturers.

These benefits have prompted many countries around the world to adopt their own MEPS. However, the actual requirements vary between the different countries (Figure 2.3.5).

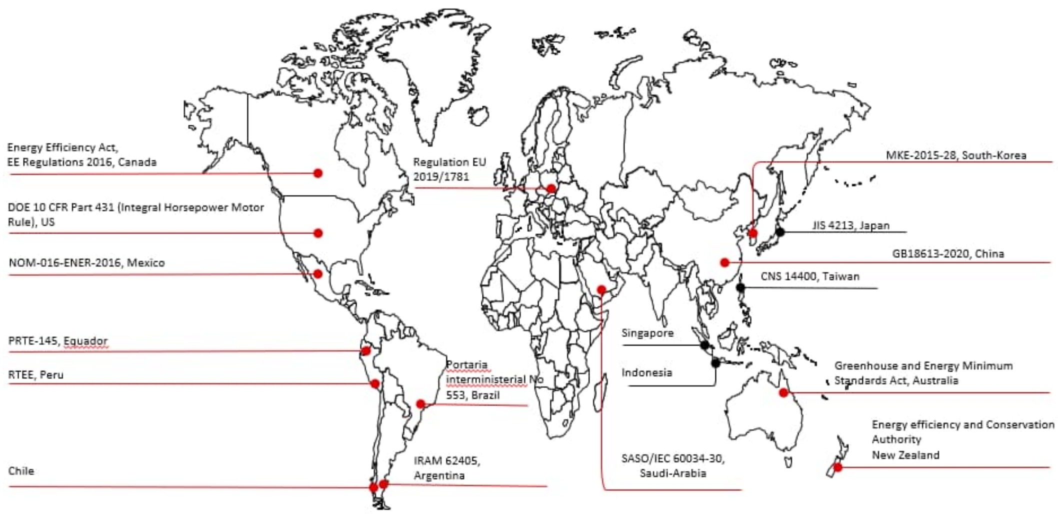

Figure 2.3.5 – MEPS requirements in different countries (Source: ABB)

Since they are created by governing bodies there is no true alignment and standardization when it comes to the marking, registration and validation of products. This produces more challenges not only for motor manufacturers, but all equipment manufacturers delivering their incorporated motor products or spare parts around the world.

2.4 Europe EE1st

According to the European Environment Agency, the EU was the world's third biggest greenhouse gas emitter after China and the United States and followed by India, Russia, and Japan in 2015. Reducing energy consumption and achieving energy savings is essential to deliver the European Green Deal (EU 2019), a roadmap for Europe becoming a climate-neutral continent by 2050. The "Energy efficiency first (EE1st) principle" was set as one of the key guideline principles of the climate governance and energy policy intended to ensure secure, sustainable, competitive, and affordable energy supply in the European Union. The Communication on the European Green Deal (EU 2019) states that energy efficiency must be prioritized and identifies energy efficiency as one of the key solutions across sectors that will help to achieve climate neutrality at the lowest possible cost (EU 2021).

The energy efficiency first (EE1st) principle is defined in Article 2(18) of the Regulation on the Governance of the Energy Union and Climate Action (EU 2018), which also requires member states to take into account the principle in the integrated National Energy and Climate Plans (NECPs). The Energy Efficiency Directive (EU 2018) contributes to the implementation of the principle. (EU 2021)

2.5 EU Ecodesign Directive

The Europe Ecodesign requirement and Directive was set into being to ensure that consumers have access to products with high energy efficiency performance but low environmental impact. Ecodesign requirements integrate environmental aspects and life cycle thinking into the product design phase. In practice, Ecodesign requirements usually concern the energy consumption of products during use and has gradually become stricter. If a product does not meet the applicable ecodesign requirements it cannot be placed on the market or put into service in the EU.

The Ecodeisgn requirements for individual product groups are created under the Europe Unin Ecodesign Directive in a process coordinated by the European Commission, Rules and Requirements for Energy Labelling and Ecodesign 2022. Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 established a framework for the setting of ecodesign requirements for energy-using products and amended Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council (EU 2005). It has been substantially amended and is currently no longer in force since further amendments and is strictly limited to the extension of the scope of application of that directive to include all energy-related products (EU 2009). The directive was recast as Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 and is currently in force and should be substantially amended and recast in the interests of clarity. This directive seeks to achieve a high level of protection for the environment by reducing the potential environmental impact of energy-related products, which will ultimately be beneficial to consumers and other end-users. Sustainable development also requires proper consideration of the health, social and economic impact of the measures envisaged. Improving the energy and resource efficiency of products contributes to the security of the energy supply and to the reduction of the demand for natural resources, which are preconditions of sound economic activity and therefore of sustainable development. (EU 2005).

The regulations under the Ecodesign Directive are applicable to 31 product groups. Provisions for the ecodesign of servers and data storage products, electric motors and variable speed drives, refrigerating appliances, light sources and separate control gears, electronic displays, household dishwashers, household washing machines and household washer-dryers, and refrigerating appliances with a direct sales function were established in the EU Official Journal L 68, 26.2.2021, p. 108–148, Commission Regulation 2021/341, with the commission regulations listed as an overview in Table 2.4.1. In this research, we are focusing on commission regulations applicable to electrical motors under Ecodesign framework Directive 2009/125/EC.

As an alternative, industry sectors may also sign voluntary agreements to reduce the energy consumption of their products. The Commission formally recognizes such agreements and monitors their implementation.

The ecodesign directive also establishes a consultation forum to advise stakeholders on the implementation of the directive. The list of members includes representatives from EU countries, industry and civil society. The group is open for observers from candidate and European Free Trade Association (EFTA) countries, and from organizations that have a legitimate interest in the discussion (EU 2022)

Overview of existing EU Ecodesign, Energy Labelling and Tyre Labelling measures (March 2022)

Product group[1]	Type(s) of measure[2]			Relevant acts/legislation[3]
	ED	EL	VA	
Horizontal: framework legislation	X			Directive 2009/125/EC
Horizontal: framework legislation		X		Regulation (EU) 2017/1369
Horizontal: Guidelines on self-regulation/VAs			X	Recommendation (EU) 2016/2125
Horizontal: Standby / off mode consumption	X			Regulation (EC) 1275 /2008
Welding equipment	X			Regulation (EU) 2019/1784
Power transformers	X			Regulation (EU) 548/2014
Electric motors + var. speed drives	X			Regulation (EU) 2019/1781
Water pumps	X			Regulation (EU) 547/2012
Circulators	X			Regulation (EC) 641/2009
Industrial fans	X			Regulation (EU) 327/2011
Professional refrigeration equipment	X			Regulation (EU) 2015/1095
Air heating/cooling products	X			Regulation (EU) 2016/2281
External power supplies	X			Regulation (EU) 2019/1782
Computers	X			Regulation (EU) 617/2013
Servers and data storage products	X			Regulation (EU) 2019/424
Simple set-top boxes	X			Regulation (EU) 107/2009
Vacuum cleaners	X			Regulation (EU) 666/2013
TVs/Electronic displays	X			Regulation (EU) 2019/2021
		X		Regulation (EU) 2019/2013
Light sources and control gears	X			Regulation (EU) 2019/2020
		X		Regulation (EU) 2019/2015
Dishwashers	X			Regulation (EU) 2019/2022
		X		Regulation (EU) 2019/2017
Washing machines + washer-dryers	X			Regulation (EU) 2019/2023
		X		Regulation (EU) 2019/2014
Tumble driers	X			Regulation (EU) 932/2012
		X		Regulation (EU) 392/2012
Domestic cooking appliances: ovens, range hoods, hubs (NB: no label for	X			Regulation (EU) 66/2014
hubs)		X		Regulation (EU) 65/2014
Household fridges and freezers	X			Regulation (EU) 2019/2019
		X		Regulation (EU) 2019/2016
Refrigerating appliances w. a sales function	X			Regulation (EU) 2019/2024
		X		Regulation (EU) 2019/2018
Ventilation units	X			Regulation (EU) 1253/2014
(labelling for residential only)		X		Regulation (EU) 1254/2014
Space and combination heaters	X			Regulation (EU) 813/2013 Council Directive 92/42/EEC
		X		Regulation (EU) 811/2013
Water heaters/storage tanks + solar devices	X			Regulation (EU) 814/2013
		X		Regulation (EU) 812/2013
Local Space Heaters	X			Regulation (EU) 2015/1188
(labelling in same regulation)		X		Regulation (EU) 2015/1186
Solid fuel space heaters	X			Regulation (EU) 2015/1185
Solid fuel boilers	X			Regulation (EU) 2015/1189
		X		Regulation (EU) 2015/1187
Air conditioners (incl. air to air heat pumps)	X			Regulation (EU) 206/2012
		X		Regulation (EU) 626/2011
Tyres		X[4]		Regulation (EU) 2020/740
Imaging equipment			X	COM (2013) 23
Game consoles			X	COM(2015) 178
Total: 31 specific product groups ,excl. standby	**29**	**15**	**2**	**50**

Table 2.5.1 – Overview of existing ecodesign, energy labelling and tyre labelling measures (source: EU 2022)

2.6 Motor efficiency requirements in Europe and Ecodesign regulation

The realization that energy usage must become more sustainable and efficient is not new. The EU has played a part in promoting energy efficiency for two decades, and it is a vision shared by many parliamentarians. The Ecodesign Directive is the European Union legal instrument establishing the framework which defines the rules for setting product-specific requirements/legislation on energy efficiency and other parameters (Anibal T. de Almeidaa, Joao Fonga, Hugh Falknerb, Paolo Bertoldic, 2017).

Step started in the European Union with first a voluntary agreement to reduce the least efficienct motors was supported by the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP), and the European Commission was established in 1998 and signed by 36 motor manufacturers, representing 80 percent of the European production of standard motors (Anibal T. de Almeidaa, Joao Fonga, Hugh Falknerb, Paolo Bertoldic, 2017). Further studies before the end of the agreement in 2009 were continuously conducted and highlighted the importance of minimum energy performance standards (MEPS) applied to electrical motors produced in Europe, through EU Commission Regulation 640/2009 under the framework Directive 2009/125/EC.

Under such a framework, Commission Regulation 640/2009 was established, which first defined the specific requirements of ecodesign in electrical motors and electrical variable speed drives (VSD). Commission Regulation 640/2009 was adopted on 22nd July 2009 and amended by Commission Regulation 4/2014, which established the ecodesign requirements for products placed on the market and the putting into service of motors, including those integrated in other products. (EU 2014)

The minimum efficiency performance requirements of electrical motors were set out as follows, and the efficiency levels were defined according to the IEC (International Electrotechnical Commission) standard 60034-30:2008.

- rated output power 0,75kW to 375kW must meet minimum efficiency level IE2 from 16th June 2011,

- rated output power 7,5kW to 375kW must meet minimum efficiency level IE3 or minimum efficiency level IE2 when equipped with a variable speed drive, from 1st January 2015
- rated output power 0,75kW to 375kW must meet minimum efficiency level IE3 or minimum efficiency level IE2 when equipped with a variable speed drive, from 1st January 2017

The market was developed towards the energy efficiency movements in electrical motors after the EU adopted framework Directive 2009/125 and Commission Regulation 640/2009, which entered into force from 2011 to 2017 (Figure 2.6.1).

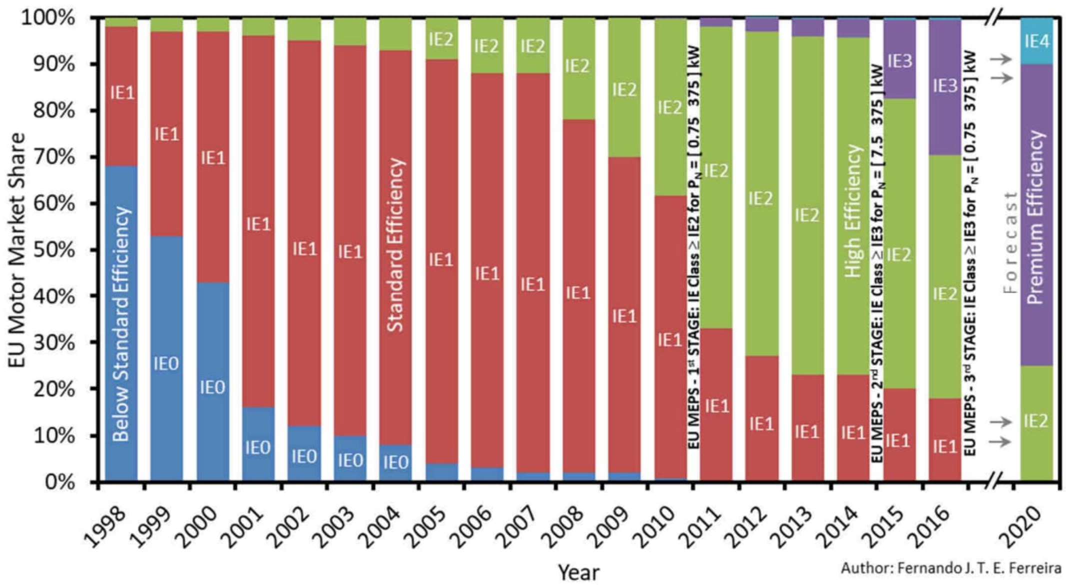

Figure 2.6.1 – Evolution of the EU motor market in terms of efficiency (0,75kW-375kW), in the period 1998-2016 (CEMEP), revised from Fernando J.T.E. Ferreira (2018)

2.6.1 Evolution of EU motor efficiency

In 2011, a dedicated study was conducted by the Commission to review the effectiveness of (i) Directive 2009/125/EC and its implementing measures, (ii) the Ecodesign methodology, (iii) the threshold for implementing measures as described in Article 15 of the Directive, (iv) market surveillance, and (v) self-regulation measures. A separate specific study was completed in order to update the ecodesign methodology, which has resulted in the methodology for the ecodesign of energy-related products (MEErP). The report of the 2012 review was submitted to the European Parliament and the Council, followed the progress of this report through the decision -making procedure (EU 2012).

The evaluation study concluded that, in general, the Ecodesign Directive is achieving its policy objectives (the free movement of goods and environmental protection) and that no revision of the directive is deemed appropriate at the moment or necessary to increase its effectiveness and that of its implementing measures. On 22 January 2014 the European Commission presented and communicated the new policy framework on climate and energy in the period from 2020 to 2030. "A reduction in greenhouse gas (GHG) emissions by 40% below the 1990 level, an EU-wide binding target for renewable energy of at least 27%, renewed ambitions for energy efficiency policies, a new governance system and a set of new indicators to ensure a competitive and secure energy system are the pillars of the new EU framework. The framework aims to drive continued progress towards a low-carbon economy and a competitive and secure energy system that ensures affordable energy for all consumers, increases the security of the EU's energy supplies, reduces our dependence on energy imports and creates new opportunities for growth and jobs, by taking into account potential price impacts on the longer term." (EU press release, 2014)

This framework was built on the existing "climate and energy package" of targets for 2020 as well as Commission's 2025 roadmap for energy and low-carbon economy. It followed the the Commission's March 2013 Green Paper, which launched a broad public consultation on the most appropriate range and structure of climate and energy targets for 2030. One of the key elements of the 2030 policy framework set by the Commission is energy efficiency. Improved energy efficiency will contribute to all objectives of EU energy policy, and no transition towards a competitive, secure and sustainable energy system is possible without it. The role of energy efficiency in the 2030 framework will be further considered in a review of the Energy Efficiency Directive due to beconcluded later this year. The Commission will consider the potential need foramendments to the directive once the review has been completed. Member states'national energy plans will also have to cover energy efficiency (EU press release, 2014).

The communication from the Commission COM (2016) 773 (2) ecodesign working plan established by the Commission in application of Article 16(1) of Directive 2009/125/EC sets out the working priorities under the ecodesign and energy labelling framework for the period 2016-2019. The ecodesign working plan identifies the energy-related product groups to be considered as priorities for the undertaking of preparatory studies and eventual adoption of implementing measures, as well as the review of Commission Regulation (EC) No 640/2009 (3).

The measures from the work plan indicated a potential excess of 260 TWh of annual energy saving by 2030, and annual greenhouse gas emission reduction of approximately 100 million tons by 2030. An estimated 10 TWh of annual energy saving in 2030 was listed for electrical motors in the work plan. Regulation (EC) No 640/2009 has established the ecodesign requirements for electrical motors, and the review of regulation in technological progress is significant in meeting the targets on energy efficiency and emission goals.

2.6.2 Ecodesign regulation 2019/1781

Since 2019, a number of ecodesign and energy labelling regulations were adopted in regard to the ecodesign requirements for different product groups. Commission Regulation 2019/1781 of 1st October 2019, laid down ecodesign requirements for electric motors and variable speed drives pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Regulation 641/2009 with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products and repealing Commission Regulation 640/2009 (EU 2019).

This regulation establishes the ecodesign requirements for the placing on the market or putting into service of electric motors and variable speed drives, including where they are integrated in other products. Therefore, Commission Regulation 2019/178 is also well known as the name of Ecodesign regulation.

This regulation applies to the following products (Scope, Article 2, Regulation 2019/178):

a)- induction electric motors without brushes, commutators, slip rings or electrical connections to the rotor, rated for operation on a 50 Hz, 60 Hz or 50/60 Hz sinusoidal voltage, that:

- (i) have two, four, six or eight poles;
- (ii) have a rated voltage U N above 50 V and up to and including 1 000 V;
- (iii) have a rated power output P N from 0,12 kW up to and including 1 000 kW;
- (iv) are rated on the basis of continuous duty operation; and
- (v) (v) are rated for direct on-line operation

b)- variable speed drives with 3 phases input that:

- (i) are rated for operating with one motor, as referred to in point (a), within the 0,12 kW-1 000 kW motor rated output range;
- (ii) have a rated voltage above 100 V and up to and including 1 000 V AC;
- (iii) have only one AC voltage output.

The regulation sets the minimum efficiency levels applied to low-voltage induction electric motors to be implemented in two steps starting on 1st July 2021. The second stage, which expands the scope further and increases the efficiency requirements for motors, commences two years later, on 1st July 2023.

- rated output power equal to or above 0,75 kW and equal to or below 1000 kW must meet minimum efficiency level IE3 from 1st July 2021,
- rated output power equal to or above 75 kW and equal to or below 200 kW must meet minimum efficiency level IE4 from 1st July 2023

If a motor does not meet these minimum efficiency requirements, it cannot be placed on the market or put into service in the EU with CE marking or be traded in the EEA without restrictions. European countries that are not EU members have adopted all or most of the EU directives and regulations in their own legislation, which means that the CE marking is recognized in those countries.

3 Empirical study

3.1 Case company background

This study was carried out in the ABB IEC Low Voltage Motor Division, which is a part of the ABB Motion Business Area. As a technology pioneer and market leader, ABB continues to be recognized around the globe for its work towards a more productive, sustainable future. ABB business is addressing the world's energy challenges by helping customers become more energy efficient and productive, and in helping to succeed, ABB contributes to a more sustainable future. Since 2020, ABB has established the strategic framework Energy Efficiency Movement, which brings together all stakeholders to innovate and act for a more energy efficiency, regenerative, adaptive world (ABB Energy Efficiency Movement, 2022). It invites companies and organizations from all sectors of society which are willing to commit to concrete action in enhancing energy efficiency and to move to a more sustainable world. Energy efficiency is not an if, it is a must. A core part of ABB Motion business, high-efficient motors play a vital role in the energy efficiency movement and reduce energy consumption through providing advanced technologies, products, solutions and continuously driving innovation and promotion in energy efficiency.

ABB IEC Low Voltage Motors is one of the global market leaders, delivering more than one million motors annually on a global scale to provide customers with optimum solutions in all industrial segments and a wide range of applications (Table 3.1.1). The ABB product portfolio has been continuously developed according to core market and customer needs, and it has incentivized rapid adoption to push the boundaries of energy efficiency. In particular, progress and evolution are significantly generated through directives, regulations, and standards, depending on national registration. For instance, alongside European motor policy development, the ABB IEC low voltage motor product portfolio has been reshaped in terms of energy efficiency classification for more than decade (Figure 3.1.2).

Product group	Product types	Eff.	Serve to industries
Process performance motors	Aluminum frame induction motors Cast iron frame induction motors Water cooled motors Permanent magnet motors Synchronous reluctance motors	IE2 IE3 IE4 IE5	Cement and mining Chemical, oil and gas Food and beverage E-mobility Marine Metals Rails Water and wastewater
General performance motors	Aluminum frame induction motors Cast iron frame induction motors	IE2 IE3	
Motors for explosive atmospheres	Dust-ignition proof motors Flameproof motors Increased safety motors Motors for underground mining	IE2 IE3	
Industry and application specific motors	Brake motors High dynamic performance motors Food safe motors Motors for heavy electric vehicles Roller table motors Smoke extraction motors Traction motors	IE2 IE3	

Table 3.1.1 – Overview of the ABB IEC low voltage motor product portfolio (source: ABB)

Figure 3.1.2 – Product portfolio development along the Ecodesign timeline (Source: ABB)

The recent major development on product portfolio was initialized in 2020, after the European Union adopted Ecodesign Regulation 2019/1781 on October 2019. Within the organization, the Ecodesign program was established at the beginning of 2020 to work on product portfolio development in transitioning from IE2 class to IE3 class motors, which must be ready for Ecodesign Regulation 2019/1781, with the first implementation on 1st July 2021, and further development will be continued to focus on Ecodesign Regulation 2019/1781, second implementation, on 1st July 2023, forcing the market transformation from IE3 class motors to IE4 class motors on rated output power from 75kW to 200 kW. The program is concentrated on the core dimensions and activities in product portfolio management such as strategic alignment, adoption of guidelines (i.e. standards, regulations), market demand analysis, and new product development (NPD). The activities and findings throughout the program formed the empirical and instrumental material for the research topics.

3.2 Methods

This section presents the methods used in collecting data, which includes data collection, analysis and explains the reliability and validity of the study as well. This research takes both qualitative and quantitative approaches in order to develop new understanding of the phenomenon of the impact of efficiency policies on energy consumption and the market trend of electrical motors driven by efficiency policy development. The methods used in this research comprised 1) a combined systematic review of expertise from the case company and narrative literature review, and 2) a structured market survey. Qualitative research provides insights into the questions under study and concepts and hypotheses for potential quantitative research, which quantifies the problem statement through numerical data. The table below presents the focus and differences in viewpoint of combined qualitative and quantitative methods performed in this research.

The qualitative approach was carried out aimed at identifying and analyzing relevant studies regarding the integration of the themes “product portfolio management”, “energy efficiency”, “ecodesign regulation”, and “electrical motor market trend”, which serve as basis for the elaboration of the problem statement. Empirical data gathered non-standardized or non-numerical information to identify business strategic vision and planning, which serve as a basis for the correlation of quantitative analysis, and the process is natural and communicative.

Then a quantitative approach is used as a systematic investigation of the phenomena using business results such as shipping units from past order intake, and a structured survey to gather quantified market forecast data for future demand. The results were depicted numerically to illustrate the actual market transformation in efficiency classification and predict the future of the changes accordingly.

Qualitative method	Quantitative method
To understand energy efficiency as a crucial role in the industrial sector, particularly in electrical motor systems	To illustrate the case company electrical motor delivery transition in efficiency classification during the period of Ecodesign regulation development
To observe electrical motor efficiency policy development, including industry standards	To compare existing research on electrical motor market share in efficiency class before the adoption of Ecodesign regulation withthe actual findings in the empirical case
To observe the impact of electrical motor efficiency policies on product portfolio development	To identify future market trends and project product portfolio transformation in the case company

Table 3.2.1 – Objectives of the research methods

3.3 Data collection

The aim of this research is to outline the business practices that manifest the trend of electrical motor market transformation in term of energy efficiency. The main purpose of reliable data is to reveal the patterns of energy efficiency policies such as Ecodesign regulation being adopted into business practice, particularly in the management of product portfolio. Product portfolio management is relevant in terms of companies coherently deciding on their marketing strategies (Marco Antonio Paula Pinheiro, Daniel Jugend, Luiz Carlos Dematte Filho, Fabiano Armellini date), for example, how to identify the market trend as translated in the product offering, and the degree of product portfolio that constitutes the market. The key dimensions of the framework for the integration of ecodesign on product portfolio management are in three aspects: i) Guides, methods and tools; 2) Organizational; and 3) Strategic. Hence, the data collected in this study had the purpose of opening out the research characteristics in the form of being exploratory and descriptive by utilizing quantitative and qualitative approaches.

Qualitative approaches were applied to open up questions to enhance the understanding of the phenomenon under study and summarize the case company strategic development in terms of the product portfolio as well as the adoption of energy efficiency regulation. As the author has been dedicated for the past two years to leading the case company product portfolio development project in the form of the Ecodesign program, aiming at implementing product adoption of the Ecodesign regulation in the case company, relevant studies and processes had been carried out during the business practice. Therefore, qualitative data was condensed from the findings and information unfolded during the Ecodesign program itself. This involved all business activities with all stakeholders such as global standard experts, product managers, business function managers, and domain expertise from the responsible project managers and core management team who comprise the steering committee of the Ecodesign program. The activities and findings throughout the program were also fundamental and instrumental in facilitating to the whole research process in terms of literature review, data collection, data analysis, and summary.

Instead of conventional academic research methods in qualitative data collection such as interviews or questionnaires, the dedicated Ecodesign program was established and semi-structured interviews were implemented in a narrative manner through the business practices; for example, project meetings and steering committee meetings during the Ecodesign program from early 2020. The program was focused on the exploration of minimum efficiency performance requirements globally and in term of Ecodesign regulation in Europe, product portfolio development needs driven by regulations and market demands, and operational execution through organization, marketing, and communications. This resulted in the author gaining an in-depth understanding of strategic alignment in translating governmental strategy in energy efficiency promotion to company strategy into a set of products to achieve a current and sustainable future, product portfolio management practice and product implementation in business processes: thus reconfiguring the theoretical findings and deploying them accordingly in business practice in the case company.

There were more than ten projects found under the Ecodesign program and more than thirty semi-structured interviews were conducted to gather knowledge, expertise, and information from different perspectives within all the core business functions such as sales, marketing and communication, product management, research and development, and operations, including production plants. Furthermore, strategic planning and decisions in energy efficiency development were also explained and integrated throughout the entire project life cycle, which was steered by the top management team, including the president of the division IEC Low Voltage Motors. In order to minimize the limitations of recalling the memory of expert data collected during the Ecodesign program since 2020, secondary data was also reviewed and collected to support and clarify the company strategic development in terms of energy efficiency movement. This included annual reports, market intelligence reports, and press releases covering the actions and responses related to enhancing energy efficiency first principles.

Research questions	Data	Details
What kinds of impacts do the existing electrical motor efficiency policies have on ABB?	- Case company 20 professional industry association publications	- 13 external energy efficiency movement white paper publications - 7 internal analysis publications
	- Case company Ecodesign program deliverables and evaluations from 5 product development projects	- 5 internal technical notes of regulation requirements (i.e., Ecodesign 2019/1781, China GB18613) and industry standards analysis (i.e., CEMEP, IEC) - 5 internal new product development projects specifications (i.e., MRS) - 5 internal product portfolio development decision notes
	- Case company product portfolio review	- Scope and categorize products according to regulation requirements (internal and confidential) - Define obsolete products (internal and confidential)
How have policies, especially European Ecodesign regulation, impacted the electrical motor market transformation?	- Case company actual order intake 2019 – 2021	- Shipping units per product types, frame size and efficiency classification (internal and confidential)
	- Case company market forecast 2022 – 2023	- Market demand estimation from more than 40 countries, analyzed per product types, frame size and efficiency classification (internal and confidential)
	- Third party consultant market analysis	- Key macro market trends (internal) - Omdia Low Voltage Motor Report 2021 Analysis, November 2021 (internal, all rights reserved, Omdia) - Omdia test forecast IE4 motor report 2021 (internal, all rights reserved, Omdia)

Table 3.3.1 – Empirical data used for research purposes

The most challenging part of this research, as well as being an essential gap identified in existing research, was to identify the empirical market demand trend of the electrical motor product portfolio in term of energy efficiency. Market demand analysis is also the key initiator to define product portfolio and core activities within the Ecodesign program in the business process of the case company, which highlighted “outside in thinking and acting” as a part of the company core strategy. Therefore, quantitative data collection was focused on description of market trend analysis of ABB IEC low voltage motors, which are influenced by Ecodesign regulation. It does not literately collect quantitative data for research purposes, but is a key step in identifying the product portfolio development needs and implementation actions to maximize the value gain for the business. The quantitative market data were collected from three perspectives: 1) actual order intake and delivery records from the past in the case company ERP system; 2) market demand survey responses that forecast the future demand for specific products in terms of efficiency classification; 3) in addition, external sources such as market intelligence reports disbursed by the case company from the third party consultant company, IHS Markit, which was acquired by Informa in August 2019 and is now part of Omdia.

A market survey form was conducted to collect market demand forecasts in sales represented areas in Europe. The survey was sent to 12 area sales managers, who are the most experienced experts and representatives of the market voice from ABB IEC LV Motor business perspectives. In the survey, the respondents went through a review of the strategic guidelines of Ecodesign regulation, scope analysis, and their interpretation from the researcher as to what was expected, and the answers were ascertained. The survey was developed based on the reality on the ground about the ABB IEC low voltage motor product portfolio and business model. The portfolio was further designed within the targeted scope of product and supply demand that was effected by the Ecodesign regulation and energy efficiency management adopted by the industry.

The demand survey was designed as a grouping of a three frame size range, and under each frame size range the product types were categorized under product groups, which belong to four main product families.

The survey mainly consists of the following structure

- Product types grouped under the product families General performance induction motors; Process performance induction motors; Motors for explosive atmosphere; Synchronous reluctance motors; and IEC Food safe stainless-steel motors.
- The product types were grouped according to IEC shaft height size in low voltage motors, namely 63-132, 160-250, 280-500.
- Each product type row was indicated as a proportion of the total volume of 2021 actual order in each product family, and a corresponding demand forecast in 2022 – 2023 was required to be entered as a percentage split quarterly.
- Key assumptions were required to be entered as descriptive or estimation.

The answers to the survey were provided by 12 respondents who are the area sales managers responsible for sales and operation planning as the core business process. Although the respondents represented only a small number of the personnel, their responsible areas contributed more than 50 percent of sales revenue of the total business in local sales representative units.

It is to be noted that the demand forecast data from Russia and Ukraine were eliminated from the scope of the survey because of the military operations in those areas during the survey period from February 2022. ABB stopped taking orders in Russia shortly after the war broke out. At the time of writing, ABB has announced it will exit the Russian market.

The survey had a 100 percent response over a two month period which provided the respondents sufficient time to collect reliable input directly from the local markets and sales units in each country (Table 3.3.2)

Survey area	Countries
Northern Europe	Norway, Denmark, UK, Ireland, Sweden, Finland, Baltics
Southern Europe	Italy, Spain, Portugal, Netherlands, Belgium, Greece
Central Europe	Germany, Poland, Czechia, Austria, Switzerland, Slovenia, Slovakia, Belarus, Kazakhstan, Ukraine, Turkey, France, Bulgaria, Hungary, Israel, Serbia, Croatia, Romania
Asia	Australia, Indonesia, Malaysia, Philippines, Singapore, Thailand, Japan, South Korea, Vietnam

Table 3.3.2 – Market demand survey countries

3.4 Data analysis

According to Marshall and Rossman (1990), data analysis is the process of bringing order, structure, and meaning to the mass of collected data, and further go on to describe it as messy, ambitious, and time-consuming, but yet a creative and fascinating process. In this study there were several mixed approaches to analyze the preliminary data, but the ultimate decision on the approaches applied to the company data analysis was through the patterns that constitute the development of Ecodesign regulation and construction of the case company product portfolio. Following a a research method that combined qualitative and quantitative approaches, the data analysis was also divided into two major phases.

First, because the qualitative data in this research were factual concentrations of legislative policies such as Ecodesign regulation and the case company business process, the observation notes and summary were taken to understand the case company strategy in product portfolio development in terms of energy efficiency promotion and outlined in the framework of implementation. The analysis was combined and followed by a theoretical review of Ecodesign regulation evolution, and this enabled a description of the case company product portfolio roadmap driven by the Ecodesign regulation development.

A quantitative model often serves three purposes, namely description, forecasting and decision-making. (Philip Hans Franses, Reichard Paap, 2001); therefore, in the second phase, the quantitative data for thematic analysis was subjected to the outcomes of

i) transcribing company market intelligence data and historical delivery data in terms of product efficiency classifications.
ii) foresting the detailed market trends through the specific classifications of energy efficiency and case company product portfolio.

The challenge in this section was to transcribe massive raw data into a condensed form that would describe the product portfolio transformation in terms of efficiency classification. Typically, in quantitative research, the conclusion concerns the impact of explanatory variables on relevant elements, where we focus only on revealed preference data (Philip Hans Franses, Reichard Paap, 2021). To be more precise of the viewpoint to be explained and described in this company case, the data was grouped according to product types indicate the efficiency classification and output power range which is relatively refer to frame size range (Table 3.4.1).

The analysis of and conclusions on the data defined specific target demand survey groups of products and volume proportion are based on an actual order in 2021, so the demand survey respondents can be used to calculate the estimation of demand forecast based on real data.

Product groups	Product types	Regulation 2019/1781 scope
General performance induction motor	IE2 Aluminum frame IE2 Cast iron frame	0,12kW to 0,75kW (not includes 0,75kW)
	IE3 Aluminum frame IE3 Cast iron frame	0,75 – 1000kW
	IE4 Aluminum frame IE4 Cast iron frame	75 – 200kW

Process performance induction motor	IE2 Aluminum frame IE2 Cast iron frame	0,12kW to 0,75kW (not including 0,75kW)
	IE3 Aluminum frame IE3 Cast iron frame	0,75 – 1000kW
	IE4 Aluminum frame IE4 Cast iron frame	75 – 200kW
Motors for explosive atmosphere	IE2 Aluminum frame IE2 Cast iron frame	0,12kW to 0,75kW (not including 0,75kW)
	IE3 Aluminum frame IE3 Cast iron frame	0,75 – 1000kW
	IE4 Aluminum frame IE4 Cast iron frame	75 – 200kW
Water cooled motors	IE3 Water cooled frame	0,75 – 1000kW 0,75 – 1000kW

Table 3.4.1 – Data analysis based on product groupings under the scope of Ecodesign regulation

3.5 Validity and reliability of the research

The validity was built into the research within different phases from the data collection, data analysis and interpretation. The following procedures were used to validate the instruments and data.

Content validity and internal validity

The content validity is usually used for effectively measuring different elements, skills, expertise, and behaviors, and to the end the research instruments and the data might be reviewed by experts in the field of research (Mohanmmad Zohrabi, 2013). Internal validity in this research is concerned with the consequences of the findings in the use in practice of the case company for business purposes; for example, the results of the market demand survey were used in decision making about the product development strategy. In this research, the content validity and internal validity were relatively consistent through the author's expertise, triangulation, experts review, member checks, and collaborative mode.

Firstly, the instruments and data were not limited to a single method approach, but mixed methods and various data sources were employed. This research used mixed method approaches whereby both qualitative and quantitative data were simultaneously collected, analyzed, and interpreted. Instruments such as observations and survey were mainly used to collect the data and obtain information that serves the research purpose and objectives. Using different types of procedures through different sources can secure the validity and reliability of the data. These different ways of gathering information can supplement each other and hence boost the validity and dependability of the data (Mohanmmad Zohrabi, 2013). Mainly, from the qualitative data obtained through observation of interactive events and actual occurrences (e.g., the case company Ecodesign program) in the business process and project deliverables, quantitative data were obtained through a structured survey and case company key financial figures: for example, actual order intake. The data analysis and key findings were evaluated and confirmed through triangulation through different resources and techniques in order to elaborate and corroborate.

Secondly, thanks to the support from the case company, the research has involved most of the participants in data collection and analysis as a collaborative mode and, in addition, the research instruments and data were participated in and reviewed by experts, for example, the head of product management, global standard and compliance manager and specialists, the sales and operation planning manager, and a number of area sales managers who are responsible for the business in different countries. Based on their comments and responses, any unclear and obscure content was revised and reworded to overcome complexity, and ineffective data controlled and discarded.

Thirdly, through the author's own expertise, values, and determination to stick to ethical rules and principles, analysis and evaluation was performed as accurately and honestly as possible. The author has been working in the case company for more than ten years, has in-depth knowledge of business practices in the electrical motor market, the product portfolio and business process. More importantly, the author was the business leader responsible for the Ecodesign program in the case company from 2020 and implemented the adoption of Ecodesign regulations in development of the product portfolio. The expert role and business responsibility of the author also naturally brings strong competence and effectiveness to the research content.

Therefore, the quality of these instruments is essential for the quality and acceptability of research, namely the validity. The conclusions researchers draw is based on the information they obtain using these instruments (Fraenkel & Wallen, 2003).

External validity

External validity is taken into consideration in this research with the applicability of the findings in other subjects. The findings are not limited to the conclusions applied to the case company objectives, but also emphasizes their generation beyond the subjects under investigation. For example, the main empirical study focus was on European Ecodesign regulation adoption in the case company product portfolio throughout market transformation; however, the findings also involved the contribution of efficiency policies to energy consumption and environmental impact, related to current research and to new trends in available technologies and products available in the market. The findings explore the possibilities and applicability for consumers, policy makers, business, and researchers to turn to more investigation and investment in terms of the sustainability goals and technology development in a long-term perspective.

Reliability deals with the consistency, dependability, and replicability of the results obtained from a piece of research (Numan, 1999). Typically, in most of the current research, obtaining the results in quantitative analysis was rather straightforward in terms of the numerical data, but in contrast, it was usually more challenging to identify the results from a qualitative perspective due to the fact that the data are in narrative form and subjective. However, to conclude the findings from both qualitative and quantitative approaches was more straightforward than anticipated since the numerical data and qualitative data was gathered from actual business and from legislation. The dependability of the results was further ensured through the techniques employed: the investigator's position, triangulation, and business implementation in internal reliability, and more aspects included for external reliability such as choice of informants, and the methods of data collection and analysis.

Procedures	Methods	Actions taken
Content validity	Triangulation: Instruments and data sources	Observations from Ecodesign program (includes numbers of interviews, deliverables, interactive business process, project activities) Market demand survey Company ERP data Third party consultant data
Internal validity	Author's expertise, responsibility, value, and view	The author was responsible for leading the case company Ecodesign program
	Expert review and validation	Research instruments and data were reviewed by responsible business leaders in product management, sales and markets, standards and compliance, sales and operation planning
	Collaborative mode	Involved most of the participants and respondents in all phases of inquiry, shared ideas and questions with different stakeholders.

	Long-term observation	Observation for qualitative data collection since 2020 when the case company Ecodesign program was initialized
External validity	Applicability of the findings	Extended to other subjects such as impact of global efficiency policies, efficiency promotion barriers in business practice, available technology, and products on the market
Internal reliability	Low inference descriptors and peer examination	Reviewed by experts like product managers, global standard manager, head of product portfolio management.
External reliability	Author's business position and responsibility The choice of informants Methods of data collection and analysis	

Table 3.5.1 – Overview of validity and reliability methods (Numan 1999; Mohanmmad Zohrabi 2013) and actions to affect them in this research.

4 Key findings

4.1 Efficiency policies help energy consumption and emission reduction

There is a rapidly growing demand worldwide for more efficient products to save energy consumption, reduce emissions and help to build a more sustainable future. Well-developed legislation, government policies and efficiency standards are effective ways to improve the environmental performance of products by setting minimum energy efficiency requirements. The case company strongly agrees that current regulatory pressure is one key driver forcing market demand transition towards more efficient product offerings. The case company is strongly engaged and is expecting higher level regulations to be introduced in future markets, driving their product portfolio and organization towards energy efficiency in order to reach the sustainability goals.

According to the IEA Energy Efficiency Report of 2021, there are more than 120 countries which have implemented or are working on developing mandatory standards and labels for key appliances, which contribute significantly to reducing energy consumption, for example electricity. The IEA reported on the major contribution of appliances to reducing total electricity consumption in major economies (Figure 4.1.1).

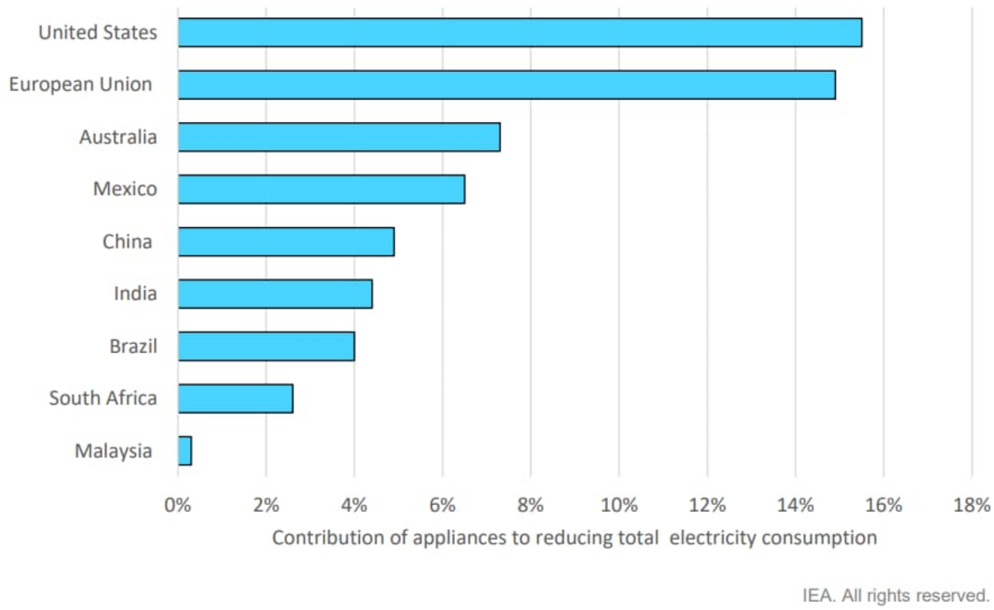

Figure 4.1.1 – Contribution of appliances to reducing total electricity consumption. (Source: IEA 2018)

Among the major leading economies, a wide range of European policies have been launched at European and national level in the last 30 years in the areas of environmental protection and use of natural resources, including energy saving. The European Union has no less than 40 laws, 11 policies and 31 climate targets set to implement mandatory regulations for key appliance (European Parliament, 2021). The effect is so large that 15 percent (IEA 2021) of total electricity generation is saved through those appliance programmes, which included, for example, the energy efficiency first (EE1st) principle as defined in Article 2(18) of the Regulation on the Governance of the Energy Union and Climate Action (EU 2018), and regulations such as Ecodesign, complemented by energy labelling rules, driving market investment and technology innovation in sustainable ways, while reducing energy consumption and CO2 emissions. If such a 15-percentage improvement is achieved by all countries and regions, world electricity consumption will be reduced by 3500 TWh (IEA 2021). In comparison with electricity consumption of 2546 TWh (IEA, 2021) in the European Union, 3500 TWh (IEA 2021) electricity saving is roughly equivalent to supplying the European Union with energy for more than one year, even considering a demand growth of about 4% (IEA 2021).

Reaching the ultimate goals in enhancing energy efficiency takes time since putting legislation, standards and policies in place can take many years, but from the long-term perspective, such efficiency policies and standards play an intensive and most efficient role in accelerating the transition towards a climate-neutral, resource-efficient economy as specific requirements must be met, and regulations force industries to focus on energy efficiency.

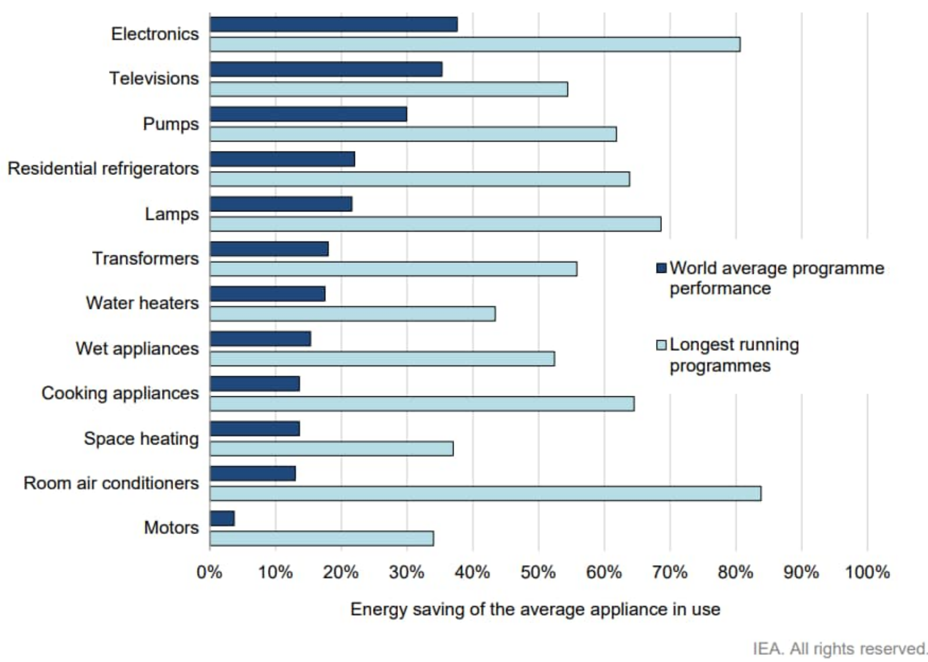

Figure 4.1.2 – Energy saving from energy efficiency standards and labels over the life of programs. (IEA 2018)

4.2 Policies to overcome energy efficiency barriers in business practice

Throughout business practice in electrical motors, there are certainly several barriers between the manufacturers, original equipment manufacturers, and end users which can be overcome by using optimized electrical motor system.

The cost is usually the first consideration from the consumer perspective in the electrical motor market, despite the potential benefits of more efficient motors. Both end users and original equipment manufacturers often find the expense upfront; however, the savings and benefits should be evaluated from the whole life cycle point of view, which is often neglected in decision making. With most end users, the main cost of a motor system is from the energy used to keep the motor running during operation. The purchasing decisions are typically first based on lower cost to make their system cheap without considering the total cost ownership, which includes purchasing price plus cost of operation (Figure 4.2.1.e.g., energy cost, and cost of downtime) and environmental impact.

Similar to end users, original equipment manufacturers, representing a significant market share of motors, usually make purchasing decisions through the department, which is interested in keeping purchasing costs as low as possible in order to satisfy end-user demands, rather than departments such as research and development, where the needs and interests are addressed more in terms of new technologies and products, for example, wanting a more efficient motor driven system to reduce energy consumption to secure long-term benefits.

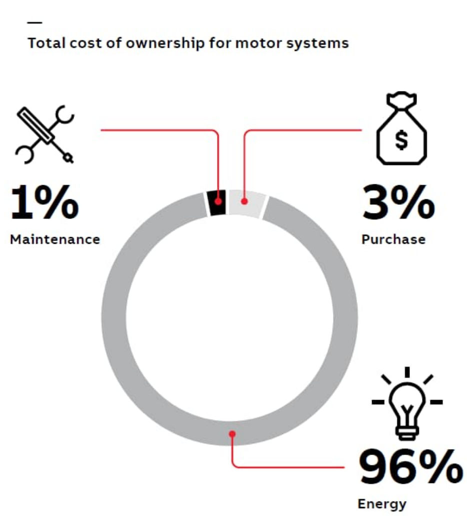

Figure 4.2.1 – Total cost of ownership for motor systems (Source: ABB)

On the other hand, the complexity and variety of electrical motor systems and applications build barriers by requiring in-depth technical skills and expertise to design efficient motor systems. For example, changes to already installed motor systems may cause production interruptions. Such changes usually require additional resources to analyze existing systems on-site before actions take place in actual demand from the production process. Motor manufacturers struggle in the early stages to explain and make users fully understand the benefits of more energy efficient motors, as the decision makers, the purchasing department, usually lack technical staff qualified to understand any potential benefits other than purchasing cost.

Governmental policies are established to achieve well-defined objectives and include mechanisms for measuring. These engage relevant stakeholders in the entire value chain of the life cycle process and fully consider the facts for taking action. The barriers created from conflicts of interests between different stakeholders for higher efficiency motors may be overcome by implementing efficiency policies with legislative force. However, regulation is often not consistent across regions, which complicates efforts and causes additional costs. In the business case, it means that there is a gap between emerging markets and developed markets. For example, Europe, the US and Canada are progressive in terms of government regulations to promote energy efficiency, while Asian and African emerging countries give little political attention to energy efficiency.

4.3 Review of existing research on market transformation

The regulation empowers consumers to purchase the most energy-efficient products from the market, which is the main purpose of the energy efficiency policies, standards, and regulations such as the Ecodesign legislative framework. In doing so, it reduces the energy consumption of consumers and businesses, and furthermore, it safeguards the internal market and prevents unnecessary costs for business and consumers due to divergent national requirements (EU 2016).

4E-EMSA published the results of global sales of higher efficiency motors which have been increasing since 1995, as shown in Figure 4.3.1, and a further estimation to 2019 seen in Figure 4.3.2 predicts the motor market moving towards the higher efficiency class; however, IE2 class motors still dominated as the majority of market share. A similar conclusion was drawn also in later research in 2018, by Fernando J.T.E. Ferreira, Adre M. Silva, V.P.Aguiar, Ricardo S. T. Prontes, who suggested a similar trend where the global market was dominated by IE2 class motors and would even increase by 2021, as shown in Figure 4.3.3

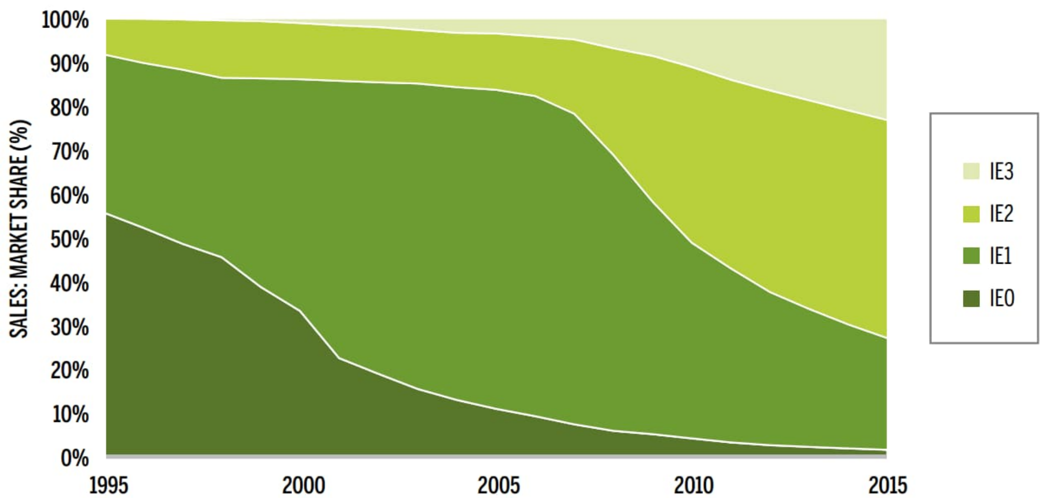

Figure 4.3.1 – Estimated global sales of motors by efficiency class 1995 – 2015 (source: 4E, 2014)

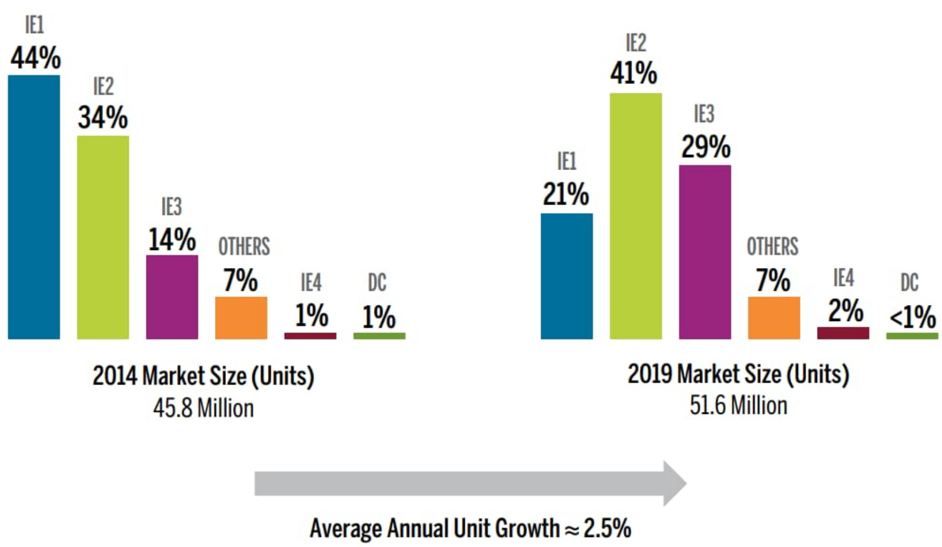

Figure 4.3.2 – Estimated low voltage motor market 2014 – 2019 (Source: IHS, Motor Summit 2014, revised by 4E-EMSA, 2014)

It is interesting to note that the research was conducted before the year 2019, when the European Commission adopted Ecodesign Regulation 2019/1781, which significantly changed the scope of and minimum requirements for efficiency performance. Different from previous research, the author presented strong arguments to claim that after the year 2020, higher efficiency motors than the IE2 class, for example the IE3 class, would take the lead in market trends driven by governmental regulation, in particular, the diffusion of Ecodesign Regulation to global market transformation.

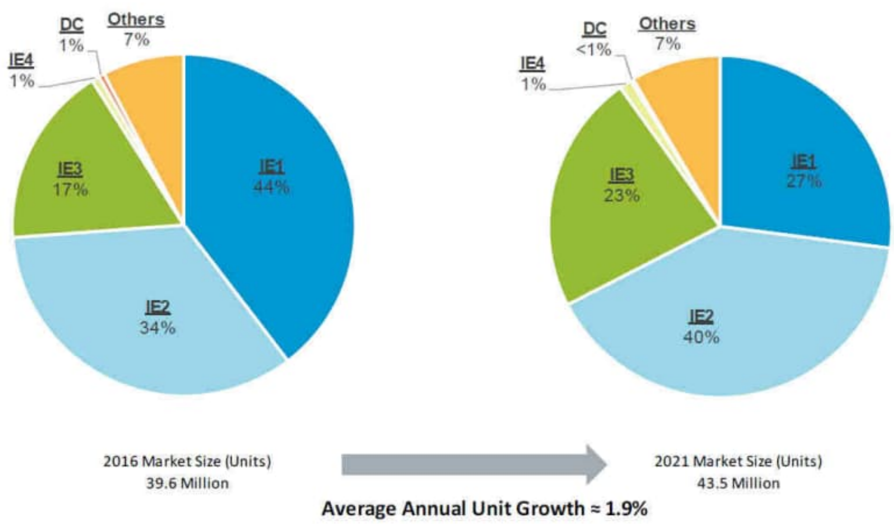

Figure 4.3.3 – Past (2016) and forecast (2021) of motor efficiency class distribution for the global market for low-voltage motors (Source: IHS Markit), revised from Fernando J.T.E. Ferreira, Adre M. Silva, V.P.Aguiar, Ricardo S. T. Prontes (2018)

This research found evidence Figure 4.3.4 to support the fact that IE3 class motors have been leading the market transformation instead of IE2 class motors after 2020. The market share of IE3 class motors more than doubled in 2021 compared to before. Meanwhile, the market share of IE2 class motors dropped from 34 percent to 18 percent which is two times less than the 40 percent estimation which was stated in research in 2018 (Fernando J.T.E. Ferreira, Adre M. Silva, V.P.Aguiar, Ricardo S. T. Prontes, 2018). Furthermore, the distribution of IE4 class motors increased more than double after 2019.

It is relevant and important to highlight that the data used in this study to compare the research conducted by Fernando J.T.E. Ferreira, Adre M. Silva, V.P.Aguiar, Ricardo S. T. Prontes (2018) are from same source, IHS Markit, which was acquired by Informa in August 2019 and is now part of Omdia.

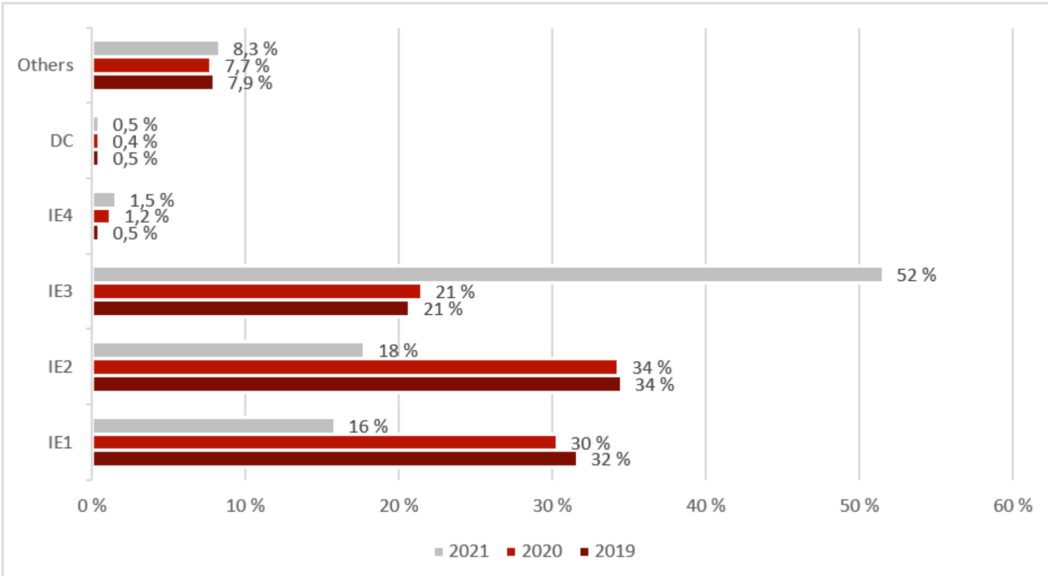

Figure 4.3.4 - Motor efficiency class distribution for the global market for low-voltage motors (Source: Omdia)

The market transformation has obviously accelerated towards a higher efficiency class than the IE2, driven by governmental regulation. For example, since the Commission adopted the Ecodesign Regulation 2019/1781 on October 2019 and first implementation came into force on 1st July 2021, fulfilling the minimum efficiency requirements such as the IE3 class in the European Union is mandatory. Figure XXX. Another example is the China minimum energy performance standard GB18613-2020 released on 29th May 2020 and whose implementation came into force on 1st June 2021. It requires minimum efficiency class IE3 in the similar power output range as Ecodesign regulation 2019/1781. The China standard GB18613-2020 extended the scope of the discussion focus on European regulation, whereby the influence and contribution from the major economies such as China should not be neglected in the analysis of global low voltage motor market transformation.

By specifically focusing on Ecodesign regulation implementation in the case company, a straightforward identification can be made of external factorsinvoved in Ecodesign regulation 2019/1781 and consumer demand drive improvement of decision-making in the portfolio of more-efficient products. The data in Figure 4.3.5 shows significant movement from low efficiency to high efficiency market demand since 2020. In particular, there is a demand for a major proportion of IE2 efficiency motors to turn to IE3 high efficiency motors in the market which is now driven by the Ecodesign regulation which came into force from 1st July 2021 onwards and requires the minimum efficiency level IE3 applied to 0,75kW to 1000kW electrical motors. Meanwhile, the demand for IE4 premium high efficiency motors has started to grow since the next implementation of Ecodesign regulation 2019/1781 from 1st July 2023 will require the minimum efficiency level IE4 applied to 75kW to 200kW electrical motors. It also explains why the demand growth for IE3 high efficiency motors will slow down from 2022 to 2023. In contract, the demand trend for IE4 premium high efficiency motors is climbing faster. Moreover, another finding from the analysisshows the Ecodesign regulation requirement of a minimum efficiency level of IE2 on electrical motors with output power equal to 0.12kW and below 0,75kW. Therefore, a demand for IE2 efficiency motors will still exist, but the trend is clearly declining.

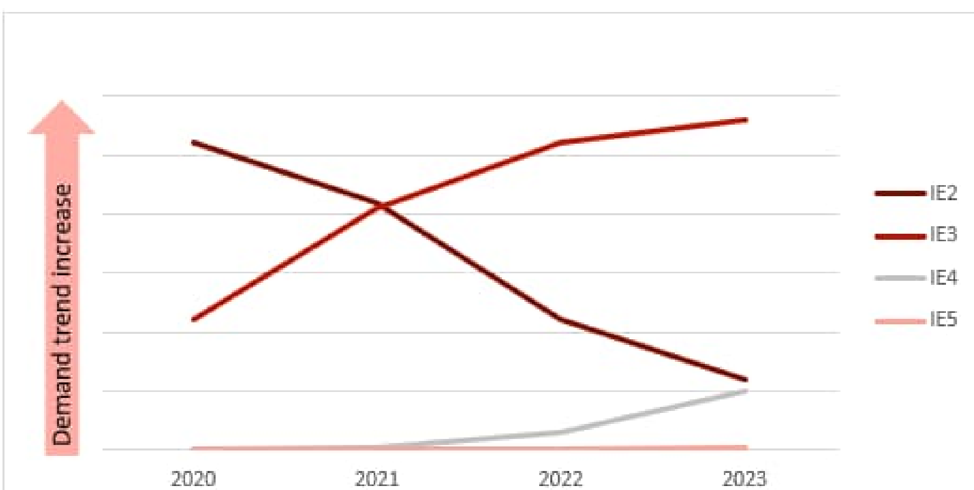

Figure 4.3.5 – Market transformation after Ecodesign adoption: Past (2020-2021) and forecast (2022-2023) for motor efficiency class distribution (Data source: ABB).

4.4 Case company future product portfolio trend

Motor manufacturers like ABB provide optimum products and solutions and continue to drive innovation that improves energy efficiency. This section is concerned with a deeper analysis of the findings that motor efficiency transition in specific product design is driven by market demand which is in turn forced by the requirements of Ecodesign Regulation after first implementation in 2021. It provides a precise explanation of the findings in the first question of a general view of the movement towards efficiency driven by Ecodesign Regulation implementation from 2021 onwards. Typically, in quantitative research, the conclusion concerns the impact of explanatory variables on relevant elements, where we focus only on revealed preference data (Philip Hans Franses, Reichard Paap, 2021). To be more precise, the variables to be explained and described in this company case should not be neglected for product portfolio decision making, and the dimension considers elements such as integration with energy efficiency classification on viewpoints of product types and frame size range. Those aspects are a matrix of descriptive of product portfolio development trends driven by Ecodesign regulation. For instance, Ecodesign regulation defines motor rated output power of 0,12kW to 0,75kW as being below the minimum efficiency level IE2, the power range typically designed to IEC frame size range of 63 to 132; the rated output power equal to 75kW or above and equal to 200kW will fulfill the minimum efficiency level IE4 from 1st July 2023, which means typical low voltage motor design to IEC frame size range of 160 and above, depending on the pole number design. Therefore, the main influence on the trend on IE2 product demand changes comes through the frame size range 63 to 132; IE3 product demand changes through frame size of 160 – 250 and 280 – 500, with IE4 product demands changes being mainly visible on frame size of 160 and above. In addition, when considering business process practice through a demand planning area which involves key sales representatives, it is also essential to draw a roadmap of efficiency demand movement per each demand survey area. Thus, to generate full understanding of product portfolio development trends, the research had to display data in three perspectives as product types and frame size group.

In comparison to the baseline of 2021, the demand trends for 2022 – 2023 were indicated as “Decrease”, “Increase” and “Remain” due to reasons of confidentiality and prohibition of showing detailed quantitative data information,

Viewpoint of efficiency classification.

This viewpoint is seen as one of the most significant aspects for product portfolio decision making when the demand for energy efficiency level changes through Ecodesign regulation effectiveness. It illustrates the trend as shown in Table 4.4.1, where the major demand growth will continue in IE4 premium high efficiency designed motors which are categorized in process performance and general performance product groups. In contrast the demand for IE2 and IE3 product groups is declining, and the research shows a part of the proportional growth in IE4 demands are transferred from these groups. Although the demand for synchronous reluctance motors demand is decreasing, equivalent growth will be expected to transfer to IE5 super premium motors. The results of analysis also showed that the demand for some specific product types jumped from IE2 to IE4 premium efficiency level, such as general performance cast iron motors. Such findings may indicate that consumer expectation goes beyond the efficiency policy minimum requirements, due to the simple fact that higher efficiency performance reduces significant operation costs by saving energy consumption. On the other hand, the decrease in demand for IE2 efficiency motors will keep dropping in the overall product range apart from motors for explosive atmosphere. As noted above, the demand movement on product types provided an indication of transition without consideration of specific output power range, or in other words the frame size range, which will be further displayed in next section.

Motor efficiency class	**ABB Product type**	**Demand trend 2022 – 2023**
IE2	Process performance aluminum motors	Decrease (double digits)
	Process performance cast iron motors	Decrease (single digits)

	General performance cast iron motors Motors for explosive atmosphere	Decrease (double digits) Remain
IE3	Process performance aluminum motors Process performance cast iron motors General performance cast iron motors Motors for explosive atmosphere	Remain Decrease (single digits) Decrease (double digits) Remain
IE4	Process performance aluminum motors Process performance cast iron motors General performance cast iron motors Synchronous reluctance motors	Increase (double digits) Increase (double digits) Increase (double digits) Decrease (single digits)
IE5	Synchronous reluctance motors	Increase (single digits)

Table 4.4.1 – ABB low voltage motor market demand trends on efficiency class, per product type (2022-2023)

Viewpoint of frame size group

A study in the last decade concluded that the share of more energy-efficient motors is higher for larger motors (Waide and Brunner, 2011), and some researchers today, for example, Svetlana Paramonova, Therese Nehler, Patrik Thollander (2021) agreed and further explained that large motors (>375 kW) and small motors (<0.75 kW) represent only a small part of industrial motors in terms of stock units, and most motors thus belong to the group of medium-sized motors (0.75–375 kW). The findings in this study partly support that the market share of higher efficiency class motors is dominated by middle size and large size more than small size motors, and the trend will move towards large size.

As explained above, the main change in Ecodesign regulation from 1st July 2021 is that required rated output power equal to 0,75kW or above and equal to 1000kW fulfills the minimum efficiency level IE3, but in comparison, Ecodesign regulation from 1st July 2023 requires a rated output power equal to 75kW or above and equal to 200kW to fulfill minimum efficiency level IE4. The higher efficiency requirement on the power range 75kW to 200kW reflects in motor frame size typically of 160 to 315 designs to the premium higher efficiency level IE4. Hence, we zoomed out the data on demand trend comparison of IE3 high efficiency motors and IE4 premium high efficiency motors, of frame size 160 and above, as shown in Figure 4.4.2. It is obvious in the data that the market for IE3 high efficiency motors has seen the highest demand since the last Ecodesign regulation effective from 1st July 2021, despite the analysis illustrating a slightly decreasing trend from 2023 on IEC frame size 160 and above. Meanwhile, the demand for IE4 premium high efficiency motors is increasing significantly on the equivalent frame size range in contrast to the decreasing trend in IE3 high efficiency motors.

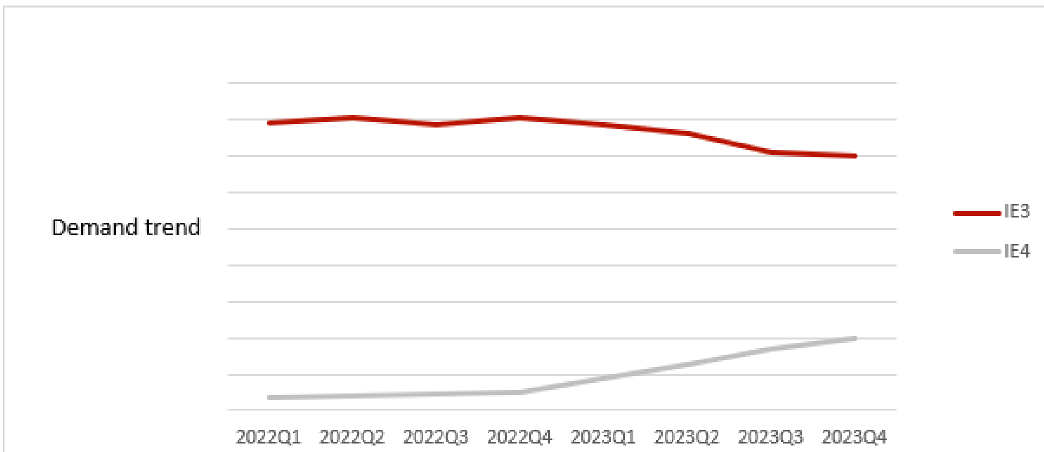

Figure 4.4.2 – ABB low voltage motor medium-sized market demand trend on efficiency class (2022-2023)

Besides the above specific demand trend analysis on IE3 high efficiency and IE4 premium efficiency, we zoom in to illustrate an overview according to frame size groups to estimate that most of the transition from IE2 to IE3 may come through frame size 280 and below, whilst the transition from IE3 to IE4 may come from frame size group 280 – 500. However, a proportion should not be neglected from frame size group 160 – 250. As noted from the view of product types, there was indication of demand transition from IE4 premium efficiency synchronous reluctance motors to IE5 super premium efficiency synchronous reluctance motors. Nevertheless, the research did not find data to support such demand transition seen from the viewpoint of frame size group. One of the key explanations could be that the proportion of IE5 super premium motors is still remaining relatively low seen from entire product portfolio per frame size groups. However, it is clearly visible from specific product type to be synchronous reluctance motors.

Motor efficiency class	**Frame size group**	**Demand trend 2022 – 2023**
IE2	63-132	Decrease (double digits)
	160-250	Decrease
	280-500	Decrease
IE3	63-132	Increase
	160-250	Decrease
	280-500	Decrease (double digits)
IE4	63-132	Increase
	160-250	Increase (double digits)
	280-500	Increase (double digits)
IE5	63-132	Remain
	160-250	Remain
	280-500	Remain

Table 4.4.3 – ABB low voltage motor market demand trend on efficiency class, per frame size (2022-2023)

4.5 Trend of best available technologies and products

There is no doubt that regulations, standards, and policies play a key role in energy efficiency to accelerate implementation in industries such as the case company. But the study also found that governmental regulations alone cannot provide a full picture of energy efficiency in business practice, while the relevant industry regulations go beyond governmental regulations. It explains why some industrial segments or companies are further ahead than required by regulation. For example, the case company offered higher efficiency products to the market already before the regulation requirement.

Gradually, more stringent minimum efficiency performance standards have been introduced, and awareness of the economic and environmental improvements of using more efficient motors is rising over time. Taking the example of Ecodesignn regulation, the scope of output power range of motors was broadened from 0,75kW – 375kW before 2021 to 0,12kW – 1 000kW, furthermore, output power of 75kW – 200kW is required to fulfill the IE4 class as a minimum in the near future from 1st July 2023 onwards.

Similar reflections of such evolution can be found both from existing standards and empirical cases. IE4 energy efficiency classification was only envisaged in the previous version of the IEC 60034-30-1, but it was defined in the latest revision of 2014. Meanwhile, a new super premium efficiency class IE5 was introduced and envisaged in the IEC 60034-30-1: 2014 version. The goal is to reduce the losses of IE5 class by 20% relative to IE4. The IE5 definition in IEC standards of future editions is just a matter of time.

As noted previously, empirical studies also found that governmental regulations alone cannot provide a full picture of energy efficiency in business practice, while the relevant industry regulations go beyond governmental regulations. The industrial segments or companies are further ahead than is required by regulation, and manufacturers of electrical motors have been developing and introducing better solutions in terms of energy efficiency. For example, the case company offers IE4 and IE5 efficiency class products on the market already before the regulation requirement. Today, IE4 class motors are reaching the market with increasingly demand, and the use of advanced technologies to reach IE5 efficiency level is not new. Products with advanced technologies such as permanent magnet motors and synchronous reluctance motors have been in existence in the product portfolio for years even before Ecodesign regulation was adopted in Europe. Although the market demand in IE5 class motors is relatively small compared to IE3 and IE4 class motors which are covered by the scope of Ecodesign regulation, it still brings clear insight into the market expectations of the best available most efficient motors.

5 Summary and conclusions

5.1 Conclusion

This chapter presents a summary of the findings of this research. First, there are brief answers to the research questions, followed by discussions and recommendations to explain the practical implications of this research. Specifically, this thesis attempts to answer the research questions:

1) What kinds of impacts do the existing electrical motor efficiency policies have on ABB?
2) How have policies, especially European Ecodesign regulation, impacted on the electrical motor market transformation?

To the first question, answers were sought from an extensive literature review, energy agency analysis publications, governmental press releases, and data analysis of the case company study. The conclusion is clear that the energy efficiency movement is a must, that efficiency policies drive customer' demand and motor technology and product offerings to the market. Exploring current trends and key challenges for industries develops energy efficient businesses and a more sustainable world. Although energy demand is predicted to grow, new energy efficiency standards and regulations are having a positive effect on global energy consumption. It overcomes a number of barriers between manufacturers, original equipment manufacturers and end users to cooperate by using optimized electrical motor systems.

Regarding the second question, the study gathered empirical information on the market and products and is a vital step towards assessing the impact of existing policies and provides valuable evidence and support for policies and better solutions for the future market. It also enhances evidence to review existing research results on market analysis and transformation estimations in terms of efficiency classification. The conclusion is obvious and is that the electrical motor market has evolved towards more energy efficiency products driven by efficiency policies, particularly in the European market, and the market transition essentially follows on from Ecodesign regulation adoption. From the entire findings, the results indicate that market demand is declining for high efficiency IE2 products in contrast to rapidly increasing demand for premium efficiency IE3 products. Particularly in Europe, there was a reversal of market domination from high efficiency IE2 to premium efficiency IE3 when the EU Ecodesign 2019/1781 came to force in 2021. A similar transition can be expected from premium efficiency IE3 to super premium efficiency IE4 medium frame size products from 2023 onwards according to the survey results, despite the fact that Ecodesign 2019/1781 second phase 2023 requires minimum efficiency requirement on IE4 when rated in the power range 75kW – 200kW. The market share of higher efficiency class motors is dominated by middle size more than small size motors (<0,75kW) and large size motors (>375kW) represent only a small part of industrial motors in terms of stock units.

We also found that advanced products and technologies in the regulations are very short-lived and limited, but the availability of emerging motor technologies, such as permanent magnet and synchronous reluctance motors offer higher levels of efficiency and are rapidly growing market share. For example, IE5 was not defined either in IEC or minimum efficiency performance standard, but there is clear evidence of the market expectations for IE 5 synchronous reluctance motors as the best available highest efficiency motors. The case company has embedded equal or greater energy efficiency improvement in the product portfolio.

5.2 Discussion and recommendations

5.2.1 Discussion

There are clear practical implications in this thesis and the case company can utilize the findings of the study to assess the impact of existing and further developing policies, to define further product portfolio development strategy based on market demand data-driven decision, to provide further advanced technologies and drive innovation to improve energy efficiency continuously, and, in addition, to increase customer awareness of total cost saving and environmental advantages which can be achieved by adopting energy efficiency policies. The results of this study might be of limited use as they partially generalized from one case company; for instance, much of the empirical data is confidential and only for internal use, therefore the detailed data cannot be presented in the paper even though the findings and results were conducted based on these empirical facts and data. However, on the other hand, considering the case company's leading role in the electrical motor industry and its domain expertise, and in addition the validity and reliability of this study is strictly conducted through the procedures of content validity and internal and external validity, the results can also be trusted and applied in the field of studies in relevant topics such as marketing and promotion of the energy efficiency movement, seeking for better solutions in improving efficiency performance in motor driven systems instead of individual motor components, Ecodesign product development in other industrial sectors, amongst others.

5.2.2 Recommendations

Recommendations for the company as well as for the development of energy efficiency policies are proposed in this thesis. By emphasizing electrical motor efficiency, policies continue to evolve in response to new technologies, markets, economies and environments. Nevertheless, realizing the full benefits of highly efficient motors and enhancing energy efficiency, all stakeholders have critical roles in investing and allocating resources in further development, and public education needs to be increased to explain and promote the value of energy efficiency improvement.

- Public decision makers and government regulators need to incentivize the rapid adoption of efficiency policies and global markets. There are still several challenges for the harmonization of global and regional standards from the technical perspective: for example, different efficiency measurements or test methods defined in different standards among Europe, America and Asia. This increases the difficulties in energy efficiency policy adoption in specific markets where the end users and manufacturers may be located differently. The precise energy-use product declaration or registration could be of different origin from region to region. The next steps that would be extremely beneficial for industry, end users and manufacturers would be the harmonization of standards, directives, regulations, and different kinds of registration schemes in countries.

- Businesses need to increase awareness and consideration of total cost saving and environmental advantages to be achieved by adopting energy efficiency policies. As stated in the key findings, most electric motors used in industry are not purchased by end users but are ordered instead by original equipment manufacturers, who may not be responsible for operation cost and therefore usually take the cost of the motor as a priority in the purchasing decision, without considering the total cost which includes operation such as energy consumption and environmental impact. It is vital to highlight and continuously increase awareness of the value of energy efficiency promotion in business practices.
- Manufacturers like ABB need to provide technologies and drive innovation towards the continuous improving of energy efficiency. Development in policies to capture the maximum saving potential from total motor systems instead of individual components is necessary. The focus should be targeting at integrated systems that include motors, variable frequency drives, transmissions, gears, and application. Therefore, further research on power drive systems is strongly recommend in the field of energy efficiency improvement and trend of market transformation. In addition, the business integration of how digital solutions and IoT will play a role in enabling energy efficient sustainable operations also needs to be explored in future studies.

Reference

Anibal T. de Almeidaa, Joao Fonga, Hugh Falknerb, Paolo Bertoldic. (2017). Policy options to promote energy efficient electric motors and drives in the EU

Anibal T. de Almeida, Fernando J.T.E. Ferreira, Joao Fong, Conrad U. Brunner. (2008). Electrical motor standards, ecodesign and global market transformation

A. De Almeidaa, J. Fonga, C.U. Brunnerb, R. Werleb, M. Van Werkhovenc. (2019). New technology trends and policy needs in energy efficient motor systems -A ma-jor opportunity for energy and carbon savings

Aníbal T. de Almeida, Fernando J. T. E. Ferreira, João A. C. Fong, Conrad U. Brunner. (2015) Electric Motor Standards, Ecodesign and Global Market Transformation

ABB Energy Efficiency Movement. (2022). https://www.energyefficiencymovement.com/en/

Bovea and Perez-Belis. (2012). Achieving environmental sustainability with ecodesign practices and tools for new product development

BP. (2021). BP statistical review of World Energy

Elliot, Jennifer. (2012). An Introduction to Sustainable Development, Taylor & Francis Group, 2012. ProQuest Ebook Central. http://ebookcentral.proquest.com/lib/tritonia-ebooks/detail.action?docID=1047018

European Union. (2018). Official Journal of the European Union L 328, 2018, p1

EMSA. (2021). Electric Motor Systems Annex https://www.iea-4e.org/emsa/

EU. (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, 2019, Official Journal of the European Union, OJ L 272, 25.10.2019, p. 74–94.

EU. (2021). Official Journal of the European Union L 350.

EU. (2018). Official Journal of the European Union L 328

EU. (2005). Official Journal of the European Union L 191, 22/07/2005, P. 0029 – 0058

EU.(2009). Official Journal of the European Union L 285, 31.10.2009, p.10–35

EU. (2022). Rules and requirements for energy labelling and ecodesign https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/rules-and-requirements_en

EU. (2014). Commission Regulation 4/2014, Official Journal of the European Union L 2, 7.1.2014, p. 1-2

EU press release. (2014). Press Release: 2030 climate and energy goals for a competitive, secure and low-carbon EU economy

EU. (2016). Communication from the commission Ecodesign Working plan 2016-2019

European Parliament (2021). Fact Sheets on the European Union https://www.europarl.europa.eu/ftu/pdf/en/FTU_2.5.2.pdf

Fong, J.; F. Ferreira; A.M. Silva; and A.T. De Almeida. (2020). IEC61800-9 System Standards as a Tool to Boost the Efficiency of Electric Motor Driven Systems Worldwide.

Fernando J.T.E. Ferreira. (2018). Overview of retrofitting options in induction motors to improve their efficiency and reliability

Fraenkel & Wallen (2003). How to design and evaluate research in education. Fifth ed. New York: McGraw-Hill.

Heike Brugger, Wolfgang Eichhammer, Nadezhda Mikova, Ewa Donitz. (2021). Energy Efficiency Vision 2050: How will new societal trends influence future energy demand in the European countries?

IEA. (2021). Greenhouse Gas Emissions from Energy: Overview, IEA, Paris. https://www.iea.org/reports/greenhouse-gas-emissions-from-energy-overview/emissions-by-sector#abstract

ISO 14006. (2020). Environmental management systems — Guidelines for incorporating ecodesign

IEA. (2020). Tracking Industry 2020 – Analysis from https://www.iea.org/reports/tracking-industry-2020

IEA (2017). OECD/IEA 2017 World Energy Outlook, IEA Publishing. License from www.iea.org/t&c.

IEA. (2021). Energy Efficiency 2021 https://iea.blob.core.windows.net/assets/9c30109f-38a7-4a0b-b159-47f00d65e5be/EnergyEfficiency2021.pdf

IEC 60034-30-1:2014. International Electrotechnical Commission, Rotating electrical machines – Part 30-1: Efficiency classes of line operated AC motor

Karlsson and Luttropp. (2006). Systematic Life Cycle Design for Sustainable Product Development

Labandeira, X., Labeaga, J. M., Linares, P., & López-Otero, X. (2020). The impacts of energy efficiency policies: Meta-analysis. Energy Policy, p147

Lawrence Berkeley National Laboratory. (2021). U.S. industrial and commercial motor system market assessment report, Volume 1: Characteristics of the installed base, p67

Malinauskaite, J., Jouhara, H., Ahmad, L., Milani, M., Montorsi, L., & Venturelli, M. (2019). Energy efficiency in industry: EU and national policies in Italy and the UK. Energy, p172, p255-269.

Mohammad Zohrabi (2013). Mixed method research: Instruments, validity, reliability, and reporting findings

Numan (1999). Research methods in language learning. Eighth printing. Cambridge: CUP

Our Common Future. (1987). also known as “Brundtland Report”, World Commission on Environment and Development

Pinheiro, Jugend, Filho, Armellini (2018). Framework proposal for ecodesign integration on product portfolio management

Philip Hans Franses, Reichard Paap. (2001). Quantitative Models in Marketing Research, Cambridge University Press, 2001. ProQuest Ebook Central http://ebookcentral.proquest.com/lib/tritonia-ebooks/detail.action?docID=157045.

Svetlana Paramonova, Therese Nehler, Patrik Thollander. (2021). Technological change or process innovation – An empirical study of implemented energy efficiency measures from a Swedish industrial voluntary agreement program

U.S Energy Information Administration. (2021). International Energy Outlook 2021, p12 https://www.eia.gov/outlooks/ieo/

United Nations. (2015). Paris Agreement. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

UN Environment. (2017). UN Environment, U4E Policy guide 2017, Accelerating the Global Adoption of ENERGY-EFFICIENT ELECTRIC MOTORS AND MOTOR SYSTEMS https://united4efficiency.org/wp-content/uploads/2017/09/U4E-MotorGuide-201709-Final.pdf

VhK. (2005). MEEuP Methodology Report, Final, VHK for European Commission

Waide,P., Brunner, C.(2011). Energy-efficiency policy opportunities for electric motor driven systems. OECD Publishing.

4E. (2014). Electrical motor systems, Policy guidelines for electrical motor systems. Part 2: Toolkit for policy makers.