**ISR- University of Coimbra**

# EUP Lot 11 Motors

Final

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# Introduction

## The EuP Directive and the Preparatory Studies

The Energy Using Product (EuP) Directive (2005/32/EC) allows the European Commission to develop measures to reduce the eco-impact of energy using products within the EC. Products that do comply with these measures may have the CE mark attached, those which do not could ultimately be prohibited from being traded within the EC.

This Directive provides for the setting of requirements which the energy using products covered by implementing measures must fulfil in order for them to be placed on the market and/or put into service. It contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply.

Furthermore, it goes beyond just energy efficiency considerations, as it also considers whole life cycle costs, including production and disposal costs. It can therefore be thought of as “energy efficiency, but not at any price”.

In order to evaluate whether and to which extent a product fulfils certain criteria that make it eligible for implementing measures under the Directive, the MEEUP methodology (Methodology for the Eco-design of Energy Using Products) developed by a previous EC-funded project, will be applied in this study.

In order to facilitate the environmental impact analysis, the MEEUP methodology provides an Excel form (EuP EcoReport). In the preparatory phase of the study data was collected for inputting to this model, and comprises economic, material and energy use data for different stages of the product’s life. The used model translates these inputs into quantifiable environmental impacts.

## The Final Report

At this stage, all tasks 1-8 are complete.

For the definition of the BaseCase models three motor power levels were selected that are thought representative of “small”, “medium” and “large” models for the considered power range. An eco-analysis for the sample BaseCase motors was then made using the MEEUP EuP EcoReport. This analysis was only made for single products.

The eco-analysis was then re-run with the data provided by CEMEP and other stakeholders for different power levels and efficiencies, in order to understand the cost/benefits of higher efficiency products.

In the last section scenarios were drawn in order to quantify the energy savings potential that can be achieved vs. a Business-as-Usual situation. The impacts of these possible scenarios were evaluated on manufacturers and consumers. Sensitivity analysis was carried out for key parameters, which can influence the cost-effectiveness of energy-efficient technologies.

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# Table of Acronyms

| | |
|---|---|
| PRODCOM | Production Communautaire |
| AC | Alternating Current |
| ACEEE | American Council for an Energy-Efficient Economy |
| AEMT | Association of Electrical and Mechanical Trades |
| ANSI | American National Standards Institute |
| AP | Acidifying Potential |
| AS | Australian Standard |
| BAT | Best Available Technologies |
| BLDC | Brushless Permanent Magnet DC Motors |
| BNAT | Best Not Available Technologies |
| BoM | Bill of Materials |
| CEE | Consortium for Energy Efficiency |
| CEMEP | Comité Européen de Constructeurs de Machines Electriques et d'Electronique de Puissance |
| CENELEC | Comité Européen de Normalisation Electrotechnique |
| CSA | Canadian Standards Association |
| DC | Direct Current |
| DoE | Department of Energy (USA) |
| ECM | Electronically Commutated Motor |
| EEE | Electrical And Electronic Equipment |
| EMF | Electromagnetic Force |
| EMI | Electromagnetic Interference |
| EP | Eutrophication Potential |
| EPAct | Energy Policy Act |
| EU | European Union |
| EuP | Energy-using Product |
| GER | Gross Energy Requirement |
| GWP | Global Warming Potential |
| HM | Heavy Metals |
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| IT | Information technology |
| LCC | Life Cycle Cost |
| MEEUP | Methodology Eco-design of Energy-using Products |
| MEPS | Minimum Energy Performance Standard |
| NEMA | National Electrical Manufacturers Association |
| NZ | New Zealand |
| ODP | Open Drip-Proof |
| OEM | Original equipment manufacturer |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PBB | Polybrominated Biphenyls |
| PBDE | Polybrominated Diphenyl Ethers |
| PM | Particulate Matter |
| POP | Persistent Organic Pollutants |
| RoHS | Restriction on the Use of Certain Hazardous Substances (in Electrical and Electronic Equipment Directive) |
| SME | Small and Medium Enterprise |
| SR | Switched Reluctance |
| TEFC | Totally Enclosed Fan-Cooled |
| VOC | Volatile Organic Compounds |
| VSD | Variable Speed Drive |
| WEEE | Waste Electrical And Electronic Equipment (Directive) |
| WIMES | Water Industry Mechanical and Electrical Specification |

# 1 Product Definition

This section defines the product and the boundaries for the study. The product is categorised and its performance parameters are defined. This section also identifies and shortly describes test standards and existing legislation.

## *1.1 Product category and performance assessment*

### 1.1.1 Product categorisation

"Electric motor" is defined as a device that converts electric energy into mechanical energy.

The product group is described in the Terms of Reference as electric motors in the output power range of 1–150 kW. However, a lower bound of 0.75 kW and an upper bound of 200 kW were considered to take into account standard power sizes, and the new proposed IEC 60034-30 efficiency classification standard on motor efficiency.

Only low voltage motors are considered in this study. Medium voltage motors are typically used in very high power applications (e.g. above 500 kW), are sold in very small numbers and have customized design.

PRODCOM is a system for the collection and dissemination of statistics on the production of manufactured goods. It is based on a product classification called the PRODCOM List which consists of about 4500 headings relating to manufactured products in which electric motors are included.

The PRODCOM classification for electric motors in the mentioned power range is presented in Table 1-1. Other existent classification schemes are of complementary nature regarding, e.g., standard power sizes, frame sizes or special purpose applications.

**Table 1-1 PRODCOM categorisation for low voltage electric motors**

| PRDCODE | Description |
|---|---|
| 31.10.10.53 | DC motors and generators of an output > 0,75 kW but ≤ 7,5 kW * |
| 31.10.10.55 | DC motors and generators of an output > 7,5 kW but ≤ 75 kW * |
| 31.10.10.70 | DC motors and generators of an output > 75 kW but ≤ 375 kW * |
| 31.10.21.00 | Universal motors of an output > 37,5 W |
| 31.10.22.50 | Single-phase AC motors of an output >0,75 kW |
| 31.10.24.03 | Multi-phase AC motors of an output > 0,75 kW but ≤ 7,5 kW |
| 31.10.24.05 | Multi-phase AC motors of an output > 7,5 kW but ≤ 37 kW |
| 31.10.24.07 | Multi-phase AC motors of an output > 37 kW but ≤ 75 kW |
| 31.10.25.40 | Multi-phase AC motors of an output > 75 kW but ≤ 375 kW ** |
| 31.10.25.30 | Multi-phase AC traction motors of an output > 75 kW |

* excluding starter motors for internal combustion engines
** excluding traction motors

For the purpose of this study, motors shall be further segmented under the following categories that take into account technologic specificities:

- **DC Motors**
    - Shunt Wound,
    - Series Wound
    - Compound Wound
    - Brushed Permanent Magnet;
    - Brushless Permanent Magnet (also called Brushless DC Motors or Electronically Commutated DC motors).

- **AC Motors**
    - Induction three-phase
    - Induction Single-phase
    - Universal (uses a commutator and brushes, having similar construction to a DC series wound motor)
    - Synchronous

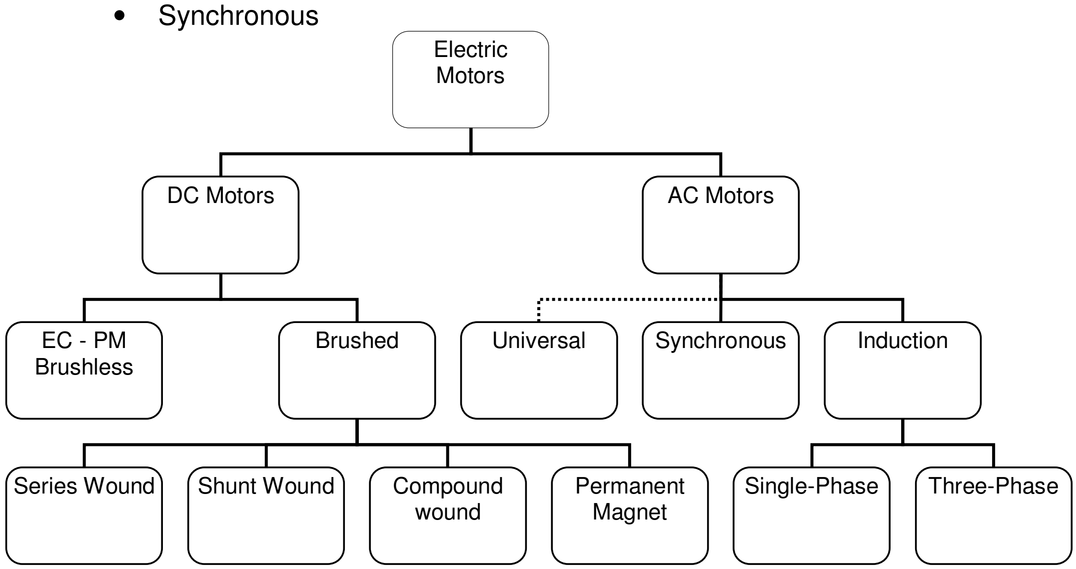


**Figure 1-1 Electric motor categorization**

### 1.1.2 Brushed DC Motors

The **Brushed DC motor** is a rotating electric machine designed to operate from a direct voltage source.

Typically this motor has windings in the fixed part, called the stator. A magnetic field is produced by the windings when an external voltage is applied to them. The classic DC motor has a rotating armature, which has a several separate windings, fed through brushes which make contact with a rotary switch called a commutator. This device enables it to switch the electric current in the several armature windings in order that the magnetic field of the stator and armature are permanently misaligned to generate maximum torque.

The stator can also use permanent magnets. The basic operating principle is still the same.

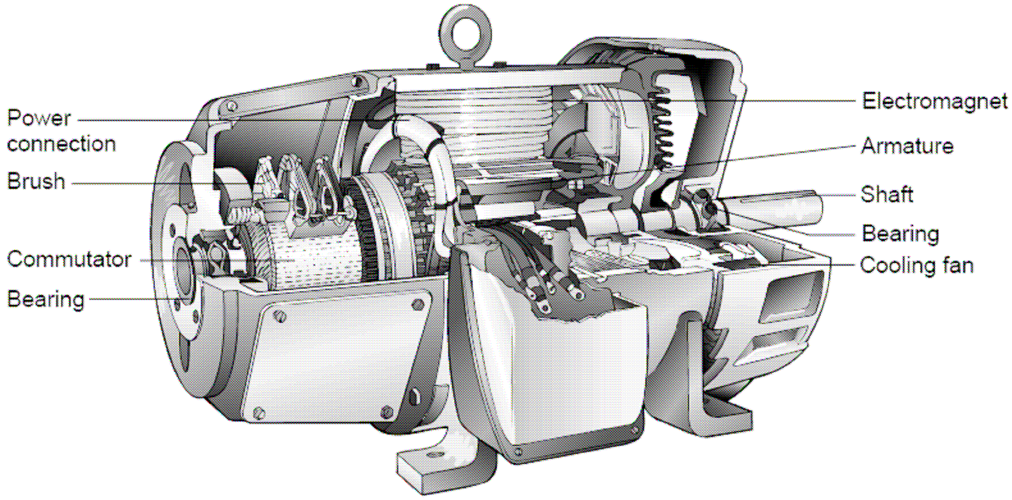


**Figure 1-2 Brushed DC motor [32]**

Traditionally, DC Motors with windings are classified as shunt, series or compound, which reflects the way the field and armature circuits are connected. These descriptions date back to the time before the advent of power electronics, and a strong association built-up between one or other type of DC Motor and a particular application.

#### *1.1.2.1 Shunt wound DC motor*

A shunt wound DC motor has the stator windings in parallel with the rotor winding. These motors run at very nearly the same speed at any load, and barely slow even when overloaded. There is only a minor variation between full load and no load, making them ideal for applications with constant-speed requirements.

#### *1.1.2.2 Series wound DC motor*

In a series wound DC motor the stator windings are connected in series with the rotor. The torque of a series wound motor varies as the square of the armature current. It therefore gives more torque per ampere than any other DC motor. As a result, this type of motor is suitable for applications that need high torque and a moderate increase in total current, such as traction work and cranes.

#### *1.1.2.3 Compound wound DC Motors*

Compound wound DC Motors have their winding partly connected in series and partly connected in parallel. They combine the best features of both the shunt and series wound motors. Like a series motor, it has extra torque for starting and, like a shunt motor, it does not overspeed at no load. They are found in applications where the load can fluctuate either suddenly or periodically, but where constant speed is not essential.

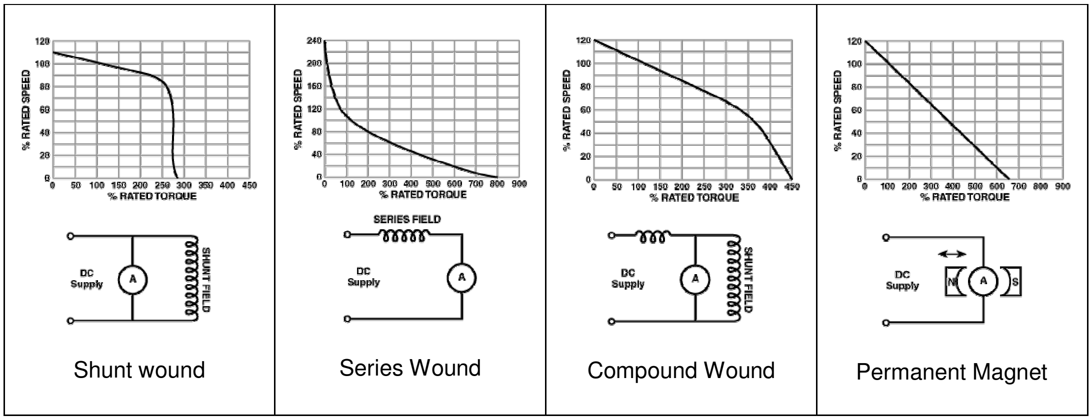


**Figure 1-3 Torque-Speed characteristics and equivalent circuits for different types of brushed DC motors [32]**

The main characteristics of brushed DC Motors are the following:

- High construction complexity leading to higher cost
- Low reliability and high maintenance requirements (brush and commutator wear)
- Low efficiency
- High EMI (brushes create sparks and ozone)
- Easy to control speed and/or torque, requiring inexpensive electronics

The use of brushes and commutator leads to high maintenance requirements and/or short lifetime. Traditionally DC motors with brushes have been used in industrial applications requiring accurate torque and/or speed control (e.g. servo drives, traction) and where only DC power is available such as forklifts. The developments in power electronics in the last 25 years allowed induction motors to achieve the same torque/speed performance of DC motors in high demand applications, but with much higher reliability leading to a decline in market share of DC motors.

### 1.1.3 Brushless Permanent Magnet DC Motors

Brushless Permanent Magnet DC Motors (BLDC) are fed through a DC link with power originating from an AC source. The DC power is then inverted back to AC which feeds the motor. Strictly speaking they are AC motors but historically they have been classified as DC.

Brushless Permanent Magnet DC Motors are rapidly becoming one of the most popular motor types. They differ from Brushed Permanent magnet motors in that the magnets are in the rotor instead of the stator, and in the commutation method which is controlled electronically. BLDC Motors, therefore, avoid the use of a commutator and brushes. The stator is normally a classic three phase stator like that of an induction motor.

Main characteristics:

- Medium construction complexity
- Moderate to high cost depending on  magnet materials
- High reliability (no brush and commutator wear), even at very high achievable speeds
- High efficiency
- Low EMI
- Driven by multi-phase Inverter controllers

- Sensorless speed control possible

These motors are still highly customized without suitable standards (e.g. dimensions, mounting, power, torque specifications, etc.) to allow a commodity market to develop. Because of mass production for specialized applications their cost has been decreasing and may become a key player particularly in the low power range. Because of their large savings potential these motors will be analysed in the chapter dedicated to the best not available technologies.

### 1.1.4 AC Motors

**AC motors** are rotating electric machines designed to operate from an AC power source. Like other motors, an AC motor has a fixed portion, called the stator and a rotor that spins with a carefully engineered air gap between the two.

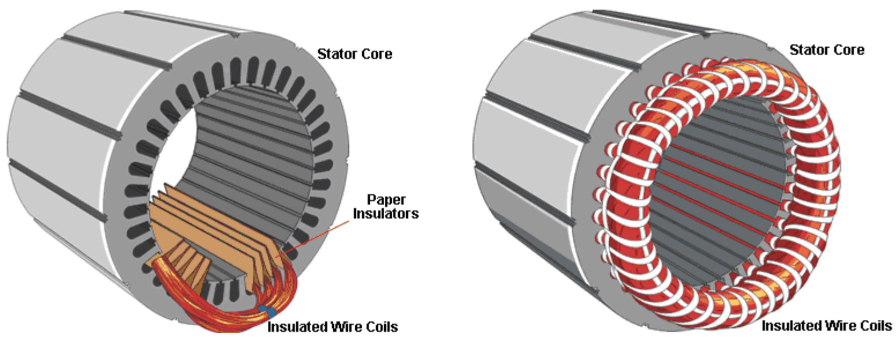


**Figure 1-4 AC Motor stator [33]**

#### *1.1.4.1 Induction Motors*

In an **AC induction motor**, one set of electromagnets in the form of a rotating magnetic field is formed in the stator when an AC supply connected to the stator windings. The rotating magnetic field induces an Electromagnetic Force (EMF) in the rotor as per Lenz's law, thus generating another set of electromagnets; hence the name – induction motor.

Interaction between the rotating magnetic field and the rotor field generates the motor torque. As a result, the motor rotates in the direction of the resultant torque.

One way to produce a rotating magnetic field in the stator of an AC motor is to use a three-phase power supply to feed 3 sets of stator coils, which are a distributed at 120 degrees intervals.

The speed of the rotating magnetic field (synchronous speed) in an induction motor depends on the frequency of the supply voltage and on the number of poles in the motor.

$$sychronous\ \ speed\,[rpm] = \frac{frequency\ of\ \ the\ applied\ voltage\,[Hz] \times 60}{number\ of\ \ pole\ pairs}$$

For example, when a 4-pole motor is supplied with 50 Hz supply, the synchronous speed will be 1500 rpm. Motors with 2, 4 and 6 poles represent the vast majority of the motor market. The rotor speed is slightly lower (a few percent at full power) than the synchronous speed and therefore the induction motor is also called asynchronous motor. The rotor slip increases in a linear manner as the load increases, being almost zero at no-load.

There are two types of three-phase induction motors classified by the type of rotor used: wound or squirrel cage, the latter representing the large majority of them.

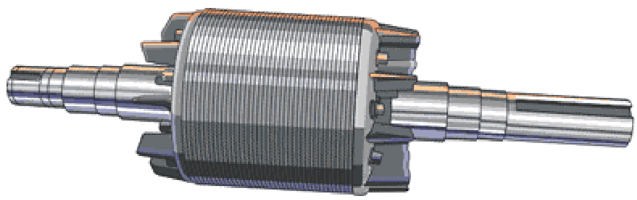

**Figure 1-5 Squirrel-cage rotor [33]**

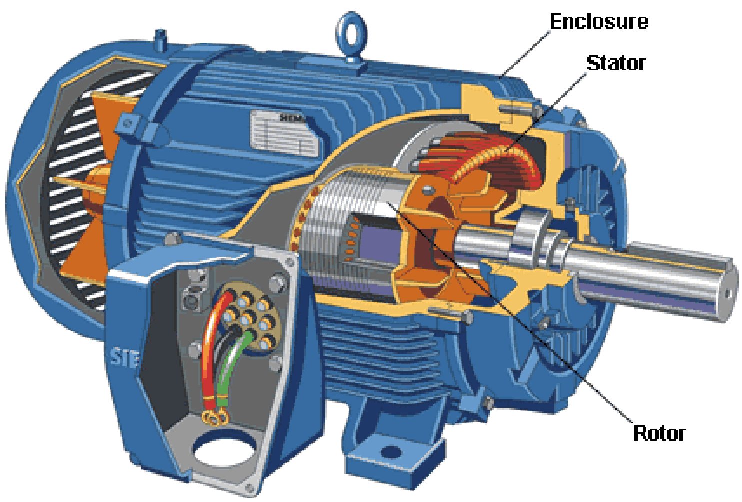


**Figure 1-6 AC Induction Motor [33]**

Main characteristics:

- Low construction complexity,
- High reliability (no brush wear), even at very high achievable speeds
- Medium efficiency at low power (below 2.2. kW), high efficiency at high power
- Driven directly by the grid or by multi-phase Inverter controllers
- Low  Electromagnetic Interference (EMI)
- Sensorless speed control possible
- Lowest cost per kW among different motor technologies

Induction motors are by far the most widely used motor in the power range under consideration, using over 90% of the electricity consumed by all motors in that range [1]. Induction motors are robust, inexpensive when compared with other technologies and their efficiency ranges from fair (around 70% for small motors) to very high (over 95% for large motors) depending on the power level and on the design.

**General purpose induction motors** are a commodity type of motor constituting a large majority of the market (they represent 80-85% of the 3-phase induction motor market), whose main characteristics are standardised. This standardisation allows motors to be easily exchanged around the world, by motors made by different manufacturers meeting the same requirements. There is a huge variety of special purpose induction motors, generally custom made for specific applications. In some applications, these motors may have to comply with strict requirements (e.g. fireproof motors) in which safety is an overriding concern.

#### *1.1.4.2 Single-Phase Induction motors*

As the name suggests, **Single-Phase Induction motors** operate with a single-phase power supply. In single-phase induction motors, there is a stator main winding and an auxiliary winding for starting purposes. The rotor is of the squirrel cage type.

When the motor is connected to a single-phase power supply, the main winding carries an alternating current. This current produces a pulsating magnetic field. Due to induction, the rotor is energized. As the main magnetic field is pulsating, the torque necessary for the motor rotation is not generated. This will cause the rotor to vibrate, but not to rotate. Hence, the single-phase induction motor is required to have a starting mechanism that can provide the starting kick for the motor to rotate. This is accomplished by the auxiliary stator winding, which normally is connected in series with a capacitor. The combination of the two windings creates a rotating field and the motor torque is generated in the rotor like in a 3-phase induction motor. After starting a centrifugal switch may be used to disconnect the auxiliary winding.

Main characteristics:

- Medium construction complexity due to extra capacitor and centrifugal switch
- Higher cost than 3-phase induction motors
- High reliability (no brushes)
- Lower efficiency than 3-phase induction motors
- Low EMI
- Driven directly from AC line or from Variable Frequency controllers

Single phase motors are more expensive and less efficient than equivalent 3 phase motors, being mainly used in residential appliances, and rarely exceeding a few kW. The most relevant electric home appliances are the subject of efficiency assessment regulation in which the efficiency of the whole equipment is regulated. Other integral single phase motors can be found, mostly in the residential sector, in applications such as submersible pumps and machine tools. In general terms single-phase motors are used when a three-phase supply is unavailable.

#### *1.1.4.3 Synchronous motors*

Synchronous motors are similar to induction motors in that they both have stator windings to produce a rotating magnetic field. However, the synchronous motors rotor field current is supplied by a separate DC power source. Conventionally the rotor was fed through slip rings and brushes, but more recent versions use a brushless DC generator to supply the rotor.

In the synchronous motor, the rotor locks into step with the rotating magnetic field and rotates at synchronous speed. There is no slip in a synchronous motor, that is, the rotor always moves at exactly the same speed as the rotating stator field. The speed is thus determined by the number of poles of the motor and frequency of the power supply. The speed will remain constant, even with wide variations in the load.

In order to accelerate the motor up to synchronous speed an auxiliary device is needed. Usually, this is accomplished by adding an additional squirrel cage winding to the rotor poles (amourtisseur or damper windings). The motor will then start as an induction motor. When the motor speed reaches approximately 97% of nameplate RPM, the DC field current is applied to the rotor producing a Pull-in Torque and the rotor will pull-in -step and “synchronize” with the rotating flux field in the stator.

Synchronous motors are somewhat more complex than squirrel-cage and wound rotor motors and, hence, are more expensive.

Main Characteristics:

- Medium construction complexity due the windings of the rotor, slip rings/brushes or brushless DC generator
- Medium reliability, if slip rings/brushes are used
- Very high efficiency
- Low EMI
- High cost
- Possibility of power factor regulation
- Very accurate speed

Synchronous motors represent only 5% of the volume of motor revenues (even much less in terms of sales volume) with their use confined to higher power ratings (typically above 500 kW) because of their slightly higher efficiency and capabilities for power factor control. Because of their large size industrial synchronous motors are generally beyond the power range of this study. Synchronous motors are also used in specialized customized applications in which very precise speed control is required.

#### *1.1.4.4 Universal motor*

The universal motor is a rotating electric machine similar to a DC series wound motor but designed to operate either from direct current or single-phase alternating current. The stator and rotor windings of the motor are connected in series through the rotor commutator. Therefore the universal motor is also known as an AC series motor or an AC commutator motor.

The principle is that in a wound field DC motor the current in both the field and the armature (and hence the resultant magnetic fields) will alternate (reverse polarity) at the same time, and hence the mechanical force generated is always in the same direction.

Main characteristics:

- Operates on both AC and DC current
- High construction complexity
- Low reliability and very limited lifetime
- Low efficiency
- High EMI (brushes create sparks and ozone)
- Good power to weight ratio, if operated at high speeds

Universal motors have the same reliability limitations of DC motors. The maximum output of universal motors is limited and motors exceeding one kilowatt are not common. They are mainly used in household appliances, such as vacuum cleaners (main appliances are regulated for the overall performance) and portable appliances such as power and garden tools having a small number of operating hours.

### 1.1.5 Performance parameters

The proposed primary functional parameters are:

- Output power (the provided mechanical power in kW);
- Speed.

The Torque is also a key functional parameter but it is worth to emphasize that the motor torque is directly related to the above mentioned quantities by the equation:

$$Torque\ [N.m] = \frac{Power\ [W]}{speed[rad\ /\ s]}$$

The proposed secondary functional parameters for this study are:

- Efficiency class/nominal value;
- Part-load efficiency

Other relevant parameters in motor selection, which are not going to be directly involved in further analysis, include:

- Nominal voltage.
- Starting torque;
- Frequency
- Breakdown torque;
- Starting current;
- Current;
- Power factor;
- Insulation class;
- Case tightness grade;
- Frame size;
- Bearing type and reference.

The following paragraphs contain a brief explanation of some of these parameters.

#### *1.1.5.1 Motor Efficiency*

Motor Efficiency is generally defined as:

$$Efficiency = \frac{Output\ mechanical\ power}{Input\ \ electrical\ power}$$

The difference between the output mechanical power and the input electrical power is due to five different kinds of losses occurring in a machine: electrical losses, magnetic losses, mechanical losses and stray load losses and in the case of brushed motors, the brush contact losses. The **electrical losses** (also called Joule losses) are expressed by $I^2R$, and consequently increase rapidly with the motor load. Electrical losses appear as heat generated by electric resistance to current flowing in the stator windings and in the rotor conductor bars and end rings. **Magnetic losses** occur in the steel laminations of the stator and rotor. They are due to hysteresis and eddy currents, increasing approximately with the square of the flux-density. **Mechanical losses** are due to friction in the bearings, ventilation and windage losses. **Stray load losses** are due to leakage flux, harmonics of the air gap flux density, non-uniform and inter-bar currents distribution, mechanical imperfections in the air gap, and irregularities in the air gap flux density. **The brush contact losses** result from the voltage drop between the brushes and the commutator.

As an example, Figure 1-7 shows the distribution of the induction motor losses as a function of the load.

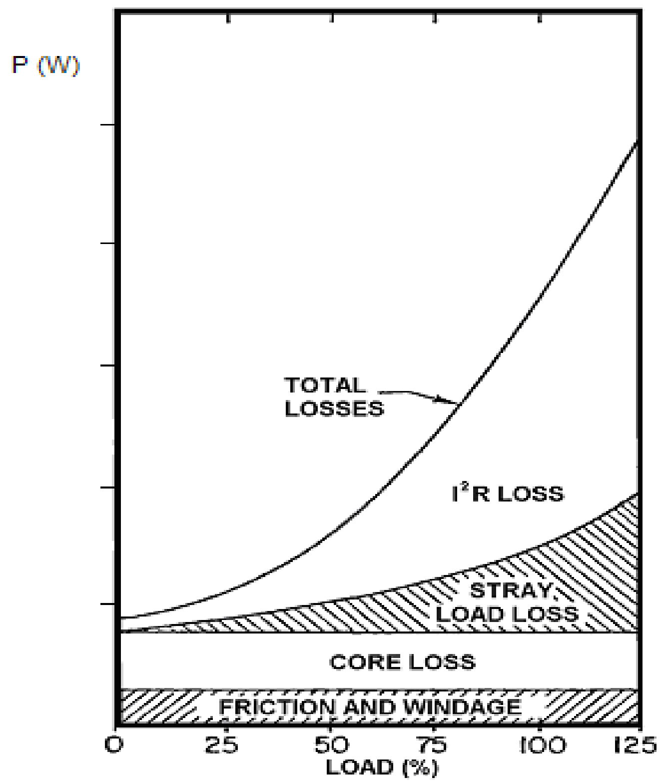


**Figure 1-7 Typical distribution of the induction motor losses as a function of the load**

Motor efficiency is measured and classified according to different efficiency testing standards around the world. These standards define different methods to evaluate losses and this can lead to significantly different motor efficiency values.  Test methods also differ in the measurement of the mechanical shaft power, which is only carried out in some methods. These differing standards are a market barrier to global trade, and currently there is work being undertaken, particularly by IEC, to move towards common efficiency test standards and classification.

### *1.1.5.2 Torque*

Torque is the rotational force exerted by the shaft of the motor. It is expressed in Newton metres (N.m).

**Full Load Torque**

Full load torque is the rated continuous torque that the motor can support without overheating.

**Starting Torque**

The amount of torque the motor produces when it is energized at full voltage and with the shaft locked in place is called starting torque. This value is also frequently expressed as "locked rotor torque". It is the amount of torque available when power is applied to start accelerating it up to speed.

**Breakdown Torque**

Breakdown torque or pull-out torque is the maximum torque that a motor can produce.

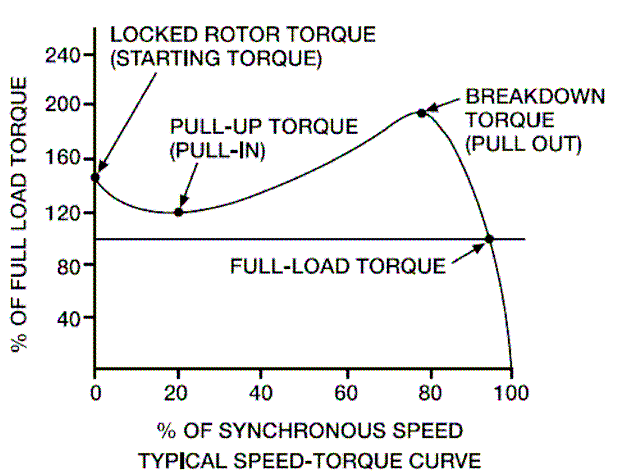


**Figure 1-8 Three-Phase Induction motor torque-speed characteristic [35]**

### *1.1.5.3 Insulation Classes*

Both the winding insulation and the grease in the bearings degrade with temperature. Significant progress has been in the development of insulation which is able to withstand high temperatures (Class F and Class H). However, the operating temperature affects the efficiency and the motor lifetime. Typically copper losses increase by 10 % when the temperature increases by 25 ºC.

Because of their lower losses energy efficient motors can operate at lower temperature, leading to a longer lifetime.

In accordance to the standard IEC 60085, Table 1-2 shows the maximum operation temperature for each thermal class. Figure 1-9 shows market evolution of winding insulation classes in Europe.

**Table 1-2 Thermal classes for insulation systems (IEC 60085)**

| Thermal classes for insulation systems | A | E | B | F | H |
|---|---|---|---|---|---|
| Maximum operation temperature (ºC) | 105 | 120 | 130 | 155 | 180 |

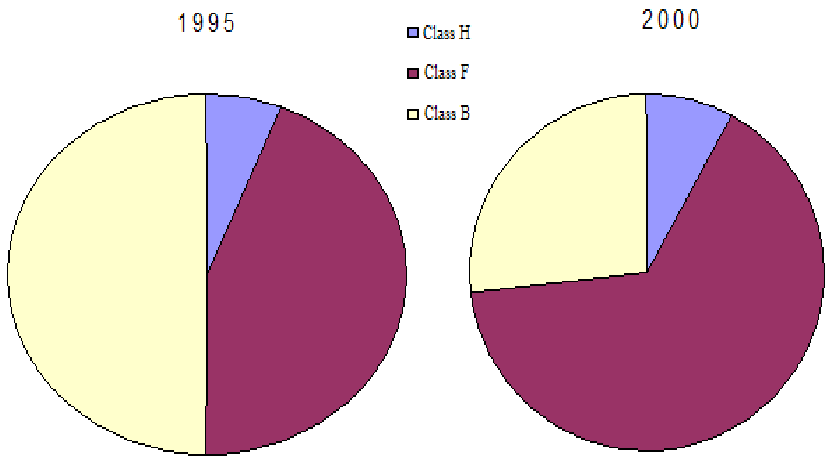


**Figure 1-9 Market evolution of winding insulation classes in Europe [25]**

The use of higher performance insulation leads to longer lifetime of the windings, making bearings the weakest link leading to motor failure.

## *1.2 Test Standards*

### 1.2.1 Relevant performance testing

Efficiency test standards are not uniform in different regions of the World. The more widely used performance testing standards, for the power range under consideration, are discussed below.

#### *1.2.1.1 IEEE 112 (2004) [2]*

This standard covers instructions for conducting and reporting the more generally applicable and acceptable tests to determine, not only efficiency but also other performance parameters and characteristics of polyphase induction motors and generators.

#### *1.2.1.2 IEEE 113 (1985)*

The IEEE 113 Guide: Test Procedures for Direct-Current Machines (latest edition 1985) included recommendations for conducting and reporting generally acceptable tests to determine the performance characteristics of conventional direct-current machines. However, it was withdrawn some years ago and is no longer endorsed by the IEEE, due to the declining importance of DC machines.

No current IEEE standard deals with performance testing of DC machines. Therefore, acceptability of a particular test as proof of DC motor performance is strictly between user and manufacturer.

#### *1.2.1.3 IEEE 114 (2001)*

This standard deals with the performance testing of single-phase induction motors.

#### *1.2.1.4 IEEE 115 (1955)*

This standard deals with the performance testing of synchronous machines.

#### *1.2.1.5 IEC 60034-2 (1996) [3]*

This standard establishes methods of determining efficiencies from tests, and also specifies methods of obtaining specific losses.

It applies to DC machines and to AC synchronous and inductions machines of all sizes within the scope of IEC 60034-1.

#### *1.2.1.6 IEC 61972 (2002) [5]*

This test standard, developed as a possible replacement of IEC 60034-2 in what concerns three-phase induction motors, allows two methods to determine their efficiency and losses.

- Method 1 - input-output method (similar to IEEE 112-B)

Stray load losses determined from measurements.

- Method 2 - Indirect method (assigned variable allowance)

The main difference is that in the revised method there is an assigned variable allowance for the stray load losses which are estimated using the following equations:

$$Output\ power \leq 1kW \ \Rightarrow Stray\,load\,losses = 0.025 \times input\ power$$

$$1 \leq Output\ power \leq 1kW \ \Rightarrow Stray\,load\,losses = \left[0.025 - 0.005 \times log_{10}\left(\frac{Output\ power}{1kW}\right)\right] \times input\ power$$

$$Output\ power \geq 10\,000kW \ \Rightarrow Stray\,load\,losses = 0.005 \times input\ power$$

European CENELEC did not adopt this testing standard in Europe due to the additional cost for testing equipment and labour cost (it was claimed to take 10% to 15% more testing time), especially for mid and large size motors. It was thought that small and mid size manufacturers might have difficulties to comply with this standard.

The IEC has decided that the contents of this publication will remain unchanged until 2007. At this date, the publication will be either: reconfirmed, withdrawn, replaced by a revised edition, or amended.

#### *1.2.1.7 IEC 60034-2-1 Edition 1, (September 2007) [6]*

This new version of IEC 60034-2, was approved by 23 countries in favour, 5 abstentions, and no disapproval., introduces the Eh-Star test as a recognized method to determine additional load losses of induction machines.

Eh-Star is an inexpensive method with good accuracy where stray load losses are calculated mathematically. Eh-star is based on an asymmetrical feeding of a three-phase induction motor, so this method is based on reverse field component (negative current sequence).

Independent comparative tests carried out by several Universities, between direct test methods and Eh Star method, show a good matching of the test results and comparative accuracy [8] [9]. Because of its relative lower costs to test the large number of motor models already in the market, motor manufacturers see this method as a cost-effective alternative to upgrade the efficiency tests of those motors.

Furthermore it excludes the Calibrated-machine test, the Retardation test and the Calorimetric test, which are only used for large machines where the facility cost for other methods is not economical. However, considering these methods are still in use, they are included in its annex D.

It is difficult to establish specific rules for the determination of efficiency. The choice of test to be made depends on the information required, the accuracy required, the type and size of the machine involved and the available field test equipment (supply, load or driving machine).

This new standard presents three tables with the preferred methods for the determination of efficiency and their levels of uncertainty.

As an example the table regarding Induction motors is presented here.

**Table 1-3 Preferred methods for determining the efficiency of Induction Motors**

| Method | Clause | Preferred method | Required facilities | Uncertainty |
|---|---|---|---|---|
| **Direct** | | | | |
| Torque measurement | 8.1.1 | All single phase and polyphase ≤ 1 kW | Torquemeter/dynamometer for full-load | Low |
| Calibrated machine test | Annex D | | Calibrated machine | See Note 4 |
| Dual-supply, back-to-back test | 8.1.2 | | Machine set for full-load<br>Two identical units | Low |
| **Total losses** | | | | |
| Calorimetric method | Annex D | | Special thermal enclosure | See Note 4 |
| Single supply back-to-back test | 8.2.1 | | Two identical units (wound rotor) | Low |
| **Summation of losses, with and without load test** | | | | |
| $P_{LL}$ determined from residual loss | 8.2.2.5.1 | Three phase > 1 kW up to 150 kW | Torquemeter/dynamometer for ≥ 1,25 × full-load | Low |
| $P_{LL}$ from assigned value | 8.2.2.5.3 | | | Medium to high |
| $P_{LL}$ from removed rotor and reverse rotation test | 8.2.2.5.2 | | Auxiliary motor with rated power ≤ 5 × total losses $P_T$ | High |
| $P_{LL}$ from Eh-star test | 8.2.2.5.4 | (see Note 3) | Resistor for 150 % rated phase current | Medium |
| **Summation of losses, without load test** | | | | |
| Currents, powers and slip from the equivalent circuit method<br>$P_{LL}$ from assigned value | 8.2.2.4.3 | | If test equipment for other tests is not available (no possibility of applying rated load, no duplicate machine) | Medium/high |

NOTE 1 Due to measurement inaccuracies, the determination of $P_{LL}$ from residual losses is limited to correlation coefficients (see 8.2.2.5.1.2) greater than 0,95 and may have uncertainties of the determined efficiency exceeding ±0,5 %.

NOTE 2 In the "Uncertainty" column, "Low" indicates a procedure determining all loss-components from tests; "Medium" indicates a procedure which is based on a simplified physical model of the machine; "High" indicates a procedure that does not determine all loss-components by tests.

NOTE 3 The method for $P_{LL}$ from Eh-star test is suitable for motors between 1 kW and 150 kW; larger ratings are under consideration. The method requires that the winding can be connected in star.

NOTE 4 Uncertainty to be determined.

#### *1.2.1.8 C390-98 (2005) [10]*

This Canadian Standard, very similar to IEEE 112-B specifies the test methods to be used in measuring the energy efficiency of three-phase induction motors. This standard applies to three-phase induction motors rated 0.746 kW at 1800 rpm (or equivalent) and greater. An equivalent motor is a motor with the same torque output but with different kilowatt output and speed.

#### *1.2.1.9 AS 1359.102*

This standard establishes methods of determining efficiencies from tests, and also specifies methods of obtaining particular losses when these are required for other purposes.

It applies to DC machines and to AC synchronous and induction machines of all sizes within the scope of IEC 60034-1.

It is expected that the Australian Standard will shortly collapse to follow the revised international standard IEC 60034-2.

#### *1.2.1.10 ANSI/NEMA MG1 – Motors and Generators*

Assists users in the proper selection and application of motors and generators. Revised periodically, the standard provides for changes in user needs, advances in technology, changing economic trends and practical information concerning performance, safety, test, construction, and manufacture of alternating-current and direct-current motors and generators.

#### *1.2.1.11 CAN/CSA C22.2 No.100-04 – Motors and Generators*

This is the Canadian equivalent to ANSI/NEMA MG1.

Other relevant standards and legislation regarding motor use and design are summarized in Appendix I.

## 1.3 Existing relevant environmental legislation inside and outside EU and existing self regulation.

There are no motor efficiency voluntary agreements or minimum efficiency standards regulation regarding motors other than AC induction motors.

Single-phase induction motors are subjected to voluntary labelling schemes in Brazil, India and Mexico.

An overview of the AC three-phase induction motor efficiency voluntary agreements and regulation around the world is presented in Table 1-4. North America (USA, Canada and Mexico) has been the leading region in promoting both high efficiency and premium motors, which now have a market share of over two thirds. Other countries around the world are taking similar initiatives.

**Table 1-4 Motor efficiency voluntary agreements and regulation around the world**
(adapted from [14])

| Country/Region | Mandatory Agreements (year of implementation) | Voluntary Agreements (year of implementation) | Market Share |
|---|---|---|---|
| U.S.A | EPAct – High Efficiency (1997)<br>NEMA Premium (2011) | NEMA Premium (2001) | NEMA Premium (16%)<br>EPACT (54%) |
| Canada | EPAct levels– High Efficiency (1997) | NEMA Premium (2001) | NEMA Premium (16%)<br>EPACT (54%) |
| Mexico | EPAct levels– High Efficiency (1998) | NEMA Premium (2003) | n.a. |
| EU | | Efficiency Classification and market reduction of EFF3 (1998) | EFF1 (12%)<br>EFF2 (85%)<br>for CEMEP members |
| Australia | High efficiency (2006) | Premium efficiency (2006) | Premium Efficiency (10%)<br>High efficiency (32%)<br>Standard (58%) |
| New Zealand | High efficiency (2006) | Premium efficiency (2006) | n.a. |
| Brazil | Standard Efficiency (2002)<br>High Efficiency (2009) | High Efficiency | High Efficiency (15%) |
| China | Standard Efficiency (2002)<br>High Efficiency (2011) | Premium efficiency (2007) | High Efficiency (10%)<br>Standard Efficiency (90%) |
| Korea | Standard Efficiency (2008) | Standard Efficiency (1996) | High Efficiency (10%)<br>Standard (90%) |

In the above Table 1-4, four efficiency classes of motors are mentioned:

- Premium efficiency motors (equivalent to IE3, USA NEMA Premium classification)
- High efficiency motors (equivalent to IE2, USA EPACT or EFF1 from CEMEP/EU)
- Standard efficiency motors (equivalent to IE1, EFF2 from CEMEP/EU agreement)
- Low efficiency motors (equivalent to EFF3 from CEMEP/EU agreement, and below standard efficiency in the rest of the world)

In Canada and the US, the MEPS relating to motors that conform to National Electrical Manufacturers Association (NEMA) requirements are identical, but the Canadian program also covers metric motors. Mexico has recently completed a revision of its MEPS, making the levels equivalent to those in the US and Canada.

### 1.3.1 Existing relevant environmental legislation/agreements at EU level

#### *1.3.1.1 Voluntary agreement CEMEP/EU [15]*

In 1998 a voluntary agreement supported by European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) and the European Commission was established and signed by 36 motor manufacturers, representing 80% of the European production of standard motors. This agreement defined a target to promote more efficient AC 3-phase induction motors. In this agreement it was decided to define a motor efficiency classification scheme with three levels for motors:

- EFF1 – High efficiency motors
- EFF2 – Medium efficiency motors
- EFF3 – Low efficiency motors

**Table 1-5 Characteristics of the motors included on CEMEP/EU agreements**

| **Motors included in CEMEP/EU agreement:** |
|---|
| 3 phase AC squirrel cage induction motors |
| Rated power: 1.1 kW to 90 kW |
| Totally enclosed fan ventilated |
| Line voltage: 400 V |
| 50 Hz |
| S1 duty class (continuous mode) |
| Efficiency tested in accordance with IEC 60034-2 using the “summation of losses” test procedure with $P_{LL}$ from assigned allowance |

Table 1-6 and Figure 1-10 show class definition by efficiency levels.

**Table 1-6 Class Definition for CEMEP/EU agreements**

| kW | 2 - Pole | | 4 - Pole | |
|---|---|---|---|---|
| | EFF2 | EFF1 | EFF2 | EFF1 |
| 1.1 | 76.2 | 82.8 | 76.2 | 83.8 |
| 1.5 | 78.5 | 84.1 | 78.5 | 85.0 |
| 2.2 | 81.0 | 85.6 | 81.0 | 86.4 |
| 3 | 82.6 | 86.7 | 82.6 | 87.4 |
| 4 | 84.2 | 87.6 | 84.2 | 88.3 |
| 5.5 | 85.7 | 88.6 | 85.7 | 89.2 |
| 7.5 | 87.0 | 89.5 | 87.0 | 90.1 |
| 11 | 88.4 | 90.5 | 88.4 | 91.0 |
| 15 | 89.4 | 91.3 | 89.4 | 91.8 |
| 18.5 | 90.0 | 91.8 | 90.0 | 92.2 |
| 22 | 90.5 | 92.2 | 90.5 | 92.6 |
| 30 | 91.4 | 92.9 | 91.4 | 93.2 |
| 37 | 92.0 | 93.3 | 92.0 | 93.6 |
| 45 | 92.5 | 93.7 | 92.5 | 93.9 |
| 55 | 93.0 | 94.0 | 93.0 | 94.2 |
| 74 | 93.6 | 94.6 | 93.6 | 94.7 |
| 90 | 93.9 | 95.0 | 93.9 | 95.0 |

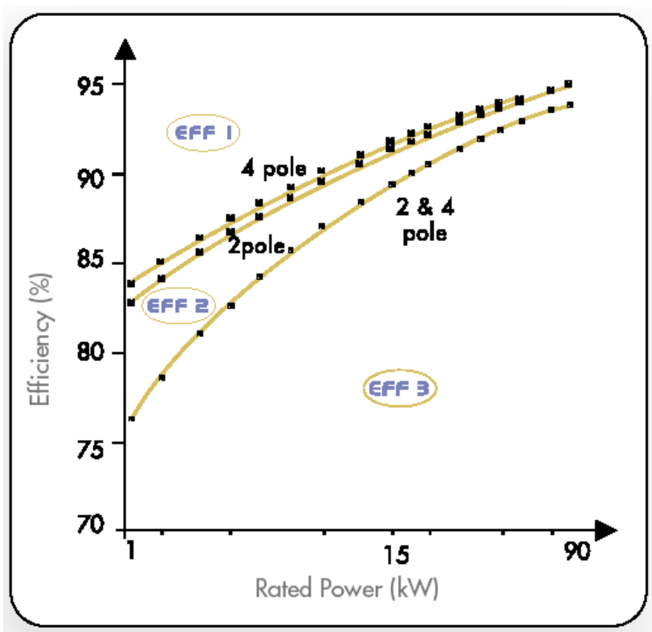


**Figure 1-10 Class definition for CEMEP/EU agreements**

Based on the classification scheme there was a voluntary undertaking by motor manufacturers to reduce the sale of motors with the current standard efficiency (EFF3).

The CEMEP/EU agreement was a very important first step to promote motor efficiency classification and labelling, together with a very effective market transformation. Low efficiency motors (EFF3) have essentially been removed from the EU induction motor market which is a positive development. However the penetration rate of EFF1 motors is still very modest in the EU:

#### *1.3.1.2 WEEE Directive (Directive 2002/96/EC)*

With the purpose of preventing waste electrical and electronic equipment (WEEE), the EU adopted Directive 2002/96/EC imposing responsibility on producers for the environmental impact of the disposal of such waste.

Furthermore, it states that Member States should encourage the design and production of electrical and electronic equipment that facilitates reuse, recycling and other forms of recovery of such wastes in order to reduce them. Producers should not prevent, through specific design features or manufacturing processes, WEEE from being reused, unless such specific design features or manufacturing processes present overriding advantages, for example with regard to the protection of the environment and/or safety requirements.

In the WEEE Directive “electrical and electronic equipment” (EEE) is defined as:

- Equipment which is dependent on electric currents or electromagnetic fields in order to work properly
- Equipment designed for use with a voltage rating not exceeding 1000 Volt for alternating current and 1500 Volt for direct current;
- Equipment for the generation, transfer and measurement of such currents and fields

And cover EEE falling under the following categories (Annex IA of the WEEE Directive):

- Large household appliances
- Small household appliances
- IT and telecommunications equipment
- Consumer equipment
- Lighting equipment
- Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
- Toys, leisure and sports equipment
- Medical devices (with the exception of all implanted and infected products)
- Monitoring and control instruments
- Automatic dispensers

Some electric motors (e.g. universal motors) can be a part of some of the products included in the above categories and so responsibilities are believed to fall on the producers of the complete equipment. However, commodity type motors in the power range under consideration do not fall in the scope of the directive.

#### *1.3.1.3 RoHS Directive (Directive 2002/95/EC)*

The Restriction on the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Directive - RoHS) Directive 2002/95/EC – which took effect July 1, 2006 – restricts the use of certain hazardous substances in electrical and electronic equipment.

Member states should ensure that from that date forward new products do not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

This directive covers electrical and electronic equipment as defined in the WEEE Directive and falling under the categories defined in its Annex IA.

As mentioned earlier, some electric motors can be a part of some of the equipments covered by the directive. Therefore, producers of such equipment should ensure that none of the motors to be included in their equipment contain any of the hazardous substances mentioned in the directive.

Exempted from the requirements are:

- Lead as an alloying element in steel containing up to 0,35 % lead by weight, aluminium containing up to 0,4 % lead by weight and as a copper alloy containing up to 4 % lead by weight;
- Lead in high melting temperature type solders (i.e. tin-lead solder alloys containing more than 85 % lead).

### 1.3.2 Existing relevant environmental legislation outside the EU

#### *1.3.2.1 USA Energy Policy Act – EPAct (1992)* *[16]*

Enforced in October 1997 it requires that motors manufactured or imported for sale in the USA meet minimum efficiency levels. It is a mandatory agreement. EPAct motors now constitute 54% of the integral horsepower[1] induction motor market share. Other motors include premium efficiency motors and non-general purpose motors.

**Table 1-7 Characteristics of the motors included on EPAct**

| **Motors included in EPACT scheme:** |
|---|
| Polyphase squirrel-cage induction motors, NEMA Design A and B |
| Rated power 1-200 hp |
| Single-speed |
| 230/400 Volts |
| 60 Hz |
| Continuous rated |
| Tested in accordance with IEEE 112- Method B |
| 2, 4 and 6 poles |
| Type of Enclosure: Totally Enclosed Fan-Cooled (TEFC) and Open Drip-Proof (ODP) |

#### *1.3.2.2 NEMA – Premium (2002)*

Because many utilities and industry associations were promoting motors with a higher efficiency than EPAct mandatory levels, the National Electrical Manufacturers Association (NEMA) felt a need to define a classification scheme for premium higher efficiency motors. In 2005 NEMA Premium motors constituted 16% of the market share in USA.

[1] There are various definitions of horsepower as it can refer to a number of non-metric units. For the purpose of this study 1 hp = 0,746 kW, valued rounded to 0.75 kW.

**Table 1-8 Characteristics of the motors included on NEMA Premium**

| **Motors included NEMA Premium scheme** |
|---|
| Polyphase squirrel-cage induction motors, NEMA Design A and B |
| Rated power 1-500 hp |
| Single-speed |
| 600 Volts or less |
| 60 Hz |
| Continuous rated |
| Tested in accordance with IEEE 112-B |
| General-purpose motors T frame |
| 2,4 and 6 poles |

Tables 1-8 and 1-9 present a comparison of Efficiency levels for EPAct and NEMA Premium motors for Open Drip-Proof and Totally Enclosed Fan-Cooled (TEFC) motors. Open Drip-Proof and Totally Enclosed Fan-Cooled (TEFC) are different types of motor enclosures. The first is not used in Europe. The two tables are required since there are different efficiency values for the two types of motors. NEMA Premium motors have about 15-20% lower losses than EPAct high-efficiency motors, which typically translates into an efficiency improvement of 1-4%, depending on the motor power level.

**Table 1-9 Efficiency levels for EPACT and NEMA Premium, Open Drip-Proof motors.**

| hp | 1200 RPM (6-pole) | | 1800 RPM (4-pole) | | 3600 RPM (2-pole) | |
|---|---|---|---|---|---|---|
| | EPAct | NEMA Premium | EPAct | NEMA Premium | EPAct | NEMA Premium |
| 1 | 80.0 | 82.5 | 82.5 | 85.5 | N/A | 77.0 |
| 1.5 | 84.0 | 86.5 | 84.0 | 86.5 | 82.5 | 84.0 |
| 2 | 85.5 | 87.5 | 84.0 | 86.5 | 84.0 | 85.5 |
| 3 | 86.5 | 88.5 | 86.5 | 89.5 | 84.0 | 85.5 |
| 5 | 87.5 | 89.5 | 87.5 | 89.5 | 85.5 | 86.5 |
| 7.5 | 88.5 | 90.2 | 88.5 | 91.0 | 87.5 | 88.5 |
| 10 | 90.2 | 91.7 | 89.5 | 91.7 | 88.5 | 89.5 |
| 15 | 90.2 | 91.7 | 91.0 | 93.0 | 89.5 | 90.2 |
| 20 | 91.0 | 92.4 | 91.0 | 93.0 | 90.2 | 91.0 |
| 25 | 91.7 | 93.0 | 91.7 | 93.6 | 91.0 | 91.7 |
| 30 | 92.4 | 93.6 | 92.4 | 94.1 | 91.0 | 91.7 |
| 40 | 93.0 | 94.1 | 93.0 | 94.1 | 91.7 | 92.4 |
| 50 | 93.0 | 94.1 | 93.0 | 94.5 | 92.4 | 93.0 |
| 60 | 93.6 | 94.5 | 93.6 | 95.0 | 93.0 | 93.6 |
| 75 | 93.6 | 94.5 | 94.1 | 95.0 | 93.0 | 93.6 |
| 100 | 94.1 | 95.0 | 94.1 | 95.4 | 93.0 | 93.6 |
| 125 | 94.1 | 95.0 | 94.5 | 95.4 | 93.6 | 94.1 |
| 150 | 94.5 | 95.4 | 95.0 | 95.8 | 93.6 | 94.1 |
| 200 | 94.5 | 95.4 | 95.0 | 95.8 | 94.5 | 95.0 |
| 250 | | 95.4 | | 95.8 | | 95.0 |
| 300 | | 95.4 | | 95.8 | | 95.4 |
| 350 | | 95.4 | | 95.8 | | 95.4 |
| 400 | | 95.8 | | 95.8 | | 95.8 |
| 450 | | 96.2 | | 96.2 | | 95.8 |
| 500 | | 96.2 | | 96.2 | | 95.8 |

**Table 1-10 Efficiency levels for EPACT and NEMA Premium, Totally Enclosed Fan-Cooled (TEFC) motors.**

| hp | 1200 RPM (6-pole) | | 1800 RPM (4-pole) | | 3600 RPM (2-pole) | |
|---|---|---|---|---|---|---|
| | EPAct* | NEMA Premium | EPAct* | NEMA Premium | EPAct* | NEMA Premium |
| 1 | 80.0 | 82.5 | 82.5 | 85.5 | 75.5 | 77.0 |
| 1.5 | 85.5 | 87.5 | 84.0 | 86.5 | 82.5 | 84.0 |
| 2 | 86.5 | 88.5 | 84.0 | 86.5 | 84.0 | 85.5 |
| 3 | 87.5 | 89.5 | 87.5 | 89.5 | 85.5 | 86.5 |
| 5 | 87.5 | 89.5 | 87.5 | 89.5 | 87.5 | 88.5 |
| 7.5 | 89.5 | 91.0 | 89.5 | 91.7 | 88.5 | 89.5 |
| 10 | 89.5 | 91.0 | 89.5 | 91.7 | 89.5 | 90.2 |
| 15 | 90.2 | 91.7 | 91.0 | 92.4 | 90.2 | 91.0 |
| 20 | 90.2 | 91.7 | 91.0 | 93.0 | 90.2 | 91.0 |
| 25 | 91.7 | 93.0 | 92.4 | 93.6 | 91.0 | 91.7 |
| 30 | 91.7 | 93.0 | 92.4 | 93.6 | 91.0 | 91.7 |
| 40 | 93.0 | 94.1 | 93.0 | 94.1 | 91.7 | 92.4 |
| 50 | 93.0 | 94.1 | 93.0 | 94.5 | 92.4 | 93.0 |
| 60 | 93.6 | 94.5 | 93.6 | 95.0 | 93.0 | 93.6 |
| 75 | 93.6 | 94.5 | 94.1 | 95.4 | 93.0 | 93.6 |
| 100 | 94.1 | 95.0 | 94.5 | 95.4 | 93.6 | 94.1 |
| 125 | 94.1 | 95.0 | 94.5 | 95.4 | 94.5 | 95.0 |
| 150 | 95.0 | 95.8 | 95.0 | 95.8 | 94.5 | 95.0 |
| 200 | 95.0 | 95.8 | 95.0 | 96.2 | 95.0 | 95.4 |
| 250 | | 95.8 | | 96.2 | | 95.8 |
| 300 | | 95.8 | | 96.2 | | 95.8 |
| 350 | | 95.8 | | 96.2 | | 95.8 |
| 400 | | 95.8 | | 96.2 | | 95.8 |
| 450 | | 95.8 | | 96.2 | | 95.8 |
| 500 | | 95.8 | | 96.2 | | 95.8 |

The American Council for an Energy-Efficient Economy (ACEEE) and the National Electrical Manufacturers Association (NEMA) have agreed to a new set of proposed energy efficiency standards for industrial electric motors that has been submitted to the House Energy and Commerce Committee and the Senate Energy and Natural Resources Committee for their consideration in energy legislation now under development.

The proposal aims not only at setting higher minimum mandatory efficiency levels but also broaden the scope of existing standards, as follows:

- Current minimum efficiency standards of general purpose induction motors as defined in the 1992 EPAct and covered by federal legislation should be raised to NEMA Premium levels.
- Seven types of low voltage poly-phase, integral-horsepower induction motors not currently covered under federal law should be subjected to minimum efficiency standards at the levels defined in 1992's EPAct for general purpose induction motors.
  - U-Frame Motors
  - Design C Motors
  - Close-coupled pump motors
  - Footless motors
  - Vertical solid shaft normal thrust (tested in a horizontal configuration)
  - 8-pole motors (~900 rpm)
  - All poly-phase motors with voltages up to 600 volts other than 230/460 volts
- General purpose induction motors with power ratings between 200 and 500 horsepower should also meet minimum efficiency levels as specified in 1992's EPAct.

#### *1.3.2.3 Australian Energy Performance Program – MEPS (AS 1359.5:2004)*

The new Australian Energy Performance Program – MEPS (AS 1359.5:2004) – has efficiency levels equivalent to EFF1/EPACT. This is a mandatory measure starting in April 2006 applied to motors described in Table 1-11.

**Table 1-11 Characteristics of the motors included in the Australian MEPS**

| **Motors in Australian/New Zealand scheme** |
|---|
| Three phase induction motors |
| Rated power 0.73-185 hp |
| Single-speed |
| Up to 1100 Volts |
| 2-, 4, 6 and 8 poles |
| Continuous rated |

Two methods of efficiency measurement, described in AS 1359.102, are allowed:

- Method A, identical to method 1 of IEC 61972 and technically equivalent to method B specified in IEEE 112;
- Method B, based on IEC 60034-2 "summation of losses" test procedure.

Therefore, there are two tables (Table 1-12 and Table 1-13) with minimum efficiency levels and high efficiency levels tested according to AS 1359.102.3 (similar to IEEE-112 –Method B) and two tables (Table 1-14 and Table 1-15) for minimum efficiency levels and high efficiency levels tested according to AS 1359.102.1 Standard (similar to

IEC 60034-2 – $P_{LL}$ from assigned allowance) [17]. The four tables below are required since motors tested with different efficiency testing standards have different values.

**Table 1-12 Minimum efficiency levels for Australian MEPS (according with AS 1359.102.3 – Direct method) enforced on April 2006**

| Rated output kW | Minimum efficiency % | | | |
|---|---|---|---|---|
| | 2 pole | 4 pole | 6 pole | 8 pole |
| 0.73 | 78.8 | 80.5 | 76.0 | 71.8 |
| 0.75 | 78.8 | 80.5 | 76.0 | 71.8 |
| 1.1 | 80.6 | 82.2 | 78.3 | 74.7 |
| 1.5 | 82.6 | 83.5 | 79.9 | 76.8 |
| 2.2 | 84.0 | 84.9 | 81.9 | 79.4 |
| 3 | 85.3 | 86.0 | 83.5 | 81.3 |
| 4 | 86.3 | 87.0 | 84.7 | 82.8 |
| 5.5 | 87.2 | 87.9 | 86.1 | 84.5 |
| 7.5 | 88.3 | 88.9 | 87.3 | 86.0 |
| 11 | 89.5 | 89.9 | 88.7 | 87.7 |
| 15 | 90.3 | 90.8 | 89.6 | 88.9 |
| 18.5 | 90.8 | 91.2 | 90.3 | 89.7 |
| 22 | 91.2 | 91.6 | 90.8 | 90.2 |
| 30 | 92.0 | 92.3 | 91.6 | 91.2 |
| 37 | 92.5 | 92.8 | 92.2 | 91.8 |
| 45 | 92.9 | 93.1 | 92.7 | 92.4 |
| 55 | 93.2 | 93.5 | 93.1 | 92.9 |
| 75 | 93.9 | 94.0 | 93.7 | 93.7 |
| 90 | 94.2 | 94.4 | 94.2 | 94.1 |
| 110 | 94.5 | 94.7 | 94.5 | 94.5 |
| 132 | 94.8 | 94.9 | 94.8 | 94.8 |
| 150 | 95.0 | 95.2 | 95.1 | 95.2 |
| <185 | 95.0 | 95.2 | 95.1 | 95.2 |

**Table 1-13 High efficiency levels for Australian MEPS (according with AS 1359.102.3 – Direct method)**

| Rated output kW | Minimum efficiency % | | | |
|---|---|---|---|---|
| | 2 pole | 4 pole | 6 pole | 8 pole |
| 0.73 | 81.4 | 82.9 | 78.8 | 75.0 |
| 0.75 | 81.4 | 82.9 | 78.8 | 75.0 |
| 1.1 | 83.0 | 84.5 | 80.9 | 77.6 |
| 1.5 | 84.8 | 85.6 | 82.4 | 79.6 |
| 2.2 | 86.2 | 86.9 | 84.2 | 81.9 |
| 3 | 87.2 | 87.8 | 85.6 | 83.6 |
| 4 | 88.1 | 88.7 | 86.7 | 85.0 |
| 5.5 | 88.9 | 89.5 | 87.9 | 86.5 |
| 7.5 | 89.9 | 90.4 | 89.0 | 87.8 |
| 11 | 90.9 | 91.3 | 90.2 | 89.3 |
| 15 | 91.6 | 92.1 | 91.0 | 90.4 |
| 18.5 | 92.1 | 92.4 | 91.6 | 91.1 |
| 22 | 92.4 | 92.8 | 92.1 | 91.5 |
| 30 | 93.1 | 93.4 | 92.8 | 92.4 |
| 37 | 93.6 | 93.8 | 93.3 | 92.9 |
| 45 | 93.9 | 94.1 | 93.7 | 93.5 |
| 55 | 94.2 | 94.4 | 94.1 | 93.9 |
| 75 | 94.8 | 94.9 | 94.6 | 94.6 |
| 90 | 95.0 | 95.2 | 95.0 | 94.9 |
| 110 | 95.3 | 95.5 | 95.3 | 95.3 |
| 132 | 95.5 | 95.6 | 95.5 | 95.5 |
| 150 | 95.7 | 95.9 | 95.8 | 95.9 |
| <185 | 95.7 | 95.9 | 95.8 | 95.9 |

**Table 1-14 Minimum efficiency levels for Australian MEPS (according with AS 1359.102.1 – Indirect method) to be enforced April 2006**

| Rated output kW | Minimum efficiency % | | | |
|---|---|---|---|---|
| | 2 pole | 4 pole | 6 pole | 8 pole |
| 0.73 | 80.5 | 82.2 | 77.7 | 73.5 |
| 0.75 | 80.5 | 82.2 | 77.7 | 73.5 |
| 1.1 | 82.2 | 83.8 | 79.9 | 76.3 |
| 1.5 | 84.1 | 85.0 | 81.5 | 78.4 |
| 2.2 | 85.6 | 86.4 | 83.4 | 80.9 |
| 3 | 86.7 | 87.4 | 84.9 | 82.7 |
| 4 | 87.6 | 88.3 | 86.1 | 84.2 |
| 5.5 | 88.5 | 89.2 | 87.4 | 85.8 |
| 7.5 | 89.5 | 90.1 | 88.5 | 87.2 |
| 11 | 90.6 | 91.0 | 89.8 | 88.8 |
| 15 | 91.3 | 91.8 | 90.7 | 90.0 |
| 18.5 | 91.8 | 92.2 | 91.3 | 90.7 |
| 22 | 92.2 | 92.6 | 91.8 | 91.2 |
| 30 | 92.9 | 93.2 | 92.5 | 92.1 |
| 37 | 93.3 | 93.6 | 93.0 | 92.7 |
| 45 | 93.7 | 93.9 | 93.5 | 93.2 |
| 55 | 94.0 | 94.2 | 93.9 | 93.7 |
| 75 | 94.6 | 94.7 | 94.4 | 94.4 |
| 90 | 94.8 | 95.0 | 94.8 | 94.7 |
| 110 | 95.1 | 95.3 | 95.1 | 95.1 |
| 132 | 95.4 | 95.5 | 95.4 | 95.4 |
| 150 | 95.5 | 95.7 | 95.6 | 95.7 |
| <185 | 95.5 | 95.7 | 95.6 | 95.7 |

**Table 1-15 High efficiency levels for Australian MEPS (according with AS 1359.102.1 – Indirect method)**

| Rated output kW | Minimum efficiency % | | | |
|---|---|---|---|---|
| | 2 pole | 4 pole | 6 pole | 8 pole |
| 0.73 | 82.9 | 84.5 | 80.4 | 76.5 |
| 0.75 | 82.9 | 84.5 | 80.4 | 76.5 |
| 1.1 | 84.5 | 85.9 | 82.4 | 79.1 |
| 1.5 | 86.2 | 87.0 | 83.8 | 81.0 |
| 2.2 | 87.5 | 88.2 | 85.5 | 83.3 |
| 3 | 88.5 | 89.1 | 86.9 | 84.9 |
| 4 | 89.3 | 89.9 | 87.9 | 86.2 |
| 5.5 | 90.1 | 90.7 | 89.1 | 87.7 |
| 7.5 | 90.9 | 91.5 | 90.1 | 88.9 |
| 11 | 91.9 | 92.2 | 91.2 | 90.3 |
| 15 | 92.5 | 92.9 | 92.0 | 91.4 |
| 18.5 | 92.9 | 93.3 | 92.5 | 92.0 |
| 22 | 93.3 | 93.6 | 92.9 | 92.4 |
| 30 | 93.9 | 94.2 | 93.6 | 93.2 |
| 37 | 94.2 | 94.5 | 94.0 | 93.7 |
| 45 | 94.6 | 94.8 | 94.4 | 94.2 |
| 55 | 94.9 | 95.0 | 94.8 | 94.6 |
| 75 | 95.4 | 95.5 | 95.2 | 95.2 |
| 90 | 95.5 | 95.7 | 95.5 | 95.5 |
| 110 | 95.8 | 96.0 | 95.8 | 95.8 |
| 132 | 96.1 | 96.1 | 96.1 | 96.1 |
| 150 | 96.1 | 96.3 | 96.2 | 96.3 |
| <185 | 96.1 | 96.3 | 96.2 | 96.3 |

### 1.3.3 Comparison of Minimum Efficiency Requirements in Different Parts of the World

In order to compare efficiency requirements, one must be aware that different test methods are used in the assessment of the motor's efficiency. These test methods can produce significantly different results and therefore efficiency levels are not straightforwardly comparable.

Furthermore, the measurement tolerances varies in the different test methods, and the impact of the supply frequency (50 Hz or 60 Hz) used during the test on the final test results complicates things further. When the torque is not changed, the output power increases by 20%, most motors develop a better efficiency at 60 Hz compared to 50 Hz.

NEMA standards apply to motors tested according to IEEE 112 – Method B. It is a direct method where output power is obtained measuring the torque and rotation speed at different load levels:

$$Ouput\ power = Torque \times Speed$$

This method requires accurate measuring instrumentation, including precision dynamometers, for the different power ranges.

The CEMEP/EU agreement, on the other hand, includes motors tested according to IEC60034-2 using the “summation of losses” test procedure.

This test procedure is an indirect method, avoiding the need to measure Mechanical Power and the associated costs. Mechanical Power is calculated by measuring the electrical input power and the losses.

$$Mechanical\ Power = Electrical\ Power - Power\ Losses$$

All losses are measured using laboratorial tests except stray load losses which are assumed. The full load stray load losses are arbitrarily assumed to be 0,5% of the full load input power.

$$Efficiency = 1 - \frac{Power\ losses}{Input\ power}$$

Because of the above mentioned assumption, the efficiency measurements between IEEE 112-B and IEC 60034-2 lead to different results. Next figure shows the difference of efficiency tests carried out in the same motors using IEEE 112-B and IEC 34-2 test standards.

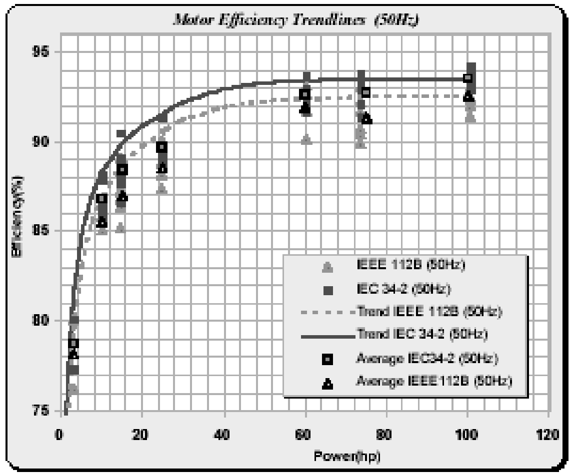


**Figure 1-11 Motor efficiency trend lines for 50Hz Motors, using IEEE 112-B and IEC 34-2 standards [4]**

IEC 34-2 “summation of losses” efficiency test method gives overestimated efficiency values because the value considered for stray load losses (0.5 % of the full load input power) is not realistic. In fact, in the most cases, particularly in the low and medium power motor ranges, stray load losses assume real values well above 0.5%.

Figure 1-13 presents a comparative assessment of different efficiency levels associated with MEPS and voluntary agreement classification schemes, in which the 60 Hz motor data was converted to 50 Hz (Figure 1-12) and adjustments were made when needed to take into account typical values for stray-load losses[18]. It is to be noted that for motors using the same amount of active materials, leading to similar torque, the operation at 60 Hz will provide slightly higher efficiency, because although some losses increase with the frequency (e.g. the mechanical losses and magnetic losses) the output power increases more intensively.

If torque remains unchanged, $I^2R$ losses remain approximately constant for 50 Hz and 60 Hz operation. Magnetic losses are considered increase with frequency[1,5], friction losses are considered to vary linearly with frequency, and ventilation losses increase with the cube of the frequency, if the fan size is not adjusted.

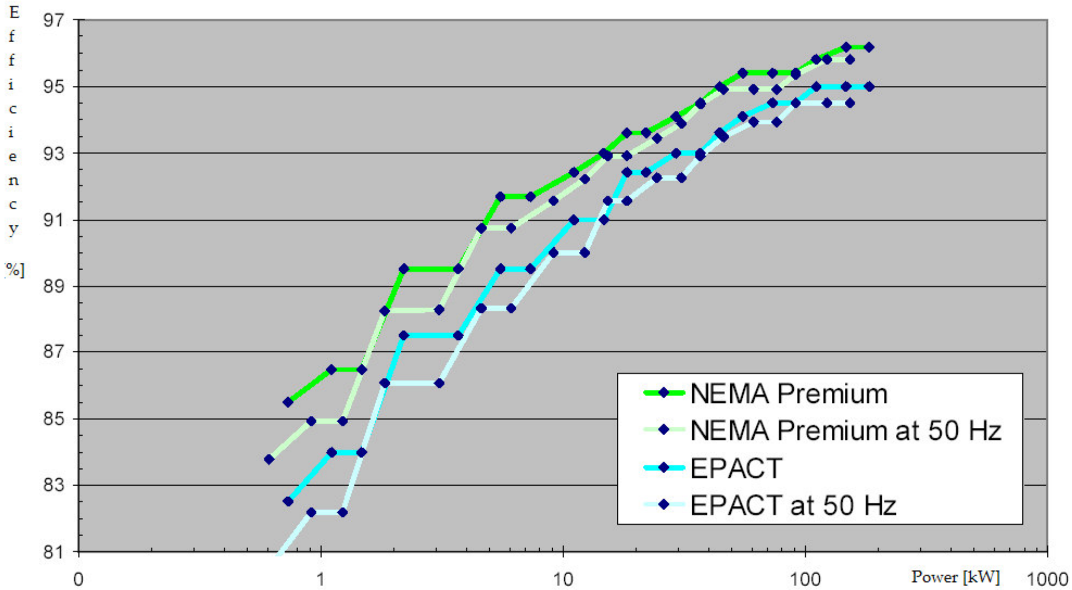


**Figure 1-12 Comparison of 60 Hz efficiency requirements at 50 Hz line frequency (EPACT and NEMA Premium)** [18]

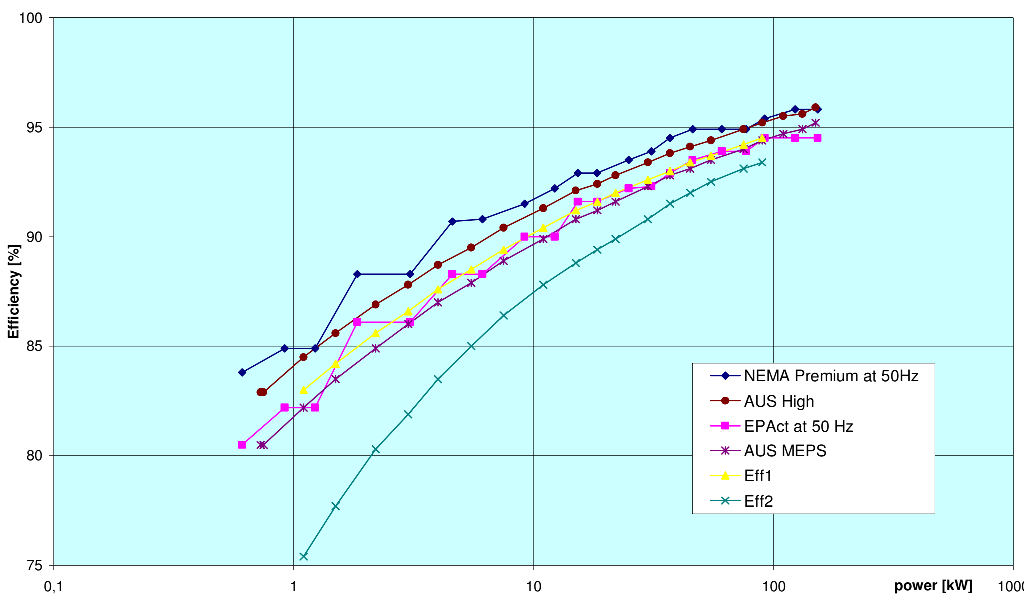


**Figure 1-13 Comparison of Efficiency requirements**

As can be seen, current EFF1 motors, under the CEMEP/EU agreement, are roughly on the same efficiency level as EPACT and Aus/NZ MEPS compliant motors. NEMA Premium and Australian/New Zealand High efficiency levels, which have not yet a European correspondent, are slightly higher.

### 1.3.4 Harmonization of efficiency classification standards in the World

As it is possible to see from the previous section, several different energy efficiency levels/classes are currently in use around the world, increasing potential confusion and creating market barriers. For the manufacturers this is a big problem because they design motors for a global market. Therefore, IEC developed a classification standard (IEC 60034-30 [19]) trying to globally harmonize energy efficiency classes for three-phase induction motors. The second draft of this standard (2/1464/CDV) has been approved by 76% of the voting countries on 1 February 2008. The comments will be discussed by IEC Working Group 31 on 26/27 March 2008. The final edition of the standard is expected to be published before the end of 2008.

The new standard will be called “IEC 60034-30: Efficiency classes of single-speed three phase cage induction motors” covering single-speed three-phase 50 Hz or 60 Hz cage induction motors that:

- have a rated voltage $U$N up to 1000 V;

*NOTE - The standard also applies to motors rated for two or more voltages and/or frequencies*

- have a rated output $P$N between 0,75 kW and 370 kW;
- have either 2, 4 or 6 poles
- are rated on the basis of duty type S1 (continuous duty) or S3 (intermittent periodic duty) with an operation time of 80% or more;
- are constructed to degree of protection IP2x, IP4x, IP5x or IP6x according to IEC60034-5;
- are constructed with a cooling method IC0Ax, IC1Ax, IC2Ax, IC3Ax or IC4Ax according to IEC 60034-6;
- are intended for direct on-line connection;
- are rated for operating conditions according to IEC 60034-1, clause 6.

Efficiency and losses shall be tested in accordance with IEC 60034-2-1. The selected test method shall be associated with low uncertainty and shall be stated in the documentation of the motor.

Four efficiency classes are defined:

- IE4 – Super Premium (under consideration)
- IE3 – Premium efficiency (equivalent to NEMA Premium)
- IE2 – High efficiency (equivalent to EPAct/EFF1)
- IE1 – Standard efficiency (equivalent to EFF2)
- No designation – below standard efficiency – (equivalent to EFF3)

As there is no sufficient market and technological information available to allow standardization, the IE4 (Super Premium) class efficiency levels are only presented in the form of an informative annex. This new class is expected to be included in the next revision of the standard which will also expand its scope to include new motor technologies.

The rated efficiency and the efficiency class shall be durably marked on the rating plate, for example 89,0 (IE3).

The 50 Hz values of standard (IE1) and high efficiency (IE2) are equivalent to the existing CEMEP/EU agreement EFF2 and EFF1. However the values have been adjusted to take the different test procedures into account (CEMEP/EU: the *stray load losses* are arbitrarily assumed to be 0,5% of full-load input power; in IEC 60034-30 standard: the *stray load losses* determined from the test).

The 50 Hz values for premium efficiency (IE3) are newly designed. They were set about 15 to 20% lower losses above the requirements for high (IE2).

The 60 Hz values were derived from the 50 Hz values taking the influence of supply frequency on motor efficiency into account. This approach will enable manufacturers to build motors for dual rating (50/60 Hz).

All efficiency curves are given in mathematical formula in smooth form to allow for various regional and national distinctions for frame dimensions and motor sizes.

The next tables [19] show the proposal efficiency requirements for each class, for 50 Hz and 60 Hz:

**Table 1-16 Nominal values for standard efficiency (IE1) for 50 Hz power supply**

| Pn kW | Number of Poles | | |
|---|---|---|---|
| | **2** | **4** | **6** |
| 0,75 | 72,1 | 72,1 | 70,0 |
| 1,1 | 75,0 | 75,0 | 72,9 |
| 1,5 | 77,2 | 77,2 | 75,2 |
| 2,2 | 79,7 | 79,7 | 77,7 |
| 3 | 81,5 | 81,5 | 79,7 |
| 4 | 83,1 | 83,1 | 81,4 |
| 5,5 | 84,7 | 84,7 | 83,1 |
| 7,5 | 86,0 | 86,0 | 84,7 |
| 11 | 87,6 | 87,6 | 86,4 |
| 15 | 88,7 | 88,7 | 87,7 |
| 18,5 | 89,3 | 89,3 | 88,6 |
| 22 | 89,9 | 89,9 | 89,2 |
| 30 | 90,7 | 90,7 | 90,2 |
| 37 | 91,2 | 91,2 | 90,8 |
| 45 | 91,7 | 91,7 | 91,4 |
| 55 | 92,1 | 92,1 | 91,9 |
| 75 | 92,7 | 92,7 | 92,6 |
| 90 | 93,0 | 93,0 | 92,9 |
| 110 | 93,3 | 93,3 | 93,3 |
| 132 | 93,5 | 93,5 | 93,5 |
| 160 | 93,8 | 93,8 | 93,8 |
| 200 and above | 94,0 | 94,0 | 94,0 |

**Table 1-17 Nominal values for standard efficiency (IE1) for 60 Hz power supply**

| Pn kW | Number of poles | | |
|---|---|---|---|
| | **2** | **4** | **6** |
| 0,75 | 77,0 | 78,0 | 73,0 |
| 1,1 | 78,5 | 79,0 | 75,0 |
| 1,5 | 81,0 | 81,5 | 77,0 |
| 2,2 | 81,5 | 83,0 | 78,5 |
| 3,7 | 84,5 | 85,0 | 83,5 |
| 5,5 | 86,0 | 87,0 | 85,0 |
| 7,5 | 87,5 | 87,5 | 86,0 |
| 11 | 87,5 | 88,5 | 89,0 |
| 15 | 88,5 | 89,5 | 89,5 |
| 18,5 | 89,5 | 90,5 | 90,2 |
| 22 | 89,5 | 91,0 | 91,0 |
| 30 | 90,2 | 91,7 | 91,7 |
| 37 | 91,5 | 92,4 | 91,7 |
| 45 | 91,7 | 93,0 | 91,7 |
| 55 | 92,4 | 93,0 | 92,1 |
| 75 | 93,0 | 93,2 | 93,0 |
| 90 | 93,0 | 93,2 | 93,0 |
| 110 | 93,0 | 93,5 | 94,1 |
| 150 | 94,1 | 94,5 | 94,1 |
| 185 and above | 94,1 | 94,5 | 94,1 |

**Table 1-18 Nominal values for high efficiency (IE2) for 50 Hz power supply**

| Pn kW | Number of poles | | |
|---|---|---|---|
| | **2** | **4** | **6** |
| 0,75 | 78,9 | 81,1 | 75,9 |
| 1,1 | 80,8 | 82,7 | 78,1 |
| 1,5 | 82,3 | 83,9 | 79,8 |
| 2,2 | 84,0 | 85,3 | 81,8 |
| 3 | 85,3 | 86,3 | 83,3 |
| 4 | 86,4 | 87,3 | 84,6 |
| 5,5 | 87,5 | 88,2 | 86,0 |
| 7,5 | 88,5 | 89,1 | 87,2 |
| 11 | 89,6 | 90,1 | 88,7 |
| 15 | 90,5 | 90,9 | 89,7 |
| 18,5 | 91,0 | 91,4 | 90,4 |
| 22 | 91,4 | 91,7 | 90,9 |
| 30 | 92,1 | 92,4 | 91,7 |
| 37 | 92,5 | 92,8 | 92,2 |
| 45 | 92,9 | 93,1 | 92,7 |
| 55 | 93,3 | 93,5 | 93,1 |
| 75 | 93,8 | 94,0 | 93,7 |
| 90 | 94,1 | 94,2 | 94,0 |
| 110 | 94,3 | 94,5 | 94,3 |
| 132 | 94,6 | 94,7 | 94,6 |
| 160 | 94,8 | 94,9 | 94,8 |
| 200 and above | 95,1 | 95,1 | 95,0 |

**Table 1-19 Nominal values for high efficiency (IE2) for 60 Hz power supply**

| Pn kW | Number of poles | | |
|---|---|---|---|
| | 2 | 4 | 6 |
| 0,75 | 75,5 | 82,5 | 80,0 |
| 1,1 | 82,5 | 84,0 | 85,5 |
| 1,5 | 84,0 | 84,0 | 86,5 |
| 2,2 | 85,5 | 87,5 | 87,5 |
| 3,7 | 87,5 | 87,5 | 87,5 |
| 5,5 | 88,5 | 89,5 | 89,5 |
| 7,5 | 89,5 | 89,5 | 89,5 |
| 11 | 90,2 | 91,0 | 90,2 |
| 15 | 90,2 | 91,0 | 90,2 |
| 18,5 | 91,0 | 92,4 | 91,7 |
| 22 | 91,0 | 92,4 | 91,7 |
| 30 | 91,7 | 93,0 | 93,0 |
| 37 | 92,4 | 93,0 | 93,0 |
| 45 | 93,0 | 93,6 | 93,6 |
| 55 | 93,0 | 94,1 | 93,6 |
| 75 | 93,6 | 94,5 | 94,1 |
| 90 | 94,5 | 94,5 | 94,1 |
| 110 | 94,5 | 95,0 | 95,0 |
| 150 | 95,0 | 95,0 | 95,0 |
| 185 and above | 95,4 | 95,0 | 95,0 |

**Table 1-20 Nominal values for premium efficiency (IE3) for 50 Hz power supply**

| Pn kW | Number of poles | | |
|---|---|---|---|
| | **2** | **4** | **6** |
| 0,75 | 82,1 | 84,0 | 80,6 |
| 1,1 | 83,8 | 85,3 | 82,4 |
| 1,5 | 85,0 | 86,3 | 83,8 |
| 2,2 | 86,4 | 87,5 | 85,4 |
| 3 | 87,5 | 88,4 | 86,6 |
| 4 | 88,4 | 89,2 | 87,7 |
| 5,5 | 89,4 | 90,0 | 88,7 |
| 7,5 | 90,3 | 90,8 | 89,7 |
| 11 | 91,2 | 91,7 | 90,8 |
| 15 | 91,9 | 92,3 | 91,6 |
| 18,5 | 92,4 | 92,7 | 92,1 |
| 22 | 92,7 | 93,1 | 92,5 |
| 30 | 93,3 | 93,6 | 93,1 |
| 37 | 93,7 | 94,0 | 93,5 |
| 45 | 94,0 | 94,3 | 93,9 |
| 55 | 94,3 | 94,5 | 94,2 |
| 75 | 94,7 | 95,0 | 94,7 |
| 90 | 95,0 | 95,2 | 94,9 |
| 110 | 95,2 | 95,4 | 95,2 |
| 132 | 95,4 | 95,6 | 95,4 |
| 160 | 95,6 | 95,8 | 95,6 |
| 200 and above | 95,8 | 96,0 | 95,8 |

**Table 1-21 Nominal values for premium efficiency (IE3) for 60 Hz power supply**

| Pn kW | Number of poles | | |
|---|---|---|---|
| | 2 | 4 | 6 |
| 0,75 | 77,0 | 85,5 | 82,5 |
| 1,1 | 84,0 | 86,5 | 87,5 |
| 1,5 | 85,5 | 86,5 | 88,5 |
| 2,2 | 86,5 | 89,5 | 89,5 |
| 3,7 | 88,5 | 89,5 | 89,5 |
| 5,5 | 89,5 | 91,7 | 91,0 |
| 7,5 | 90,2 | 91,7 | 91,0 |
| 11 | 91,0 | 92,4 | 91,7 |
| 15 | 91,0 | 93,0 | 91,7 |
| 18,5 | 91,7 | 93,6 | 93,0 |
| 22 | 91,7 | 93,6 | 93,0 |
| 30 | 92,4 | 94,1 | 94,1 |
| 37 | 93,0 | 94,5 | 94,1 |
| 45 | 93,6 | 95,0 | 94,5 |
| 55 | 93,6 | 95,4 | 94,5 |
| 75 | 94,1 | 95,4 | 95,0 |
| 90 | 95,0 | 95,4 | 95,0 |
| 110 | 95,0 | 95,8 | 95,8 |
| 150 | 95,4 | 96,2 | 95,8 |
| 185 and above | 95,8 | 96,2 | 95,8 |

### 1.3.5 Other relevant efficiency standards

Several industries in which the induction motors operate a very large number of hours per year, and in which there are strict requirements on performance and reliability, have created sector specific standards which address the recommended minimum efficiency levels in order to promote high efficiency/premium motors. Not only energy savings are possible, but also longer lifetimes can be expected. Below, some major examples are given.

#### *1.3.5.1 WIMES 3.03 (Special standard for water industry) – United Kingdom*

The Water Industry Mechanical and Electrical Specification (WIMES) defines minimum standards of performance and construction of low voltage motors, and was drawn up with the assistance of water companies, manufacturers and suppliers. Figure 1-14 shows the minimum efficiency requirements for this standard.

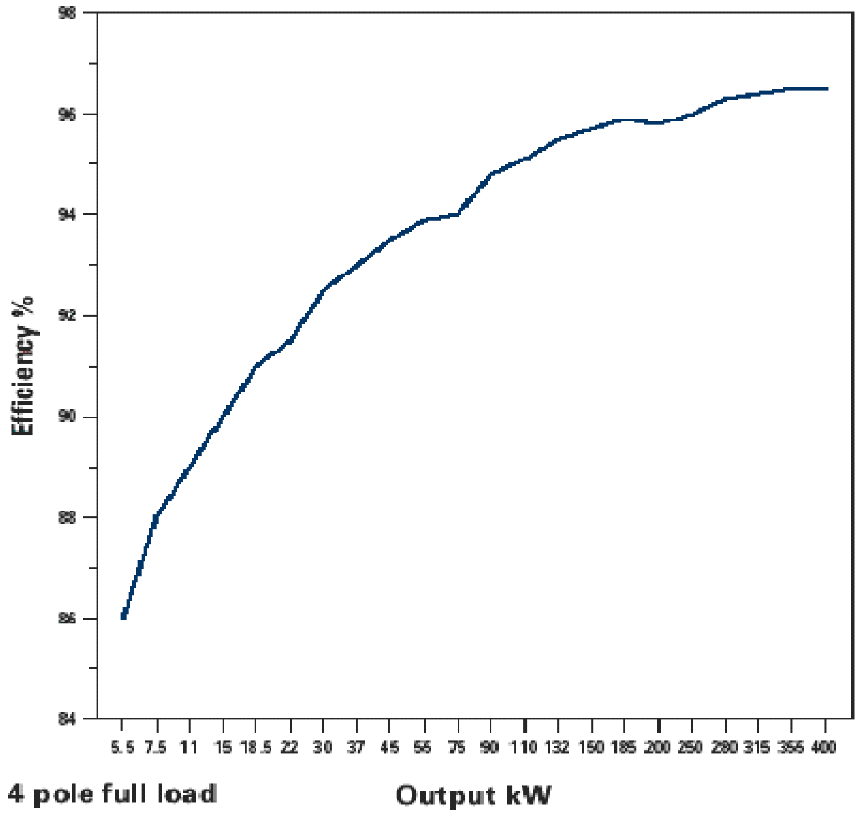


**Figure 1-14 WIMES 3.03 minimum efficiency requirements** [20]

#### *1.3.5.2 IEEE-841*

The IEEE Standard for Petroleum and Chemical Industry regards Severe Duty Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors, up to and Including 370 kW (500 hp). It is currently being revised and will adopt NEMA Premium efficiency levels.

### 1.3.6 Europe vs. other countries

The approval of the IEC 60034-30 efficiency classification standard, currently under development, that harmonizes the currently different requirements for induction motors efficiency levels around the world, will hopefully end the difficulties manufacturers encounter when producing motors for a global market. Additionally customers will benefit by having access to a more transparent and easier to understand information.

Another important factor is the minimum efficiency levels adopted by each country. Although the CEMEP/EU agreement was an important first step towards the reduction of less efficient motor sales, other countries have achieved better results by the implementation of mandatory agreements which introduced higher minimum efficiency levels. These mandatory agreements have produced more relevant market transformations. As an example, EPAct motors (equivalent to EFF1 in Europe) now constitute 70% of the USA motor market while in Europe EFF1 motors have a modest 12% market share.

## 1.4 Summary

This chapter presents an overview of electric motor technologies, its categorization and the most relevant standards and legislation that apply to them worldwide.

There is a wide variety of standards regarding the performance testing of electric motors for the more common technologies. This study gives an overview of these performance standards but focuses on induction motors, which are the dominating technology.

The revised IEC60034-2-1 (Ed.1) standard, regarding motor efficiency testing, introduces the eh-star method as a recognized method to determine additional load losses of induction machines. This standard will become the normative reference for motor efficiency testing once the IEC60034-30 classification standard comes into use.

Several different energy efficiency levels/classes are currently in use around the world, increasing potential confusion and creating market barriers. IEC is now developing an efficiency classification standard trying to globally harmonize energy efficiency classes for three-phase induction motors (IEC60034-30).

Efficiency and losses shall be tested in accordance with IEC 60034-2-1. The selected test method shall be associated with low uncertainty and shall be stated in the documentation of the motor. using

Both standards will hopefully end the difficulties manufacturers encounter when producing motors for a global market and will help make it a more transparent one.

Almost all the major economies have some kind of voluntary or mandatory regulatory scheme regarding motor efficiency. Most of these economies have mandatory minimum efficiency levels for motors sold in the respective countries and labelling schemes for the promotion of higher efficiency motors.

In the European Union, a voluntary agreement supported by CEMEP and the European Commission was established and signed in 1999 by 36 motor manufacturers, representing 80% of the European production of standard motors. In this agreement it was decided to define a motor classification scheme with three efficiency levels for motors:

- EFF1 – High efficiency motors
- EFF2 – Medium efficiency motors
- EFF3 – Low efficiency motors

Based on the classification scheme there was a voluntary undertaking by motor manufacturers to reduce the sale of motors with the current standard efficiency (EFF3).

The CEMEP/EU agreement was a very important first step to promote motor efficiency classification and labelling, together with a very effective market transformation. Low efficiency motors (EFF3) have essentially been removed from the EU induction motor market. However, other countries have achieved better results by the implementation of mandatory standards which introduced higher minimum efficiency levels leading to a more relevant market transformation as it can be seen in Chapter 2.

# 2 Economics and Market

This section gives data on current market figures, stock and market trends so as to indicate the place of possible eco-design measures. Data that will be used for the calculation on Life Cycle Costs, such as prices and rates are also collected here.

The data available from PRODCOM was found to be of limited usefulness for this study as the product categories are not stringent enough (e.g. DC motors and generators are found in the some group), there is not enough disaggregation by motor category and power range, and some of the data fields are not disclosed.

The highly complex motor market has caused some difficulties in the collection of accurate data, particularly regarding minority type motors which are a very fragmented market.

## *2.1 Generic economic data*

The European market forecast for integral horsepower motors (all motors with a power rating in excess of one horsepower) is presented in this section. This survey includes market data from EU-25 countries[2].

The integral horsepower market is a mature market with expected slight growth in the near future. A rise in demand in Eastern Europe countries will be the major driver for this growth.

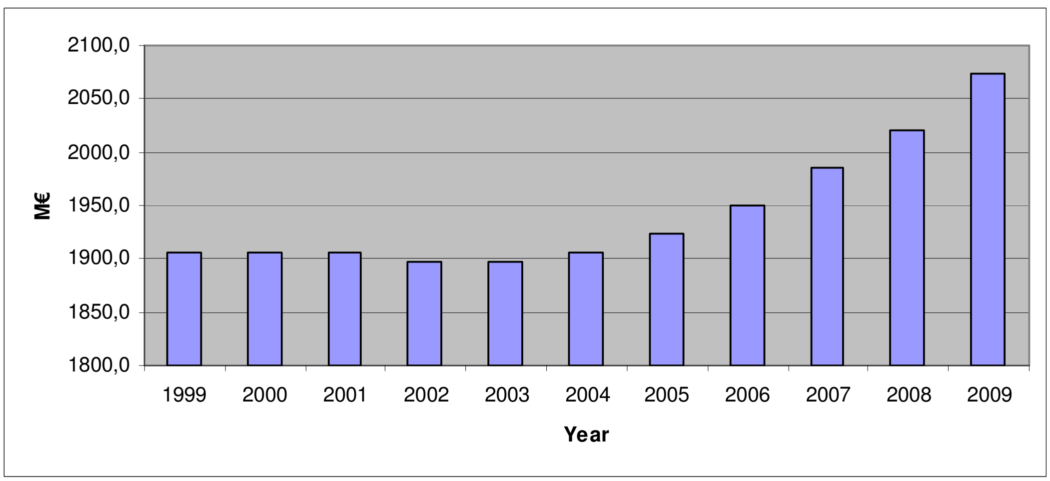


**Figure 2-1 Revenue forecast for integral horsepower motors in EU-25** [21]

It is also possible to estimate the integral motors market share in Europe by their type and observe that AC motors completely dominate the sales (Figure 2-2), representing over 96% of units sold. This translates into around 9 million AC motors sold compared to only 350 thousand DC motors sold.

[2] In this section, EU-25 refers to all EU-25 countries except Malta and includes Switzerland.

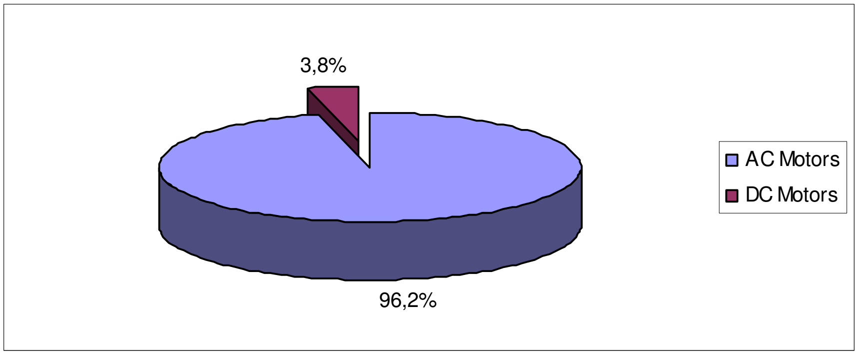


**Figure 2-2 Share of shipments by motor type in EU-25 (integral motors)** [21]

The DC integral horsepower motors market is dominated by shunt wound motors, which offer precise control of speed and torque. The developments in power electronics in the last decades allowed induction motors to achieve the same torque/speed performance of DC motors in high demand applications, but with much higher reliability.

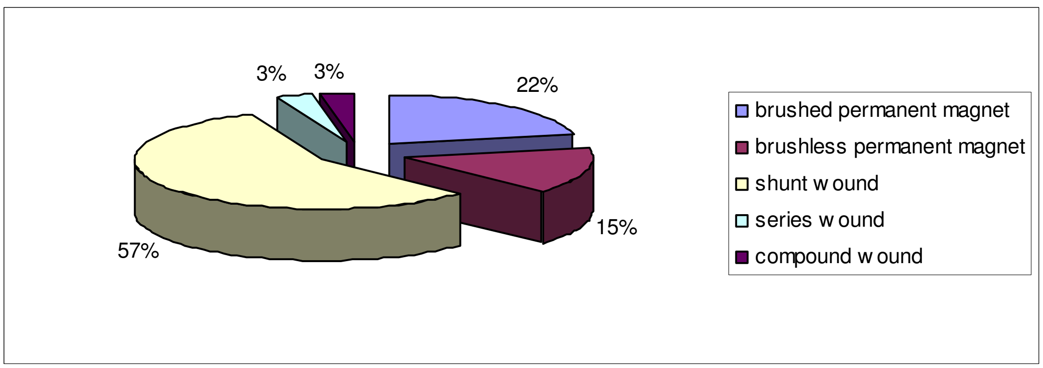


**Figure 2-3 Revenues share of integral DC motors in EU-25 (2002)** [21]

The largest single sector in terms of shipments was for DC motors with power ratings between 0.75 kW and 7.5 kW accounting for 87.3 percent of shipments in 2002.

This remains a key market for DC motors, but is also one of the main ones that has seen the shift towards AC technology. It should be noted that the respective AC market is more than 21 times the size of the DC market at these power ratings showing the shift away from DC solutions in industry as a whole [21].

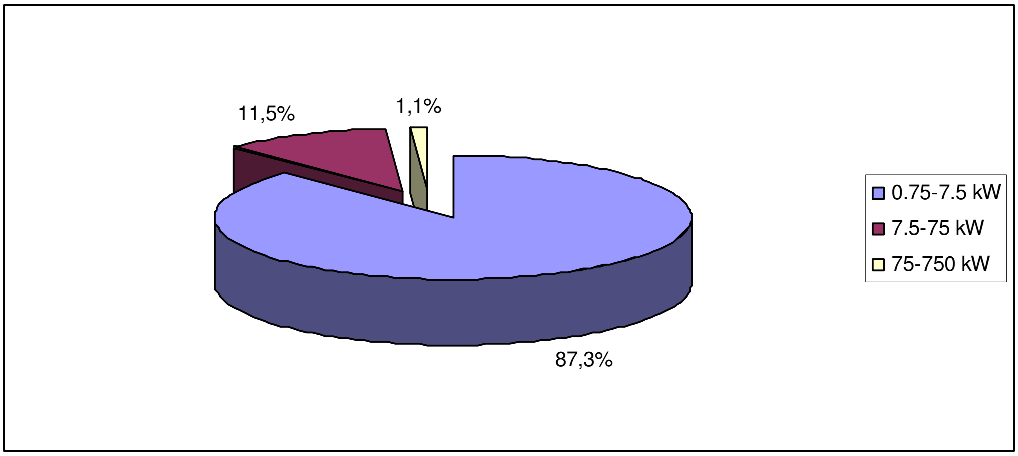


**Figure 2-4 Shipments share of DC integral motors by size in EU-25 (2002)** [21]

The AC integral motors market in Europe is largely dominated by three-phase induction motors, and single-phase motors represents less than 5% of the total integral AC motors in Europe, as can be seen in Figure 2-5.

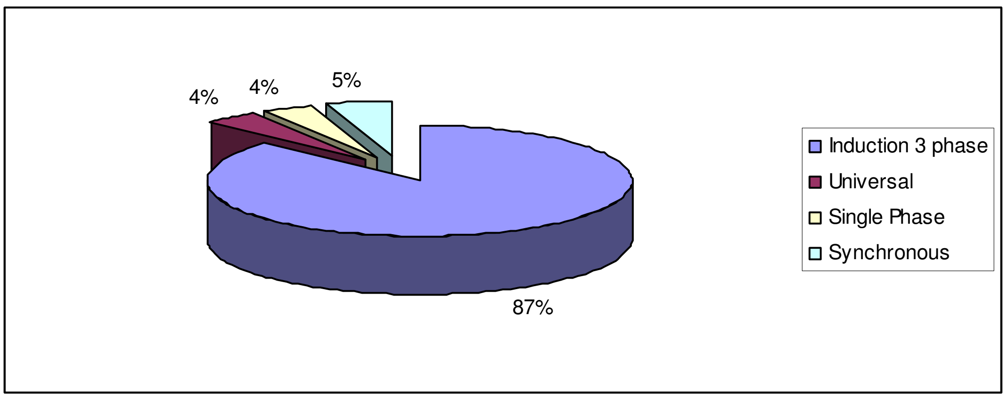


**Figure 2-5 Projected revenues - share of integral AC motors in EU-25 (2006)** [21]

Figure 2-6 shows the market characterization of AC motors by size.

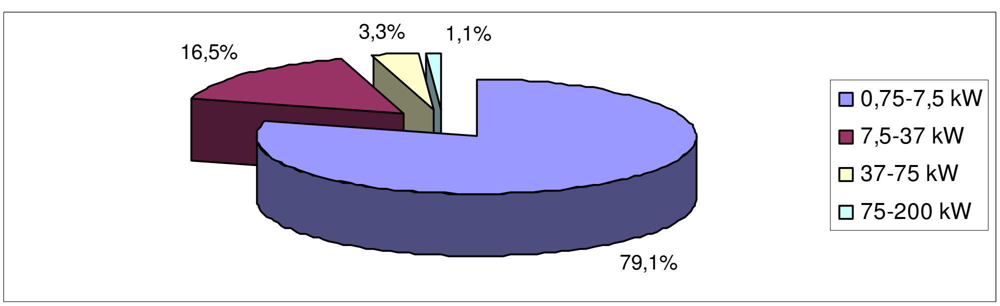


**Figure 2-6 Market share of AC integral motors in units by size in EU-15 (2005)** [22]

The generic economic data of the Low Voltage A.C. motor market in the EU-15 (2006) is shown in Table 2-1 [22]. It is important to notice that motor trade is mainly between European countries. Only 15 to 25% of imports are from outside Europe.

**Table 2-1 EU-15 AC motor market information [22]**

| Power Range | Market EU-15 in Mio. Units | Market Share (Units) | Capacity in Giga Watt | Market Share (Capacity) |
|---|---|---|---|---|
| 0,75-7,5 kW | 7,2 | 79,1% | 22,5 | 28,2% |
| 7,5-37 kW | 1,5 | 16,5% | 30,0 | 37,6% |
| 37-75 kW | 0,3 | 3,3% | 15,6 | 19,6% |
| 75-200 kW | 0,1 | 1,1% | 11,6 | 14,6% |
| **Total** | **9,1** | **100%** | **79,7** | **100%** |

Figure 2-5 shows how AC motor sales are dominated by 3-phase induction motors. By comparison, the other types only account for a total of 11% of sales by value. This market segment is characterised by a wide diversity of designs, many custom made for particular OEM products. Although we do not currently have detailed market statistics on these products, we believe that the very wide variations of these products mean that it is not practical to regard them as commodity products of the type that would be addressed by the EuP Directive. Additionally 3-phase induction motors are also used in applications with a large number of operating hours due to their superior efficiency, robustness and overall cost-effectiveness. In the few cases in which single-phase integral horsepower motors have a relevant electricity consumption, such as air conditioners and heat pumps, efficiency policies are directed at whole equipment and not just the motor, which is customized for each type of equipment.

The low Voltage AC 3-phase motors market share by number of poles is dominated by 4-pole motors as shown in Table 2-2:

**Table 2-2 EU-15 and EU-25 market information** [22]

| Motor type | Share (%) |
|---|---|
| 2-pole | 15-35 |
| 4-pole | 50-70 |
| 6-pole | 7-15 |
| 8-pole | 1-7 |

## *2.2 Market and stock data*

The estimation of the Low Voltage AC motor market in the EU-15 and EU-25 is shown in Figure 2-7 [23].

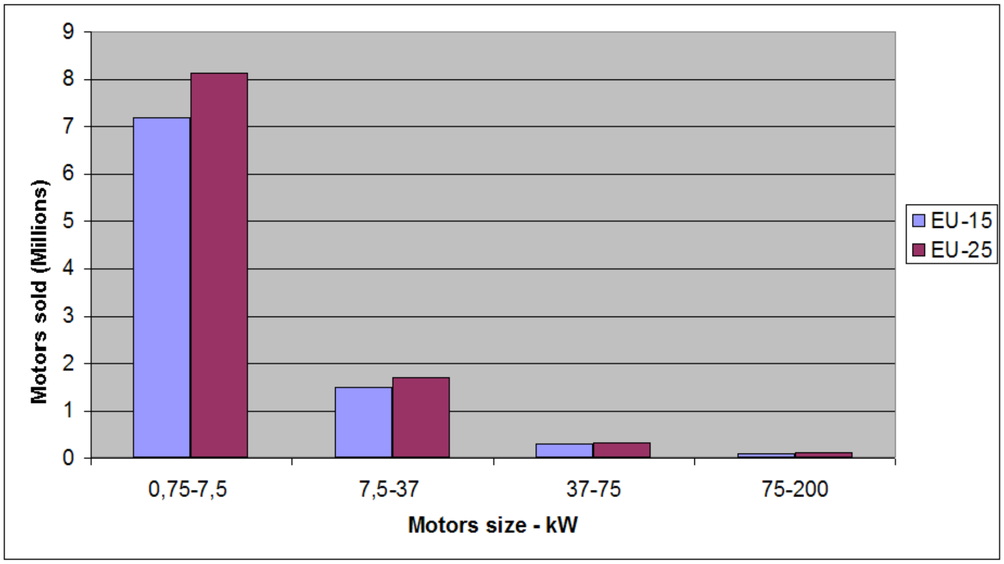


**Figure 2-7 EU-15 and EU-25 market information (low voltage A. C. motors), 2005**

Tables 2-3 and 2-4 show the evolution of 3-phase induction motors' stock, for EU-15, based on the installed base [30] and on the expected evolution of electricity consumption in the respective sectors [38].

**Table 2-3 3-phase induction motors' installed base for EU-15 – Industry (Million units)**

| | 1992 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|
| 0,75 - 7,5 | 40,2 | 46,0 | 49,0 | 52,7 | 55,4 | 57,3 | 59,2 | 60,1 |
| 7,5 - 37 | 4,71 | 5,39 | 5,74 | 6,17 | 6,48 | 6,71 | 6,93 | 7,04 |
| 37 - 75 | 1,06 | 1,22 | 1,30 | 1,39 | 1,46 | 1,51 | 1,56 | 1,59 |
| >75 | 0,66 | 0,76 | 0,81 | 0,87 | 0,91 | 0,95 | 0,98 | 0,99 |
| **Total** | **46,6** | **53,4** | **56,9** | **61,1** | **64,26** | **66,5** | **68,6** | **69,7** |

**Table 2-4 3-phase induction motors' installed base for EU-15 – Tertiary Sector**

| | 1992 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|
| 0,75 - 7,5 | 20,9 | 23,8 | 27,7 | 32,2 | 36,6 | 40,2 | 43,2 | 45,4 |
| 7,5 - 37 | 2,07 | 2,36 | 2,75 | 3,19 | 3,62 | 3,98 | 4,28 | 4,50 |
| 37 - 75 | 0,21 | 0,23 | 0,27 | 0,32 | 0,36 | 0,40 | 0,43 | 0,45 |
| >75 | 0,03 | 0,04 | 0,04 | 0,05 | 0,06 | 0,06 | 0,07 | 0,07 |
| **Total** | **23,2** | **26,4** | **30,8** | **35,7** | **40,6** | **44,6** | **48,0** | **50,5** |

## *2.3 Market trends*

The trends show that the DC motors market share is projected to see a decline in the next few years (three-phase induction motors can have a high dynamic performance when fed by VSDs, cost less and require much less maintenance). The number of brushed DC motors sold is projected to drop sharply at a 10-15% rate per year from around 300.000 units sold today. Large manufacturers have stopped new developments in these motors for several years.

All of the DC motor types are expected to see a decline in sales, except for brushless permanent magnet DC motors. These motors have high efficiency and overcome the reliability limitations of conventional DC motors, but they are more expensive (due to the cost of permanent magnets and of the electronic controls), being mostly used in premium motion control applications. These motors are still highly customized without suitable standards (e.g. dimensions, mounting, power, torque specifications, etc.) to allow a market to develop. Because of increasing production their cost has been decreasing and may become a key player particularly in the low power range [0,75-5 kW]. Innovative approaches are being undertaken in brushless DC motors, using low cost magnetic materials for applications not requiring high torque/weight ratio (e.g. fans).

In the AC motor market, a slight increase in the demand for three-phase induction motors is expected as customers continue to upgrade old technologies taking into account the more favourable economic climate. All other AC motor types are expected to maintain their market share, as they are much more specialized items, except for single-phase integral motors which will face a decrease in demand due to the increased use of electronic speed controls. These controls allow a single-phase supply to feed a cheaper and comparatively more efficient 3-phase motor.

**EU Induction Motor Market**

In EU, the original target of CEMEP/EU agreement was to reduce joint sales of EFF3 motors by 50% after agreement period (2003). The aim was completely achieved, since EFF3 motor sales decreased from 68% in 1998 to 4% in 2005. On the other hand, penetration of EFF1 efficiency motors was very small until now. The main reason for this situation is due to the fact that the motor market is largely an OEM market, in which OEM purchases represent 80-90 % of the sales. This large share of the market combined with the higher EFF1 prices, which typically are 20-30% above EFF2 motors price, leads to a low penetration of EFF1 motors. Motor manufacturers were able to introduce EFF2 motors with a similar price to EFF3 motors, by improved design, manufacturing and more competitive marketing.

The updating of this voluntary agreement is now being prepared.

Figures 2-8, 2-9 and 2-10 show the market transformation and energy saved following the introduction of the CEMEP/EU agreement in the EU.

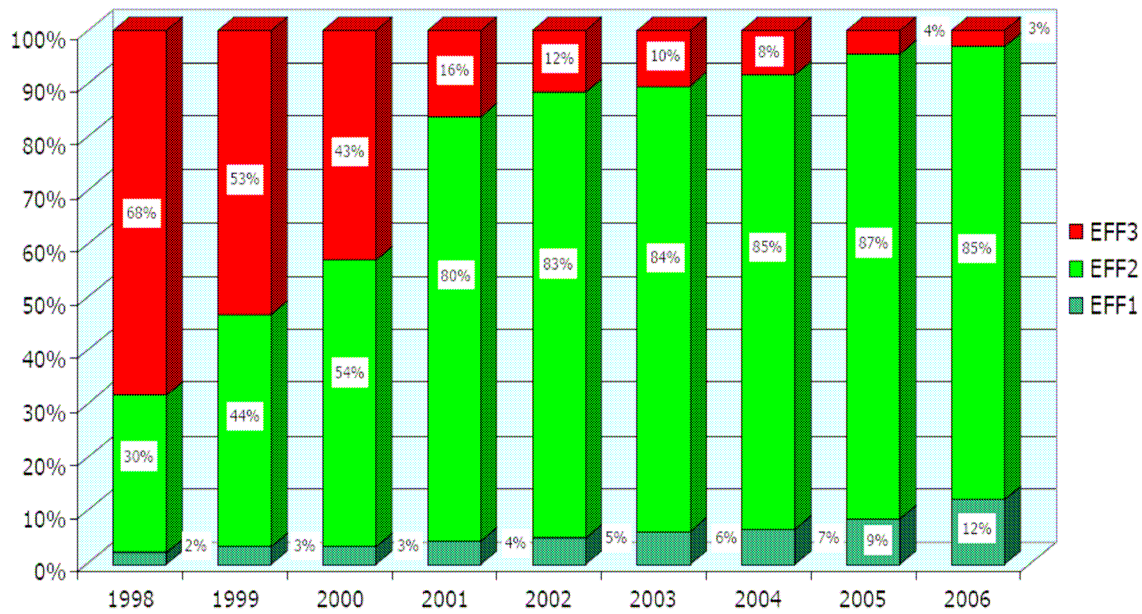


**Figure 2-8 Total motor-sales in the scope of the CEMEP/EU Voluntary Agreement in the period 1998-2006 [22]**

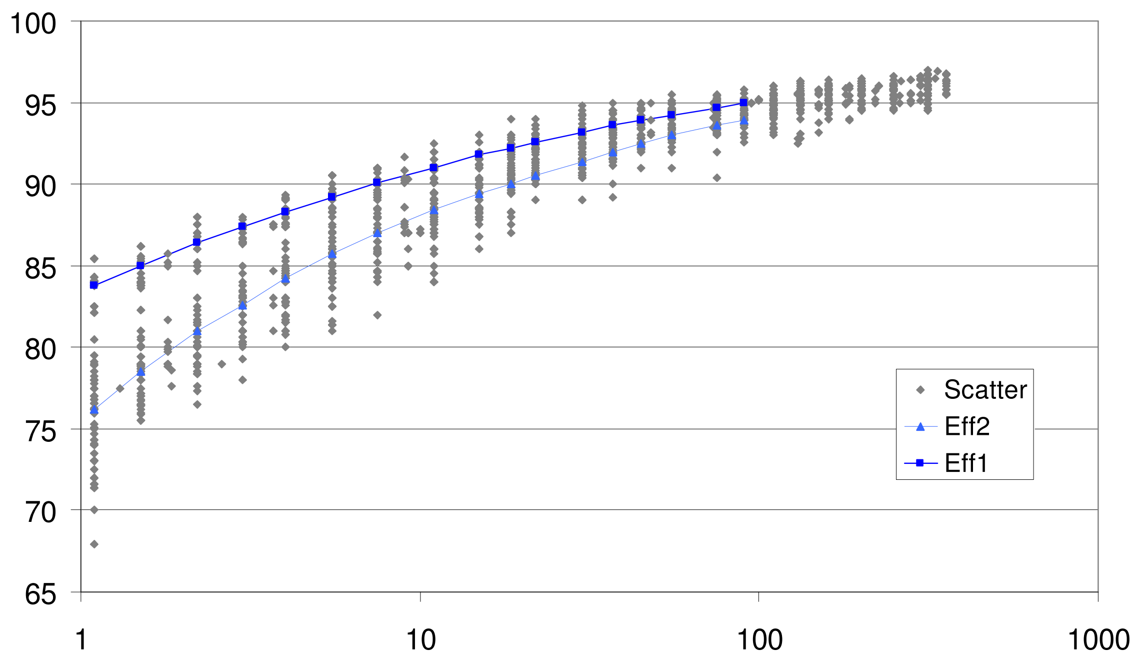


**Figure 2-9 4-Pole motor motors distribution in EU– 50 Hz, based on the EURODEEM efficiency distribution (1999), showing few high-efficiency motors available in the market at the time [24]**

EURODEEM is the European Database of Efficient Electric Motors
http://re.jrc.cec.eu.int/energyefficiency/eurodeem

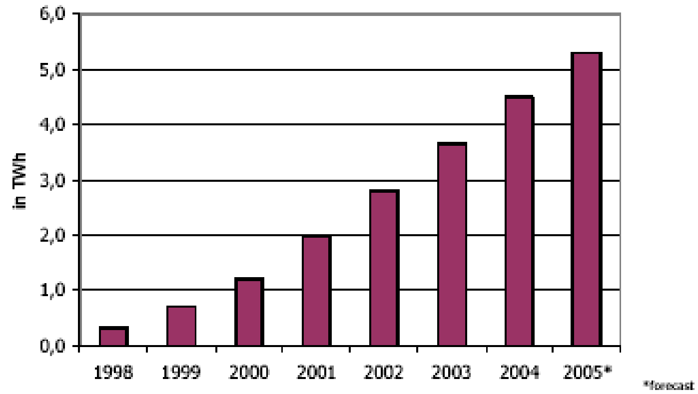


**Figure 2-10 Energy-Saving by the use of energy-saving motors in Europe [22]**

### US Induction Motor Market

In 1992, the US Congress approved the Energy Policy Act (EPAct), which granted the USA Department of Energy (DOE) the authority to set minimum efficiency standards for electric motors to be sold in the US. These mandatory standards became effective in October 1997. At the time market sales for the same level of efficiency is estimated at around 15%. Today EPAct motors constitute 54% of the integral horsepower induction motor market.

Since many of the motors sold exceeded these minimum requirements, and the industry continued to improve their products efficiency, NEMA created, in June 2001, a special label for motors which have very high efficiency levels designated NEMA Premium.

The Consortium for Energy Efficiency (CEE), a non-profit organization that includes many electric utilities among its members, recognizes NEMA Premium motors up to 200 hp as meeting their criteria for possible energy efficiency rebates.

In 2001–2002 the total net units shipped went up approximately 30 percent. In 2002–2003 there was a 14 percent increase over the previous years.

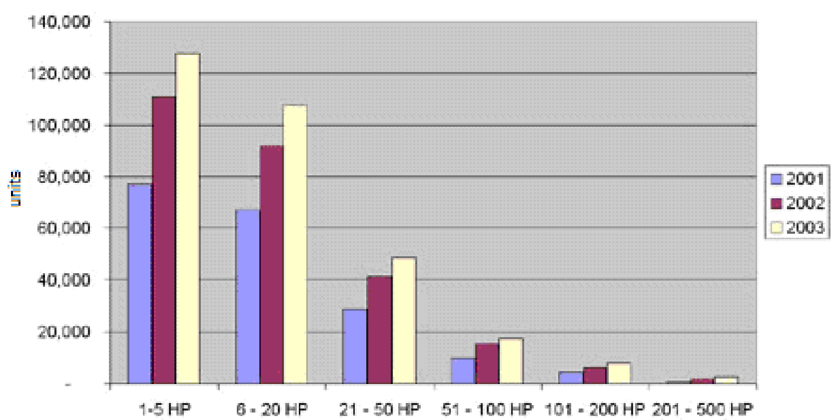


**Figure 2-11 NEMA Premium motors shipped 2001-2003**

Sales in 2002 were less than 300.000 units (less than 5%). In 2005 NEMA Premium motors represented 16% of market sales in the USA.

The penetration of high efficiency motors in the US market is currently much better than that of the EU. This can be understood by the different efficiency levels used for market transformation in both regions (The CEMEP/EU agreement is not aimed at EFF1 or Premium motors). High efficiency and Premium motors now account for more than two thirds of motor sales in North America (USA, Canada and Mexico).

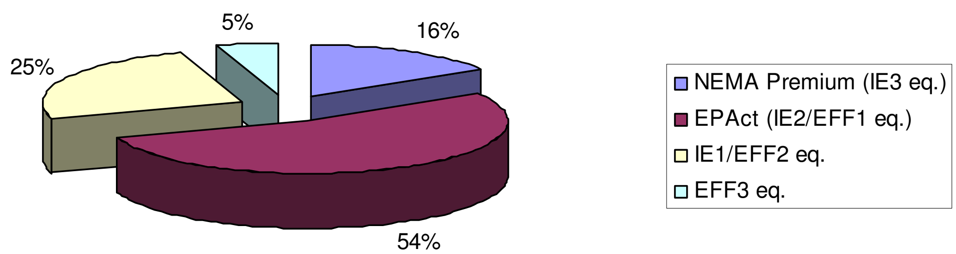


**Figure 2-12 Efficient Motor Market in USA (2005)**

The EU (50Hz) and US (60Hz) motor markets have the same key players and use the same design techniques and materials. Market transformation has been initiated mostly in 60Hz markets and lessons learned may influence the 50Hz markets.

## *2.4 Consumer expenditure*

### 2.4.1 Motor Prices

In terms of price distribution, the average list price of a motor ranged from around €160 for an EFF2 three-phase AC induction motor of 0,75 kW to around € 15000 for a 200 kW AC motor. In general the market is very competitive with large discounts offered to OEMS, although there are lesser pressures at higher power ratings as the degree of competition is not considered as fierce. Based on consultation with manufacturers a 40% discount below list price is assumed for this study. The value of a IE2/EFF1 motor is estimated at around 20-30% higher cost than an EFF2 motor, which accounts for the vast majority of sales in the market. Prices for IE3/Premium motors can be 40-60% higher than the price of an EFF2 motor. The difference is attenuated as power grows.

### 2.4.2 Electricity prices

Electricity prices vary significantly in the EU, and even in each country the prices are strongly influenced by the consumption level. EUROSTAT has different data, for different years, for the industrial electricity prices, considering the average prices and prices for SMEs.

The electricity prices for industry in EU-25 in January 2006 are shown in Table 2-5.

**Table 2-5 Electricity prices for EU-25 (Jan 2007)** [29]

| Country | Cost of electricity (euros/kWh) - industrial | Cost of electricity (euros/kWh) - domestic |
|---|---|---|
| EU (25 countries) | 0,0754 | 0,1078 |
| EU (15 countries) | 0,0766 | 0,1094 |
| Belgium | 0,083 | : |
| Bulgaria | 0,046 | 0,114 |
| Czech Republic | 0,0731 | 0,1123 |
| Denmark | 0,0724 | 0,0552 |
| Germany (including ex-GDR from 1991) | 0,0871 | 0,0829 |
| Estonia | 0,0511 | 0,0997 |
| Ireland | 0,0998 | 0,1374 |
| Greece | 0,0668 | 0,062 |
| Spain | 0,0721 | 0,1285 |
| France | 0,0533 | 0,0643 |
| Italy | 0,0934 | 0,094 |
| Cyprus | 0,1114 | 0,0905 |
| Latvia | 0,0409 | 0,1548 |
| Lithuania | 0,0498 | 0,1225 |
| Luxembourg (Grand-Duché) | 0,0845 | 0,0702 |
| Hungary | 0,0753 | 0,0609 |
| Malta | 0,0711 | 0,139 |
| Netherlands | 0,0855 | 0,0896 |
| Austria | 0,0653 | 0,0904 |
| Poland | 0,0543 | 0,1207 |
| Portugal | 0,0817 | 0,0894 |
| Romania | 0,0773 | 0,0923 |
| Slovenia | 0,0651 | 0,134 |
| Slovakia | 0,0773 | 0,0792 |
| Finland | 0,0517 | 0,0874 |
| Sweden | 0,0587 | 0,1216 |
| United Kingdom | 0,0799 | 0,0809 |
| Croatia | 0,0596 | 0,0876 |
| Turkey | : | 0,0971 |
| Iceland | : | 0,0759 |
| Norway | 0,052 | : |

The prices presented in Table 2-5 refer to ‘medium sized household’ (annual consumption of 3,500 kWh of which 1300 during night).

The industrial prices presented here are based on a medium sized industrial consumer on a non-interruptible contract with a maximum demand of 500 kW and using 2 000 MWh of electricity annually.

### 2.4.3 Repair and maintenance costs

Motor larger than 5 kW are normally repaired when they fail. In general, for small motors it is not economical to repair them, if they need to be rewound. However the stator windings have become very reliable due to the use of improved insulation materials. This means that nowadays most small motors are also repaired.

From a study at a large chemical plant in Germany (Fa. Hüls AG) [39] the distribution of long-time failures was the following:

- Bearing failures (76%)

- Other mechanical parts (14%)

- Stator Winding (6%)

- Rotor Winding (4%)

Typically, the repair process includes bearing replacement and if necessary rewinding. Provided that rewinding is done following good practice recommendations, no significant decrease in efficiency occurs [34].

Of course, good practice recommendations are not always followed. Previous detailed studies identified an average 1.5 % decrease in efficiency per rewinding [26].

A motor is normally repaired at least 2 times during its lifetime but this can occur up to 4 times [26].

Figure 2-13 allows the comparison between repair prices and new motor prices by power. It shows that for smaller motors the repair price exceeds the new motor price.

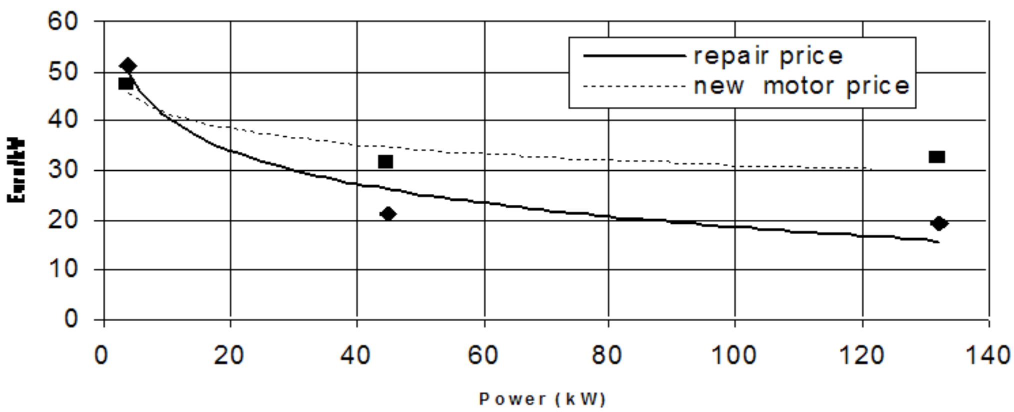


**Figure 2-13 Comparison between repair prices and new motor prices [26]**

## *2.5 Summary*

The developments in power electronics in the last decades allowed induction motors to achieve the same or even better torque/speed performance of DC motors in high demand applications, but with much higher reliability, leading to a shift away from DC solutions in industry.

Nowadays, AC motors completely dominate motors sales representing 96% of all motors sold.

The AC market is, in its turn, dominated by three-phase induction motors which represent 87% of AC motors sold.

Brushless Electronically Commutated Permanent Magnet motors are one technology that has seen an increase in demand, especially in premium motion control applications. This type of motor is expected to gain market importance in the low power range [0,75-5 kW].

The market for efficient motors in the EU has seen a significant transformation following the introduction of the CEMEP/EU agreement. EFF3 motors have essentially been removed from the market which is now dominated by EFF2 motors (87% of motors sold). This has been a positive development, but the penetration of EFF1 motors is still very small (9% of motors sold).

On the other hand, the North American motor market, which has been subject to mandatory policies regarding motor efficiency since 1997 has witnessed a much more effective market transformation. EPAct motors (equivalent to EFF1 motors) and NEMA Premium motors (about 15% lower losses than EFF1 motors) now account for 70% of the market.

It is to be noted that for motors using the same amount of active materials, leading to similar torque, the operation at 60 Hz will provide slightly higher efficiency, because although some losses increase with the frequency (e.g. the mechanical losses and magnetic losses) the output power increases more intensively.

# 3 Consumer analysis and local infrastructure

Consumer behaviour can influence the environmental impact of the product during its life cycle. This section aims at identifying these user parameters and also the barriers to possible eco-design measures, due to social, cultural or infra-structural factors.

## *3.1 Identification of possible barriers to eco-design innovations*

Previous studies [1] [30] identified a number of constraints to the penetration of more efficient motors.

### 3.1.1 Market structure

The motor market, particularly the low and medium power ranges, is largely an OEM market, in which OEM purchases represent 80-90 % of the sales. In the EU this large share of the market, combined with the higher EFF1 prices, which typically are 20-30% above EFF2 motors price, leads to a low penetration of EFF1 motors. OEM manufacturers tend to base their purchases on motor cost, since they will not pay the motor operating costs.

### 3.1.2 Efficiency of low importance

When considering several alternative motors for an application, other factors such as availability, service, and known brand name are usually more important than efficiency. Although first cost is often regarded as being the principle barrier to the specification of EEMs, many users actually consider these other factors to be of at least the same importance.

### 3.1.3 Ambiguous definition of motor efficiency

As mentioned above, diverse efficiency test methods result in different values causing some scepticism among purchasers regarding nominal efficiency.

### 3.1.4 Motors not interesting

Motors are seen as being of low interest by many non-technical personnel, and the relatively small improvements in efficiency possible seem just too low to get very excited about.  A site-wide approach is therefore a good option to promote, but this can involve considerable work to develop and to get all affected parties to agree to.

### 3.1.5 Split budgets

There can be a situation in which one budget is used to spend money so that another budget can show savings. For instance, investing in new parts of a compressed air or pump system can be the responsibility of the maintenance department and earmarked for its budget, while the savings due to energy efficiency accrue to a budget of general costs.

It also happens that the energy costs are not apportioned to individual production areas; another case where little incentive is generated to reduce energy use.

### 3.1.6 Stocks of old motors

Many sites have stocks of older “salvaged” motors, and there is a natural tendency to use these “free” motors rather than purchase new motors.

### 3.1.7 Company motor specifications

Many larger organisations have their own specification of motors, which may limit choice by either insisting that all motors are designed for operation in their worse case application, or trivial considerations such as colour.

### 3.1.8 Repair of failed motors

For maintenance personnel, the need for rapid vital plant to be brought on line again as soon as possible, will mean that when a motor fails they will do whatever is quickest. Very often it will be quickest to have the failed motor repaired rather than replaced, and as well documented elsewhere this will very likely lead to a decrease in efficiency. This is technically the lowest risk option too, an important consideration when the costs of downtime are high.

### 3.1.9 Economical factors

Generally, it does not compensate economically to substitute motors until they fail. So, although personnel are aware of the problems that come with the use of, for example, oversized or older "imperial" motors, it is not realistic to change them.

## *3.2 Real load efficiency (vs. nominal)*

The nominal efficiency represents the average value of a representative sample of manufactured motors for each product category. The motor real full load efficiency can deviate from the nominal efficiency, due to several effects, namely the following:

-Testing errors. Round-robin tests with the same motors performed in different laboratories, using direct test methods (e.g. IEEE 112-B), lead to maximum errors of near 10%.

-Different characteristics of raw materials (particularly magnetic steel) and manufacturing tolerances can lead to a variation of up to 10% in the motor losses.

In USA NEMA allows a maximum 20% tolerance in the losses, tested in at least 5 motors, which applied to the nominal efficiency, leads to the minimum guaranteed efficiency.

The induction motor efficiency also varies with the load, as it can be seen in the next figure. Motor efficiency drops sharply below 50% load due to the constant load losses (mechanical and magnetic losses show little change with the load).

Sometimes, and for short periods, motors can be operated above 100% load. Over this point, a slight decrease in efficiency is observed. Typically, a service factor of 1.15 (this represents a 15% overload) is permitted, without damage to the motor.

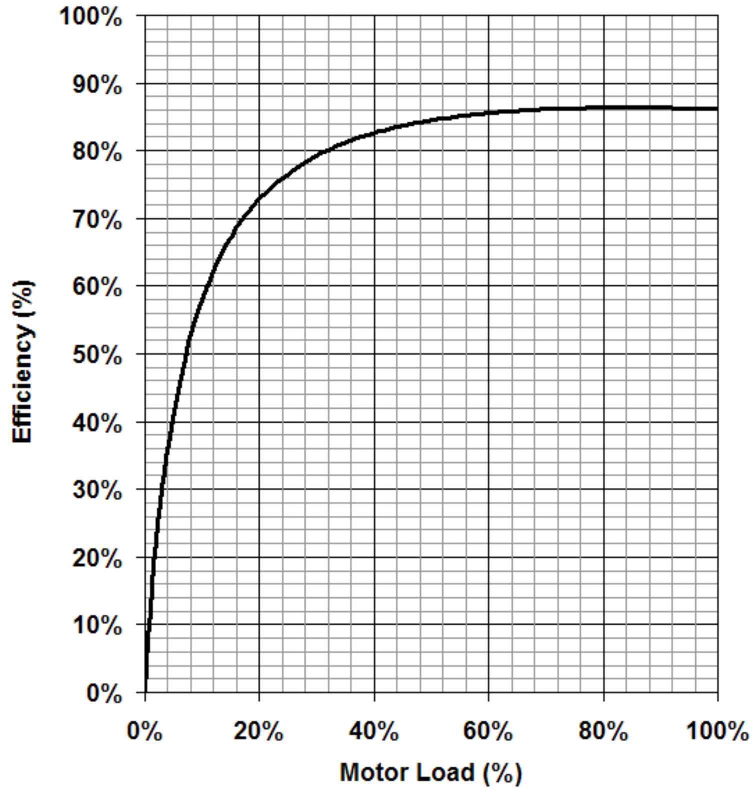


**Figure 3-1 Motor efficiency vs. motor load for a standard 3-Phase, 4-pole, 11-kW, Squirrel-Cage Induction Motor.**

Typically, the maximum efficiency is obtained in the range 60-100% of motor load, although the maximum efficiency operating point is dependent upon the motor design.

## *3.3 Dosage of auxiliary inputs during use*

Larger motors are periodically lubricated. Most motors are subjected to repair upon failure (or show signs of imminent failure). In this operation new copper windings and bearings are installed. Old bearings and copper wire can be recycled.

## *3.4 Economical Product Life (=in practice)*

Motor lifetime is influenced by many factors including number of operating hours, load factor including possible overloading, frequency of start/stop cycles, power quality and environmental conditions (temperature, vibrations, humidity, chemical pollutions).

The average life of AC induction motors (including repairs) varies according to the motor power and is shown in Table 3-1.

**Table 3-1 Average motor life** [2]

| Power range | Average life – years |
|---|---|
| 1.0 – 7.5 kW | 12 |
| 7.5 – 75 kW | 15 |
| 75 – 250 kW | 20 |

As mentioned earlier, small motors (up to 5 kW) are normally not repaired if they need to be rewound. However, since bearing failure is the most common cause of failure its replacement is done. Nevertheless, motors with a high number of operating hours typically have a lower number of start-stop cycles leading to longer lifetime.

Another critical factor is the bearing load which influences the bearing failures:

The bearings of small and medium sized motors are typically designed for a nominal lifespan of 20.000 hours:

L10h = aDIN x 1.000.000 / (60 x n) x (C/P)^3

with

L10h = Life Time in hours
aDIN = correction factor depending on greasing conditions (typically aDIN = 2)
n = rotational speed in rpm (1.500 for 4-pole)
C = characteristic for the capabilities of the selected type of bearing
P = average load of the bearing (calculated from the actual axial and actual radial force)

Partial loading (i.e. reduction of P with a 60% average load) increases lifetime by a factor of 4.6, so for a typical machine the lifetime 92.600 hours.

The life of small brushed DC motors is mainly limited by the lifetime of the brushes and of the commutator. In most applications where small power DC motors are used (e.g. small appliances) brushes are not checked for wear or replaced and so the motor's life is equal to the lifetime of the brushes.

General purpose DC motors operating at moderate speeds (750-1300 rpm) have an estimated 7500 hours brush life. The minimum life might be 2000–5000 hours, with 10000 h being about maximum. It is not uncommon, however, for motors with light or variable loads, such as machine tool motors, to have brush life that is less than 2000 hours [36].

The lifetime of Universal motors, which also use a commutator and brushes, rarely exceeds 1000 hours since they normally operate at much higher speeds.

## *3.5 End-of-Life actual behaviour (present fractions to recycling, re-use, disposal, etc)*

As a default, end-of-life behaviour fractions used in the MEEUP EcoReport for materials in all products across the EC will be used.

## *3.6 Best Practice in Sustainable product use*

High efficiency motors, such as EFF1, seem a good option for most industrial applications. In some situations the use of high efficiency motors may not be the best technical or economical choice, namely in the following cases:

-In applications in which the number of operating hours is small (e.g. emergency pumps and ventilators) high efficiency motors may lead to higher lifecycle costs.

-High efficiency motors, because of lower rotor slip, normally have a higher rotating speed than standard efficiency motors. In retrofit applications, when driving loads such as centrifugal pumps or fans, the power consumption of the high efficiency motor may be higher, because of the sharp increase of the mechanical power of the load with the motor speed (it grows approximately with the cube of the speed). This can easily be corrected by downsizing the motor when replacing it.

In the future, IE3/Premium efficiency motors may be considered for applications with a large number of operating hours.

Another problem normally affecting electric motors operation is oversizing. Designers tend to oversize motors aiming at the improvement of:

- the systems reliability
- the starting torque
- the ability to accommodate increasing power requirements
- the allowance for higher load fluctuations
- the operation under adverse conditions (like voltage unbalance or undervoltage)
- the inventory of spare parts

As shown in Figure 3-1, motor efficiency remains almost constant from 75% to full-load and it normally drops sharply below 50%. This effect is more noticeable for small motors. So, even the benefits of using a more efficient motor can be wasted if the load-factor is abnormally low.

There is also a need to consider the efficiency of the whole motor systems, in which a much higher savings potential is normally available (typically 25-30%). Electric motors can only tap about 10% of the available savings potential. As an example, figure 3-2 shows possible improvements in several parts of a pumping system.

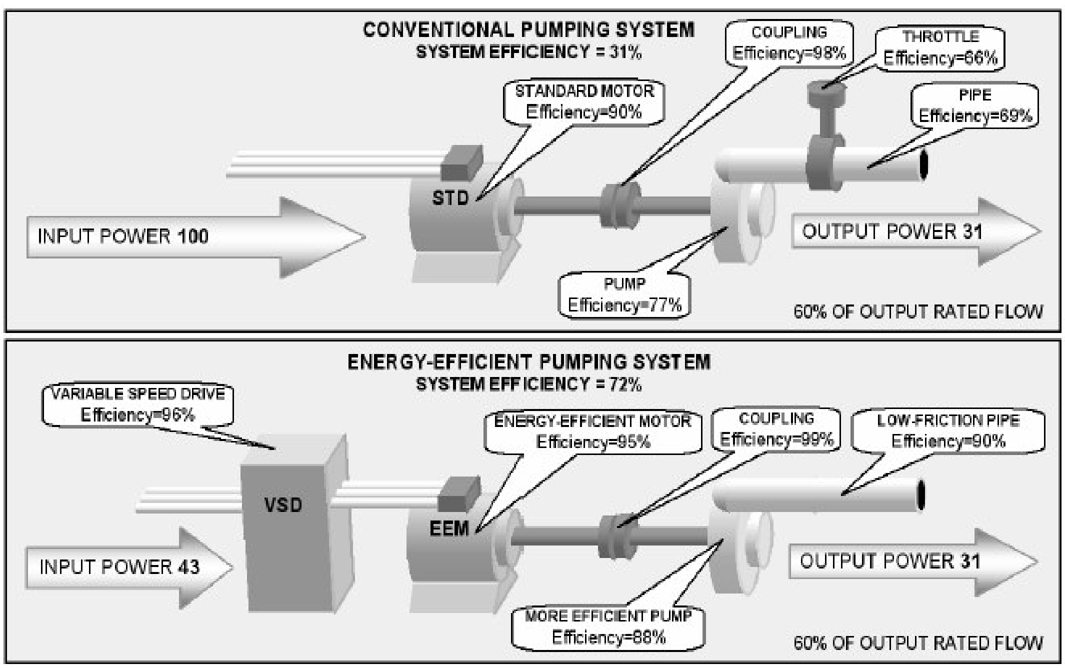


**Figure 3-2 Efficiency of an electric motor system, showing the energy saving potential[27]**

## *3.7 Local infrastructure (energy, water, telecom, physical distribution, etc.)*

High efficiency motors not only lead to electricity savings, but also to similar demand savings. Since most industrial motors operate a large number of hours per year, it is expected that the percentage demand reduction is similar to the equivalent percentage related to the energy savings. Therefore, this demand reduction translates into additional economic benefits since there is less need to invest in the expansion to the power system infrastructure (generation, transmission and distribution). Additionally there will be a small reduction in the transmission and distribution losses both in the network and inside the industrial plants.

## *3.8 Summary*

This section identified possible barriers to the introduction of eco-design measures.

The motor market structure, which is largely a OEM market, the ambiguous definition of motor efficiency, the use of repaired motors and the resistance to replacement of old motors are just some of these key barriers. Also, lifetimes of motors, repair practices, and end-of-life behaviour were analysed.

The consumer behaviours that can influence the environmental impact of motors have also been identified.

The importance of correct sizing the motor and optimum design of the motor system to which it is connected is stressed in this chapter, as it is very important in reducing energy consumption.

# 4 Technical analysis existing products

This section entails a general technical analysis of current products, as defined in section 1, and provides general inputs for the definition of the BaseCases.

## *4.1 Production phase*

The material composition of electric motors is presented in the following BoMs provided by manufacturers and repairers.

In order to use a neutral and highly representative source, CEMEP[3] agreed to collect data from manufacturers and produced bill-of-materials (BoMs) for EFF2 and EFF1 motors, for the defined individual motor rated powers:

- 1.1 kW, 11 kW and 110 kW, all having 4 poles

This data will be used in the definition of the BaseCase models and the evaluation of best available technologies (BAT).

Table 4-1, shows BoMs for IE1/EFF2 motors of the agreed reference output powers.

**Table 4-1 Bill-of-Materials for EFF2 motors (materials average values).**

| **Materials** | **Motor Rated Power** | | |
|---|---|---|---|
| | **1,1 kW** | **11 kW** | **110 kW** |
| Electrical steel (kg/kW) | 5,40 | 3,60 | 3,10 |
| Other steel (kg/kW) | 1,50 | 0,95 | 0,67 |
| Cast iron (kg/kW) | 2,5 (0,0 - 5,0) | 1,3 (0,0 - 2,0) | 3,00 |
| Aluminium (kg/kW) | 1,7 (0,5 - 2,5) | 0,9 (0,2 - 1,5) | 0,18 |
| Copper (kg/kW) | 1,24 | 0,64 | 0,54 |
| Insulation material (kg/kW) | 0,05 | 0,02 | 0,01 |
| Packing material (kg/kW) | 1,00 | 0,90 | 0,50 |
| Impregnation resin (kg/kW) | 0,30 | 0,10 | 0,05 |
| Paint (kg/kW) | 0,10 | 0,05 | 0,01 |

Table 4-2, shows BoMs for IE2/EFF1 motors of the agreed reference output powers.

[3] CEMEP - Comité Européen de Constructeurs de Machines Electriques et d'Electronique de Puissance (European Committee of Manufacturers of Electrical Machines and Power Electronics).

**Table 4-2 Bill-of-Materials for EFF1 motors (materials average values).**

| Materials | Motor Rated Power | | |
|---|---|---|---|
| | 1,1 kW | 11 kW | 110 kW |
| Electrical steel (kg/kW) | 8 | 4,8 | 3,6 |
| Other steel (kg/kW) | 1,6 | 1 | 0,7 |
| Cast iron (kg/kW) | 2,5 (0,0 - 5,0) | 1 (0,0 - 2,0) | 3 |
| Aluminium (kg/kW) | 0,5 - 4,0 | 0,25 - 1,8 | 0,2 |
| Copper (kg/kW) | 1,9 | 0,9 | 0,6 |
| Insulation material (kg/kW) | 0,05 | 0,02 | 0,01 |
| Packing material (kg/kW) | 1 | 0,9 | 0,5 |
| Impregnation resin (kg/kW) | 0,3 | 0,1 | 0,05 |
| Paint (kg/kW) | 0,1 | 0,05 | 0,01 |

A motor design is the balance of different parameters. Therefore the material fractions are only an average value. Depending on the motor design and the steps in lamination diameter, the single value of each different material can deviate from the average value by approximately +/- 40 %.

A major factor in the balance of different parameters is the usage of cast iron or aluminium for the motor case. Therefore, these two materials have got a wide range of values. Their average value is used in the analysis of the BaseCase models and BAT.

## *4.2 Distribution phase*

The average volume of the packaged products for each power level is considered in the analysis of the BaseCase models and BAT.

## *4.3 Use phase*

For motors, the main resource consumed during life is electricity. This topic has been thoroughly studied in [1].

Figure 4-1 shows the motor electricity consumption, and for the other loads, in the surveyed industrial sectors and in the tertiary sector in the European Union. Tables 4-4 and 4-5, show the motor electricity consumption in industrial and tertiary sectors by end-use application, in the European Union, respectively. The methodology used for the estimations presented here can be found in [1].

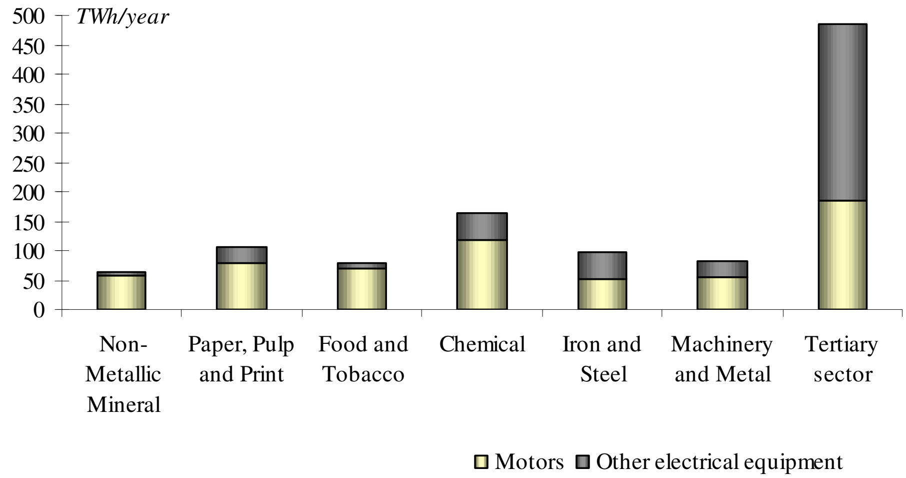


**Figure 4-1 Electricity motor consumption in each industrial sector and in the tertiary sector** [1]

**Table 4-3 Motor electricity annual consumption in industry by end-use applications (EU-25, 2000)**[1]

| End-use applications | Total motor electricity consumption in EU-25 [TWh] | Share of motor electricity consumption in EU-25 [%] |
|---|---|---|
| Conveyors | 13.0 | 2 |
| Cooling compressors | 45.5 | 7 |
| Air compressors | 117.0 | 18 |
| Fans | 104.0 | 16 |
| Pumps | 136.5 | 21 |
| Other motors | 234.0 | 36 |
| TOTAL | 650.0 | 100 |

**Table 4-4 Motor electricity annual consumption in tertiary sector by end-use applications (EU-25, 2000)**[1]

| End-use applications | Total motor electricity consumption in EU-25 [TWh] | Share of motor electricity consumption in EU-25 [%] |
|---|---|---|
| Pumps | 33.1 | 16 |
| Fans | 50.3 | 24 |
| Refrigeration | 54.7 | 26 |
| Air conditioning | 34.8 | 17 |
| Conveyors | 22.9 | 11 |
| Other | 13.8 | 7 |
| TOTAL | 209.7 | 100 |

Figures 4-2 and 4-3 show the motor electricity consumption, the installed motor capacity and the average number of operating hours in the industrial and tertiary sectors, respectively.

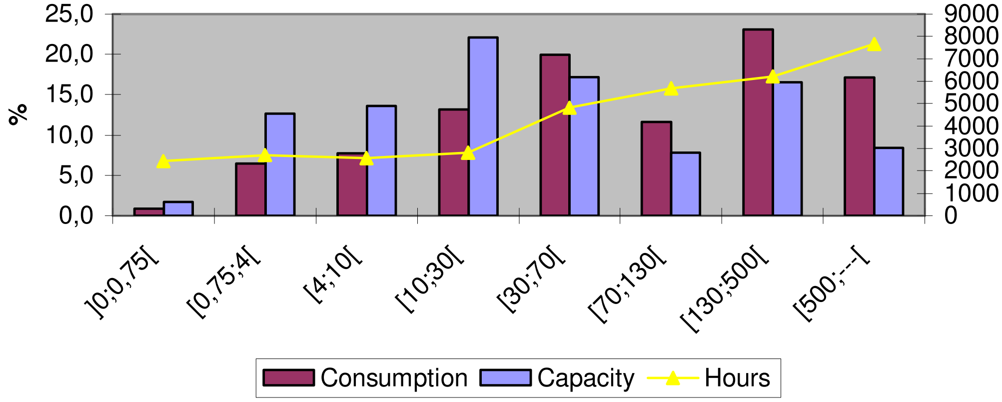


**Figure 4-2 Installed motor capacity, electricity consumption and average operating hours by power range in the industrial sector** [1]

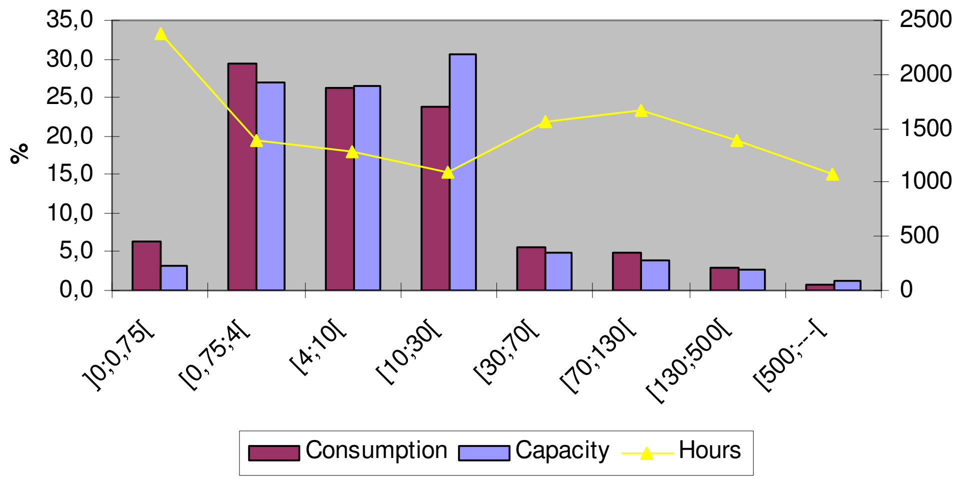


**Figure 4-3 Installed motor capacity, electricity consumption and average operating hours by power range in the tertiary sector** [1]

Figure 4-4 shows the load-factor[4] for motors running in the industrial and tertiary sectors by power range.

[4] The ratio of the average load to the rated output power.

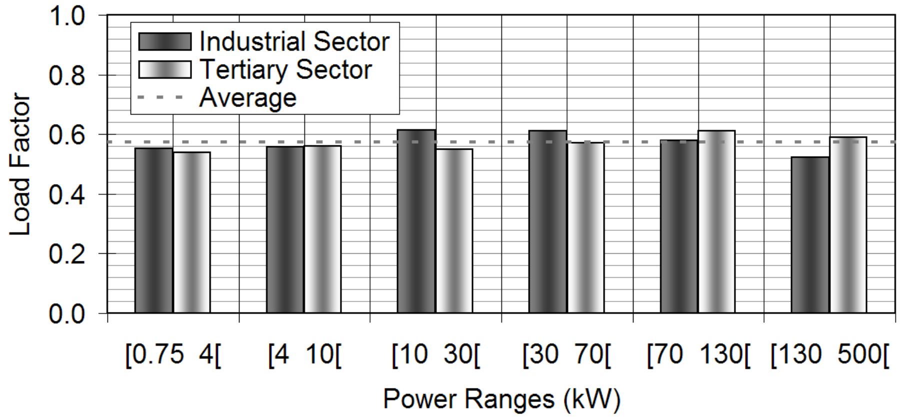


**Figure 4-4 Load Factor in the industrial and tertiary sectors by power range [1]**

## *4.4 Motor system electricity use*

Typically electric motors are a component in a motor system, being responsible for the conversion of electrical power into mechanical power. Therefore, the motor system's consumption corresponds to the electricity consumption of their motors.

Electric motor systems are by far the most important type of electric load in industry, in the EU, using about 70% of the consumed electricity. In the tertiary sector, electric motor systems use one third of the consumed electricity.

There is a potential to improve the energy efficiency of industrial motor systems by roughly 20% to 30%. The three major contributors to these savings are:

- Use of Energy Efficient Motors;
- Use of adjustable-speed drives, where appropriate, to match the speed and the torque to the load requirements; this allows in some cases the replacement of inefficient throttling devices and in other cases the simplification (or even avoidance) of wasteful mechanical transmissions;
- Optimize the complete system, including a correct sized motor, pipes, gears and efficient end-use equipment (fans, pumps, compressors, traction systems) to deliver the required energy service most efficiently. An example of motor system optimization is given in section 3.6

## *4.5 End-of-life phase*

The EcoReport's default values are being used. It is assumed that 5% of the materials go to landfill, 90% of the plastics are incinerated and 10% are recycled and that 95% of the metals and glass is recycled.

## *4.6 Summary*

This section provides the inputs needed to run the MEEUP model. It gives a technical characterization of existing products in what regards use of materials, typical loads, average operating hours and end-of life behaviour.

Bills of materials for the three selected power representative of "small motors" (1.1 kW), "medium motors" (11 kW) and "large motors" (110 kW) are presented.

Average load factor and operating hours were taken from previous studies [1] [30]. Motors typically run with a 0,60 Load Factor. The average operating hours per year are 2250, 3000 and 6000 for 1.1, 11 and 110 kW motors, respectively.

The EcoReport's default end-of-life assumptions are considered for this study.

# 5 Definition of BaseCase

This section will describe the modelling of base case models that provide the reference for the environmental and technical/economical improvements to be established further on.

The description of the BaseCase is the result of previous chapters in what concerns the products' Bill of Materials (BOM) including packaging, estimated volume of the packaged product, energy and other resources consumption during the use-phase and, finally, a scenario for recycling, re-use and disposal.

Figures for EU sales and stock, used for assessing EU total impact and product prices, electricity rates, etc. that serve to make a financial Life Cycle Cost assessment are also taken from previous chapters.

Here, three BaseCase models for three-phase induction motors will be defined for three different output powers, 1.1 kW, 11 kW and 110 kW, to cover the considered power range, all being EFF2 efficiency class, which corresponds to 87% of induction motors sold in Europe.

BaseCase models are defined for Standard and Real-Life situations and for different usage scenarios.

Electric motors are defined as "energy converters" and not as "end-use device". Only the motor losses are really consumed inside the motor, with the remaining consumed energy being transmitted as mechanical power. Therefore, a loss-based environmental analysis is presented in this and the next chapters. LifeCycle Costs are calculated considering the whole energy use.

For the sake of clarity, the main results presented are in summary form in this chapter. A more complete set of results is presented in Appendix II.

## *5.1 Standard BaseCase*

### 5.1.1 Product-specific inputs

#### *5.1.1.1 Bill of Materials (BoM)*

The Bill of Materials for IE2/EFF2 efficiency level motors of the defined power levels were, as mentioned earlier, provided by CEMEP and presented in paragraph 4.1.

The MEEUP model assumes 1% of the total weight as spare parts. This is thought highly inadequate and so, to compensate for this, the equivalent weight of replacement windings and bearings were introduced directly in the bill of materials.

#### *5.1.1.2 Primary scrap production during sheet metal manufacturing*

At this time, the EcoReport default value of 25% will be used.

#### *5.1.1.3 Volume of packaged product*

The average volumes of the packaged products for each output power are:

**Table 5-1 Average volume of packaged products**

| | Motor Rated Power | | |
|---|---|---|---|
| | **1,1 kW** | **11 kW** | **110 kW** |
| Average volume ($m^3$) | 0,02 | 0,15 | 1,1 |

### *5.1.1.4 Use phase*

The inputs for the use phase are:

**Table 5-2 Use phase specific inputs**

| | Motor Rated Power | | |
|---|---|---|---|
| **Variable** | **1,1 kW** | **11 kW** | **110 kW** |
| Lifetime (years) [2] | 12 | 15 | 20 |
| Efficiency (%) [19] | 75,1 | 87,6 | 93,3 |
| Operating hours | 2250 | 3000 | 6000 |
| Distance covered over motor life (km) | -- | 250 | 250 |

In accordance with the used methodology for the standard base case, a load factor of 100% (equal to the test) is used in these calculations. The distance covered over the motor life only includes trips for repair and maintenance. The MEEUP model assumes a distance of 200 Km for the first trip from manufacturer (or retailer) to the installation site.

## 5.1.2 Environmental Impact

Tables 5-3, 5-4 and 5-5 show the environmental impact per product for each of the Standard BaseCase models. It should be noted that in these tables a loss-based environmental impact analysis is presented because electric motors are defined as “energy converters” and not as “end-use device”. Only the motor losses are really consumed inside the motor, with the remaining consumed energy being transmitted as mechanical power.

**Table 5-3 Lifecycle impact (per product) of 1.1 kW motor (IE1), Lifetime 12 years, 2250 hour/year**

| Nr | Life cycle Impact per product: | Date | Author |
|---|---|---|---|
| 0 | 3-Phase AC Induction motor 1.1 kW | 0 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **385** | | | 347 | 39 | **385** | **0** |
| 3 | Ferro | g | | | **10340** | | | 517 | 9823 | **10340** | **0** |
| 4 | Non-ferro | g | | | **3234** | | | 162 | 3072 | **3234** | **0** |
| 5 | Coating | g | | | **110** | | | 6 | 105 | **110** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **14069** | | | 1031 | 13038 | **14069** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 729 | 171 | **900** | **79** | **79389** | 75 | 27 | **48** | **80416** |
| 9 | of which, electricity (in primary MJ) | MJ | 49 | 99 | **148** | **0** | **79381** | 0 | 0 | **0** | **79530** |
| 10 | Water (process) | ltr | 149 | 1 | **150** | **0** | **5293** | 0 | 0 | **0** | **5443** |

| Nr | Resources Use and Emissions | unit | Material | Manuf. | Total | DISTRIBUTION | USE | Disposal | Recycl. | Total | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Water (cooling) | ltr | 251 | 42 | **293** | **0** | **211683** | 0 | 1 | **-1** | **211976** |
| 12 | Waste, non-haz./ landfill | g | 41734 | 808 | **42542** | **64** | **92462** | 930 | 1 | **929** | **135998** |
| 13 | Waste, hazardous/ incinerated | g | 11 | 0 | **11** | **1** | **1829** | 347 | 0 | **346** | **2188** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 51 | 10 | **61** | **6** | **3465** | 6 | 2 | **4** | **3536** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 617 | 42 | **659** | **17** | **20447** | 11 | 2 | **9** | **21132** |
| 17 | Volatile Organic Compounds (VOC) | g | 2 | 0 | **2** | **0** | **30** | 0 | 0 | **0** | **32** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 252 | 20 | **272** | **0** | **523** | 6 | 0 | **6** | **802** |
| 19 | Heavy Metals | mg Ni eq. | 350 | 48 | **398** | **3** | **1366** | 21 | 0 | **21** | **1788** |
| | PAHs | mg Ni eq. | 41 | 0 | **41** | **4** | **157** | 0 | 0 | **0** | **201** |
| 20 | Particulate Matter (PM, dust) | g | 88 | 6 | **94** | **69** | **438** | 98 | 0 | **98** | **698** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 200 | 0 | **200** | **0** | **514** | 6 | 0 | **6** | **720** |
| 22 | Eutrophication | g PO4 | 9 | 0 | **10** | **0** | **3** | 0 | 0 | **0** | **12** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

**Table 5-4 Lifecycle impact (per product) of 11 kW motor (IE1), Lifetime 15 years, 3000 hour/year**

| Nr | Life cycle Impact per product: | Date | Author |
|---|---|---|---|
| 0 | 3-Phase AC Induction motor 11 kW | Dec 2006 | ISR |

| Nr | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | Total | BUTION | | Disposal | Recycl. | Total | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **1320** | | | 1188 | 132 | **1320** | **0** |
| 3 | Ferro | g | | | **64350** | | | 3218 | 61133 | **64350** | **0** |
| 4 | Non-ferro | g | | | **34540** | | | 1727 | 32813 | **34540** | **0** |
| 5 | Coating | g | | | **550** | | | 28 | 523 | **550** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **100760** | | | 6160 | 94600 | **100760** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 6608 | 1057 | **7665** | **255** | **496803** | 459 | 118 | **341** | **505064** |
| 9 | of which, electricity (in primary MJ) | MJ | 272 | 607 | **880** | **0** | **496134** | 0 | 1 | **-1** | **497013** |
| 10 | Water (process) | ltr | 888 | 8 | **896** | **0** | **33084** | 0 | 0 | **0** | **33980** |
| 11 | Water (cooling) | ltr | 1007 | 258 | **1264** | **0** | **1323013** | 0 | 3 | **-3** | **1324274** |
| 12 | Waste, non-haz./ landfill | g | 585327 | 5096 | **590423** | **149** | **581133** | 6784 | 2 | **6782** | **1178487** |
| 13 | Waste, hazardous/ incinerated | g | 58 | 1 | **59** | **3** | **11433** | 1188 | 0 | **1188** | **12682** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 428 | 60 | **489** | **17** | **21702** | 34 | 8 | **26** | **22233** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 8676 | 262 | **8938** | **49** | **127888** | 67 | 11 | **57** | **136932** |
| 17 | Volatile Organic Compounds (VOC) | g | 10 | 1 | **11** | **3** | **197** | 2 | 0 | **2** | **213** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 1626 | 135 | **1760** | **1** | **3269** | 47 | 0 | **47** | **5077** |
| 19 | Heavy Metals | mg Ni eq. | 3120 | 316 | **3436** | **8** | **8676** | 132 | 0 | **132** | **12252** |
| | PAHs | mg Ni eq. | 315 | 0 | **315** | **9** | **1111** | 0 | 0 | **0** | **1435** |
| 20 | Particulate Matter (PM, dust) | g | 537 | 40 | **577** | **513** | **4939** | 597 | 0 | **597** | **6626** |
| | **Emissions (Water)** | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Heavy Metals | mg Hg/20 | 1320 | 0 | **1321** | **0** | **3212** | 38 | 0 | **38** | **4571** |
| 22 | Eutrophication | g PO4 | 50 | 0 | **50** | **0** | **16** | 2 | 0 | **2** | **68** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | | | | | negligible | | | | |

**Table 5-5 Lifecycle impact (per product) of 110 kW motor (IE1), Lifetime 20 years, 6000 hour/year**

| Nr | Life cycle Impact per product: | Date | Author |
|---|---|---|---|
| 0 | 3-Phase AC Induction motor 110 kW | Dec 2006 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **6600** | | | 5940 | 660 | **6600** | **0** |
| 3 | Ferro | g | | | **744700** | | | 37235 | 707465 | **744700** | **0** |
| 4 | Non-ferro | g | | | **227700** | | | 11385 | 216315 | **227700** | **0** |
| 5 | Coating | g | | | **1100** | | | 55 | 1045 | **1100** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **980100** | | | 54615 | 925485 | **980100** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 54362 | 8869 | **63231** | **1544** | **8846434** | 3940 | 602 | **3339** | **8914548** |
| 9 | of which, electricity (in primary MJ) | MJ | 1829 | 5089 | **6918** | **3** | **8845269** | 0 | 3 | **-3** | **8852188** |
| 10 | Water (process) | ltr | 6369 | 69 | **6438** | **0** | **589744** | 0 | 2 | **-2** | **596180** |
| 11 | Water (cooling) | ltr | 5528 | 2149 | **7677** | **0** | **23587277** | 0 | 14 | **-14** | **23594940** |
| 12 | Waste, non-haz./ landfill | g | 5012808 | 43284 | **5056093** | **771** | **10306068** | 63451 | 10 | **63441** | **15426373** |
| 13 | Waste, hazardous/ incinerated | g | 323 | 7 | **329** | **15** | **203823** | 5940 | 2 | **5939** | **210106** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 3575 | 507 | **4082** | **93** | **386087** | 294 | 43 | **251** | **390512** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | | | | | negligible | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 72659 | 2200 | **74860** | **284** | **2278434** | 578 | 55 | **523** | **2354101** |
| 17 | Volatile Organic Compounds (VOC) | g | 103 | 10 | **113** | **23** | **3342** | 16 | 1 | **15** | **3493** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 12338 | 1170 | **13508** | **4** | **58112** | 437 | 0 | **437** | **72061** |
| 19 | Heavy Metals | mg Ni eq. | 24615 | 2740 | **27355** | **39** | **152154** | 1143 | 0 | **1143** | **180690** |
| | PAHs | mg Ni eq. | 3092 | 1 | **3093** | **51** | **17586** | 0 | 0 | **0** | **20730** |
| 20 | Particulate Matter (PM, dust) | g | 7225 | 335 | **7560** | **3761** | **50929** | 5127 | 1 | **5126** | **67376** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 10248 | 1 | **10249** | **1** | **57134** | 328 | 0 | **328** | **67712** |
| 22 | Eutrophication | g PO4 | 313 | 3 | **316** | **0** | **275** | 19 | 0 | **19** | **610** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | | | | | negligible | | | | |

It should be noted that the use-phase clearly has the most impact, completely dominating the life-cycle impact of the product.

**Table 5-6 Percentage of use-phase impact of base cases, considering only losses.**

| | Motor Rated Power | | |
|---|---|---|---|
| **Main Indicators** | **1.1 kW** | **11 kW** | **110 kW** |
| Total Energy, (GER) | 98,72% | 98,36% | 99,24% |
| Of which, electricity | 99,81% | 99,82% | 99,92% |
| Water (process) | 97,25% | 97,36% | 98,92% |
| Waste, non-hazardous/landfill | 67,99% | 49,31% | 66,81% |
| Waste, hazardous/incinerated | 83,60% | 90,15% | 97,01% |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 | 97,99% | 97,61% | 98,87% |
| Acidification Agents, AP | 96,76% | 93,40% | 96,79% |
| Volatile Organic Compounds, VOC | 92,52% | 92,51% | 95,68% |
| Persistent Organic Pollutants, POP | 65,22% | 64,39% | 80,64% |
| Heavy Metals, HM | 76,37% | 70,82% | 84,21% |
| PAHs | 77,83% | 77,41% | 84,83% |
| Particulate Matter, PM, dust | 62,66% | 74,55% | 75,59% |
| **Emissions to the Water** | | | |
| Heavy Metals, HM | 71,32% | 70,27% | 84,38% |
| Eutrophication, EP | 20,45% | 23,12% | 45,13% |

### 5.1.3 Life Cycle Costs of Standard BaseCase Models

The lifecycle costs of the standard BaseCase models are presented in Table 5-7. In all the presented LCC analysis, the total consumed energy and a discount rate (interest minus inflation) of 2% are considered.

**Table 5-7 LCC for Standard (IE1) BaseCase motors.**

| | LCC (new product) | | |
|---|---|---|---|
| Item | **1.1 kW** | **11 kW** | **110 kW** |
| Product list price | 160 € | 750 € | 7.500 € |
| Electrical energy | 2.476 € | 29.695 € | 865.642 € |
| Repair & maintenance costs | -- | 578 € | 4.599 € |
| **Total** | **2636 €** | **31023 €** | **877741 €** |

## *5.2 Real-Life BaseCase*

In order to take into account real-life situations, where motors are hardly ever used at full-load, an average load factor of 60% from previous studies [1] is considered.

Since list prices are normally subjected to a significant discount a 40% discount is assumed.

Also, to help understand the weight of the various factors that contribute to the environmental impact and lifecycle costs of electric motors, four scenarios are analysed for four distinct annual operating hours: 2000, 4000, 6000 and 8000.

Regarding repair costs, a linear relation is considered with the maximum for 8000 hours, for 11 and 110 kW motors (2 repairs). Motors smaller than 5 kW are, normally, not repaired upon failure.

### 5.2.1 Environmental impact of Real-Life BaseCase

Table 5-8 presents a summary of the environmental impact of the Real-Life BaseCase models, for a 4000 operating hours pa. scenario.

**Table 5-8 Summary of the loss-based environmental impacts of Real-Life BaseCase (4000h scenario)**

| | Motor Rated Power | | |
|---|---|---|---|
| **Main Life-Cycle Indicators** | **1.1 kW** | **11 kW** | **110 kW** |
| Total Energy, GER (MJ) | 111.412 | 596.028 | 4.031.313 |
| Of which, electricity *(in primary* MJ) | 110.526 | 589.308 | 3.980.188 |
| Water, process (l) | 7.510 | 40.133 | 271.380 |
| Waste, non-hazardous/landfill (g) | 171.936 | 1.102.377 | 8.231.871 |
| Waste, hazardous/incinerated (g) | 2.902 | 14.802 | 97.779 |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 (kg $CO_2$ eq.) | 4.888 | 26.191 | 177.315 |
| Ozone Depletion Emissions (mg R-11 eq) | | negligible | |
| Acidifying Agents, AP (g $SO_2$ eq.) | 29.113 | 157.926 | 1.076.158 |
| Volatile Organic Compounds, VOC (g) | 44 | 247 | 1.655 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | 1.005 | 5.642 | 39.789 |
| Heavy Metals, HM (mg Ni eq.) | 2.320 | 13.311 | 92.683 |
| Polycyclic Aromatic Hydrocarbons PAHs (mg Ni eq.) | 263 | 1.566 | 10.707 |
| Particulate Matter, PM, dust (g) | 869 | 7.066 | 40.009 |
| **Emissions to the Water** | | | |
| Heavy Metals, HM (mg Hg/20) | 920 | 5.105 | 35.780 |
| Eutrophication, EP (g $PO_4$) | 13 | 69 | 446 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | | negligible | |

**Table 5-9 Percentage of use phase impact of real-life base cases, considering only losses (4000h scenario)**

| | Motor Rated Power | | |
|---|---|---|---|
| **Main Indicators** | **1.1 kW** | **11 kW** | **110 kW** |
| Total Energy, (GER) | 99,08% | 98,84% | 98,59% |
| Of which, electricity | 99,87% | 99,85% | 99,83% |
| Water (process) | 98,01% | 97,77% | 97,63% |
| Waste, non-hazardous/landfill | 74,68% | 62,26% | 56,39% |
| Waste, hazardous/incinerated | 87,63% | 91,61% | 93,64% |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 | 98,55% | 98,23% | 97,83% |
| Acidification Agents, AP | 97,65% | 96,01% | 95,12% |
| Volatile Organic Compounds, VOC | 94,50% | 93,71% | 91,09% |
| Persistent Organic Pollutants, POP | 72,25% | 68,66% | 65,78% |
| Heavy Metals, HM | 81,79% | 77,04% | 73,94% |
| PAHs | 82,98% | 82,49% | 74,57% |
| Particulate Matter, PM, dust | 69,98% | 77,09% | 60,31% |
| **Emissions to the Water** | | | |
| Heavy Metals, HM | 77,55% | 74,57% | 71,87% |
| Eutrophication, EP | 26,13% | 26,78% | 28,04% |

### 5.2.2 Life Cycle Costs of Real-Life BaseCase Models

The following tables present the LCC of the Real-Life BaseCase models considering the four different scenarios established earlier.

**Table 5-10 LCC for 1,1 kW Real-Life BaseCase motors (Lifetime 12 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 96 € | 96 € | 96 € | 96 € |
| Electrical energy | 1.402 € | 2.804 € | 4.205 € | 5.607 € |
| **LCC (new product)** | **1.498 €** | **2.900 €** | **4.301 €** | **5.703 €** |

**Table 5-11 LCC for 11 kW Real-Life BaseCase motors (Lifetime 15 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 450 € | 450 € | 450 € | 450 € |
| Electrical energy | 14.591 € | 29.181 € | 43.772 € | 58.363 € |
| Repair & Maintenance | 145 € | 289 € | 434 € | 578 € |
| **LCC (new product)** | **15.185 €** | **29.920 €** | **44.656 €** | **59.391 €** |

**Table 5-12 LCC for 110 kW Real-Life BaseCase motors (Lifetime 20 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 4.500 € | 4.500 € | 4.500 € | 4.500 € |
| Electrical energy | 174.430 € | 348.861 € | 523.291 € | 697.722 € |
| Repair & Maintenance | 1.150 € | 2.290 € | 3.449 € | 4.599 € |
| **LCC (new product)** | **180.080 €** | **355.660 €** | **531.240 €** | **706.821 €** |

## *5.3 EU total Environmental Impacts*

The following tables present the environmental impacts of the motor stock, for the reference year (2005), per power range (small motors [0,75-7,5[ kW, medium motors [7,5-75[ kW and large motors [75-200] kW), for a 4000h scenario. For each of these power ranges the base models of 1,1 kW, 11 kW and 110 kW were respectively used to provide representative data. Two tables are presented:

- Table 5-13 shows the environmental impacts resulting from all the energy consumed by the motors.
- Table 5-14 shows the environmental impacts considering only the losses in the use-phase.

**Table 5-13 Summary of Environmental Impacts EU-Stock 2005**

| **Main Life-Cycle Indicators** | **Small Motors** | **Medium Motors** | **Large Motors** |
|---|---|---|---|
| Total Energy, GER (PJ) | 2550 | 4550 | 2600 |
| Of which, electricity (TWh) | 242,3 | 432,4 | 247,4 |
| Water, process (M.m$^3$)* | 170 | 304 | 173 |
| Waste, non-hazardous/landfill (kton)* | 3213 | 5985 | 3203 |
| Waste, hazardous/incinerated (kton)* | 61 | 106 | 60 |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 (Mton $CO_2$ eq.) | 111 | 199 | 114 |
| Acidifying Agents, AP (kton $SO_2$ eq.) | 659 | 1180 | 672 |
| Volatile Organic Compounds, VOC (kton) | 1 | 2 | 1 |
| Persistent Organic Pollutants, POP (g i-Teq.) | 18 | 32 | 18 |
| Heavy Metals, HM (ton Ni eq.) | 46 | 82 | 46 |
| Polycyclic Aromatic Hydrocarbons PAHs (ton Ni eq.) | 5 | 9 | 5 |
| Particulate Matter, PM, dust (kton) | 16 | 29 | 15 |
| **Emissions to the Water** | | | |
| Heavy Metals, HM (ton Hg/20) | 18 | 31 | 17 |
| Eutrophication, EP (kton $PO_4$) | 0 | 0 | 0 |

*** caution: low accuracy for production phase**

**Table 5-14 Summary of Loss-Based Environmental Impacts EU-Stock 2005**

| Main Life-Cycle Indicators | Small Motors | Medium Motors | Large Motors |
|---|---|---|---|
| Total Energy, GER (PJ) | 604 | 550 | 172 |
| Of which, electricity (TWh) | 57,0 | 51,7 | 16,2 |
| Water, process (M.m$^3$)* | 41 | 37 | 12 |
| Waste, non-hazardous/landfill (kton)* | 957 | 1131 | 332 |
| Waste, hazardous/incinerated (kton)* | 16 | 14 | 4 |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 (Mton $CO_2$ eq.) | 27 | 24 | 8 |
| Acidifying Agents, AP (kton $SO_2$ eq.) | 158 | 147 | 46 |
| Volatile Organic Compounds, VOC (kton) | 0 | 0 | 0 |
| Persistent Organic Pollutants, POP (g i-Teq.) | 6 | 6 | 2 |
| Heavy Metals, HM (ton  Ni eq.) | 13 | 13 | 4 |
| Polycyclic Aromatic Hydrocarbons PAHs (ton Ni eq.) | 1 | 2 | 0 |
| Particulate Matter, PM, dust (kton) | 5 | 7 | 2 |
| **Emissions to the Water** | | | |
| Heavy Metals, HM (ton Hg/20) | 5 | 5 | 1 |
| Eutrophication, EP (kton $PO_4$) | 0 | 0 | 0 |

*** caution: low accuracy for production phase**

## *5.4 Summary*

This section has analysed the environmental impact and Life Cycle costs of both Standard and Real-Life BaseCases, using the MEEUP Model (EcoReport).

The results show that for all the BaseCases the use-phase clearly dominates both the environmental impact and LCC. The next sections will concentrate in the analysis of motor efficiency technology improvements and their impact in energy use and environmental impacts.

# 6 Technical analysis for BAT

As it can be seen in by the analysis of the BaseCase models, most of the environmental impact and life-cycle costs are associated to the use-phase. Therefore, the manufacturers' research and development effort has mainly been concentrated in the improvement of motor efficiency without a substantial increase in motor prices.

Brushed DC motors have not seen any major development in the last decades. In the past, DC motors were the only available solution for demanding applications in terms of torque and speed control. Nowadays, AC motors with electronic Variable speed drives (VSDs) can achieve similar performance but they are cheaper, much more reliable, easy to source and more cost effective in terms of maintenance. Brushed DC motors are being gradually replaced by these AC technologies.

Three-phase induction motors, on the other hand, have seen, for the same period, incremental technological advances accompanied by major improvements in efficiency.

Furthermore, other motor technologies have surfaced, which although having not yet reached the status of standard commodity products, present a large savings potential and have been gaining market importance in some particular applications.

This section gives an overview of the state-of-the-art of the best existing technologies at product and component level.

## *6.1 BAT product level*

### 6.1.1 High efficiency and Premium efficiency induction motors

The most efficient induction motors available in the world market today have efficiency levels above the IE3 minimum requirements. This represents a decrease in losses of about 15% in relation to the high efficiency motors (IE2/EFF1) available in the EU market.

High efficiency motors are typically constructed with superior magnetic materials, larger magnetic circuits with thinner laminations, larger copper/aluminium cross-section in the stator and rotor windings, tighter tolerances, better quality control and optimized design. These motors, therefore, have lower losses and improved efficiency. Because of lower losses the operating temperature can be lower, leading to improved reliability.

Same of the options to increase induction motors efficiency are presented in Figure 6-1.

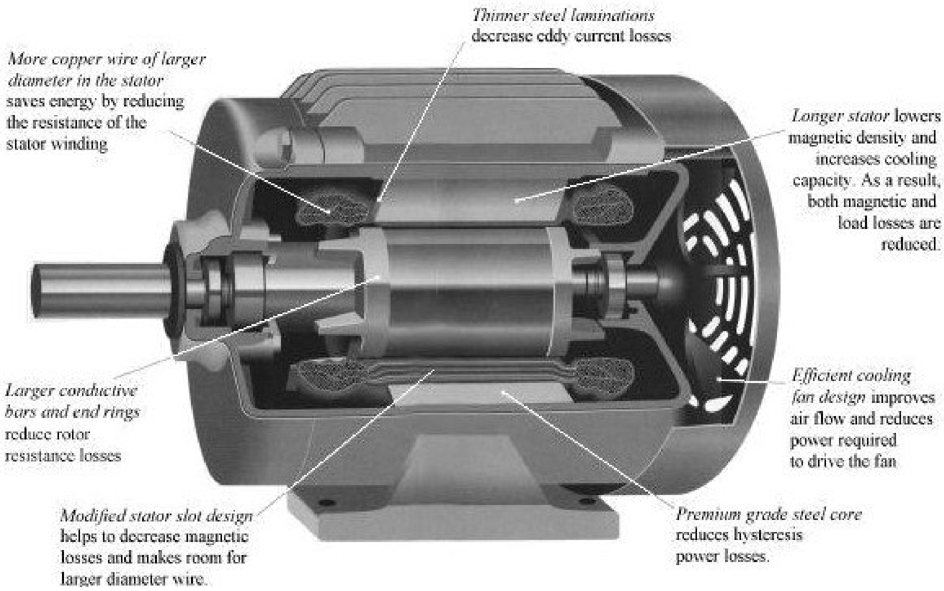


**Figure 6-1 NEMA Premium motor features** [30]

Stator losses can be reduced by increasing the cross-section of stator windings which lowers their electrical resistance reducing $I^2R$ losses. This modification is where the largest gains in efficiency are achieved. High efficiency motors typically contain about 20% more copper than standard efficiency models of equivalent size and rating.

Increasing the cross-section of the rotor conductors (conductor bars and end-plates) and/or increasing their conductivity (e.g. using copper instead of aluminium), and to a lesser extent by increasing the total flux across the air gap between rotor and stator reduces the rotor losses.

Magnetic core losses occur in the steel laminations of the stator and rotor and are mainly due to hysteresis effects and to induced eddy currents. Both types of losses approximately increase with the square of the magnetic flux density. Lengthening the lamination stack, which reduces the flux density within the stack, therefore reduces core losses.  These losses can be further reduced through the use of magnetic steel with better magnetic properties (e.g. higher permeability and higher resistivity) in the laminations. Another means to reduce the eddy currents magnetic core losses is to reduce the laminations' thickness. Eddy current losses can also be reduced by ensuring adequate insulation between laminations, thus minimizing the flow of current (and $I^2R$ losses) through the stack.

The additional materials used in order to improve efficiency can present themselves as a problem, as it may be difficult to meet the standard frame sizes especially in the low power range. Of course, this is not always the case since in many cases only the stator and rotor laminations are a little longer and this can be compensated in part by using a smaller fan, as the thermal losses to be dissipated are lower.

Figure 6-2 shows the relationship between power and shaft-height considering the different European and North-American standard frame sizes for 4-pole motors.

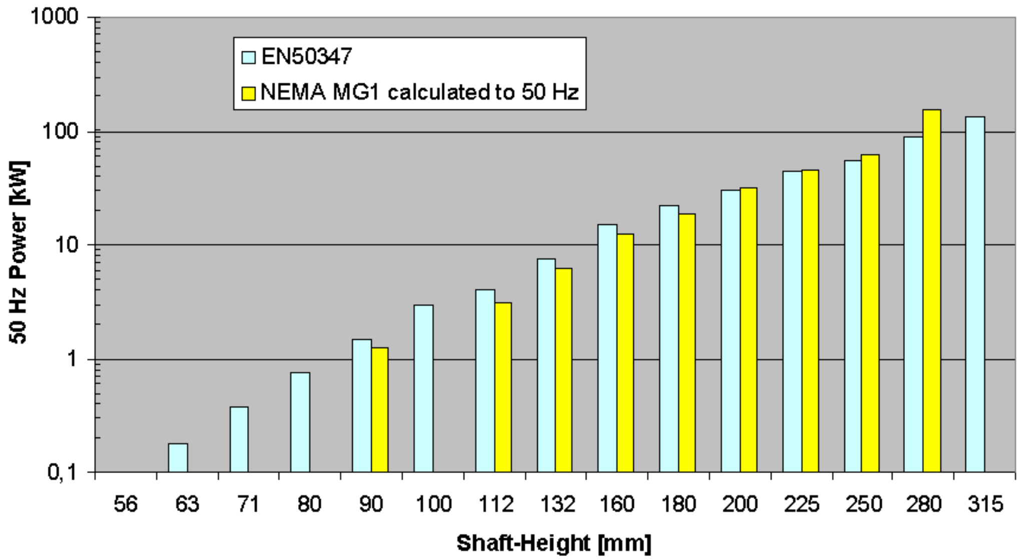


**Figure 6-2 4-Pole Output Power per Shaft-Height**

For the environmental impact and LCC assessment of BAT, the motor efficiencies presented in Table 7-1 are considered. These efficiencies are drawn from the proposed IEC 60034-30 efficiency classification standard.

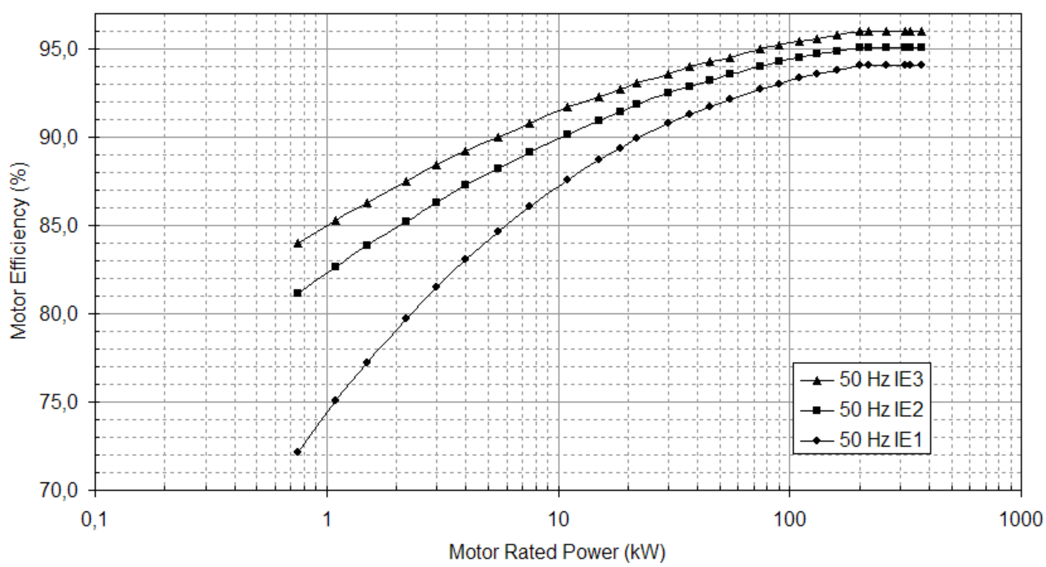


**Figure 6-3 Efficiency levels in the proposed IEC 60034-30 for 4 poled motors.**

### 6.1.2 Electronically Commutated (EC) / Brushless Permanent Magnet DC Motors

An Electronically Commutated (EC) motor also called Brushless DC (BLDC) motor is a rotating electric machine where the stator is a classic three-phase stator like that of an induction motor and the rotor has  permanent magnets which create the rotor magnetic field without incurring in excitation losses.  Unlike a brushed DC motor, the commutation of an EC/BLDC motor is controlled electronically.  Typically the AC supply is converted to a DC supply, which feeds a Pulse-Width Modulation (PWM) inverter, which generates an almost sinusoidal waveform, supplied to the stator windings. Based on the required magnetic field density in the rotor, the proper magnetic material and geometry is chosen to make the rotor.

Ferrite magnets have traditionally been used to make permanent magnets in low cost applications. As the technology advances and with decreasing costs, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive, but they have the disadvantage of lower flux density for a given volume. In contrast, the alloy material has high magnetic density improving the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets. Samarium Cobalt (SmCo) and the alloy of Neodymium, Ferrite and Boron (NdFeB) are some examples of rare earth alloy magnets used in high performance motors. Continuous research is going on to improve the flux density to compress the motor volume even further.

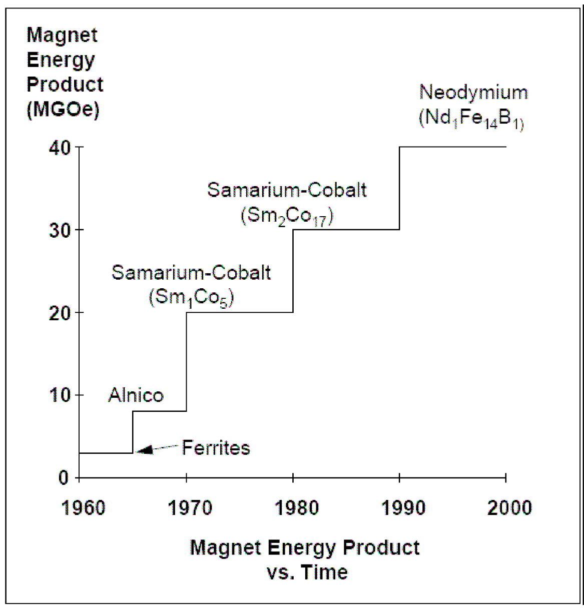


**Figure 6-4 Advances in magnet energy product [32]**

EC/BLDC are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor, rotate at the same frequency. EC/BLDC motors do not experience the "slip" that is normally seen in induction motors.

To rotate the EC/BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall effect sensors embedded into either the stator or the rotor, but new sensorless designs are becoming available.

EC/BLDC motors using permanent magnets have less Joule losses than induction motors because they do not have the secondary windings in their rotors, and the rotor magnetic losses are also much lower.  In the low power range, and in applications requiring variable speed control EC/BLDC motors can lead to efficiency improvements of up to 10-15%, when compared with variable speed induction motors, as shown in Figure 6-5.

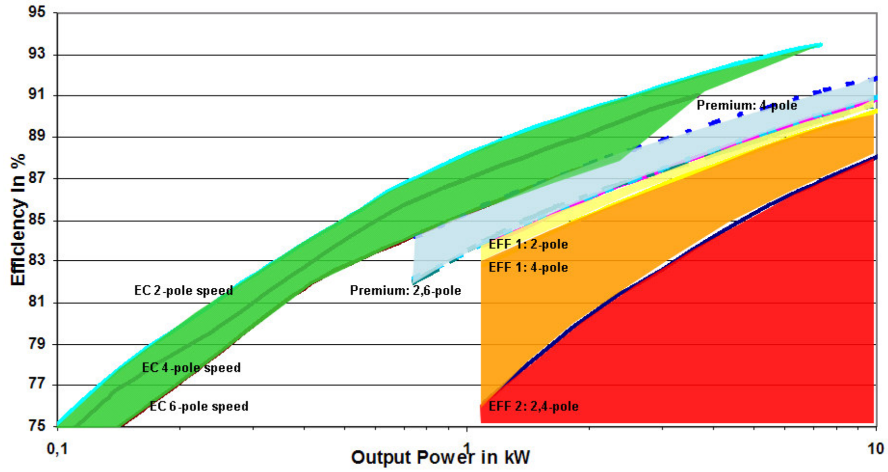


**Figure 6-5 Efficiency of EC/BLDC motors  (Source EBM-Papst)**

They also are much more efficient than brushed dc motors since they eliminate the excitation circuit losses.

EC/BLDC motors have not yet reached the status of standard commodity products, but present a large savings potential and have been gaining market importance in some particular applications such as high performance motion control, in some types of variable speed fans and also in some high efficiency appliances (e.g. air conditioners).

### 6.1.3 Variable Speed Drives (VSDs)

A variable speed drive is an electronic device designed to control the speed of the motor's shaft by varying the frequency and voltage applied to the stator windings in order to meet the application requirements.

The typical configuration of a VSD is shown in Figure 6-6.

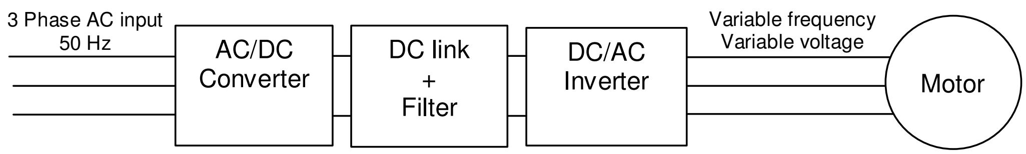


**Figure 6-6 Typical configuration of VSD**

The adjustment of the motor speed through the use of VSDs can lead to better process control, less wear in the mechanical equipment, less acoustical noise, and significant energy savings.

This study deals with "products" rather than "components" but, although VSDs are mainly sold separately from the motor, integrated motor and VSDs are growing in importance in the low power range (0.75 to 22 kW).

This type of technology can be regarded as a product that has the same primary function as the motor alone.

Speed control can produce large savings in many applications. VSDs have practically replaced other technological solutions for speed control (mechanical, hydraulic, as well as direct current (DC) motors) in process control applications where speed/torque variation is necessary for industrial reasons (for instance in paper production lines or in steel mills). However, in fluid-handling applications with variable flow requirements VSDs have experienced a slow diffusion, although this is a field of application identified as having the greatest potential for savings. This is because the consumed power is roughly proportional to the cube of the flow.

## *6.2 BAT at component level*

### 6.2.1 Copper rotor induction motors

One way to reduce $I^2R$ losses is to substitute the aluminium conductor bars with copper. Due to the excellent electrical conductivity of copper (57 MS/m compared to 37 MS/m), replacing the aluminium in a rotor's conductor bars with die-cast copper can produce a significant improvement in the efficiency of an electrical motor.

If this replacement is accompanied by a redesign of the motor that takes into account the higher conductivity of copper, even a greater efficiency improvement is achieved.

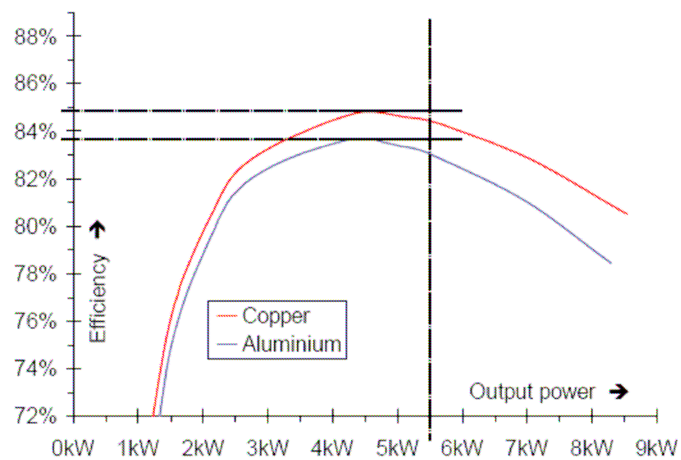


**Figure 6-7 Comparison of the efficiency of an aluminium and copper rotor in an otherwise identical 5.5 kW motor [37]**

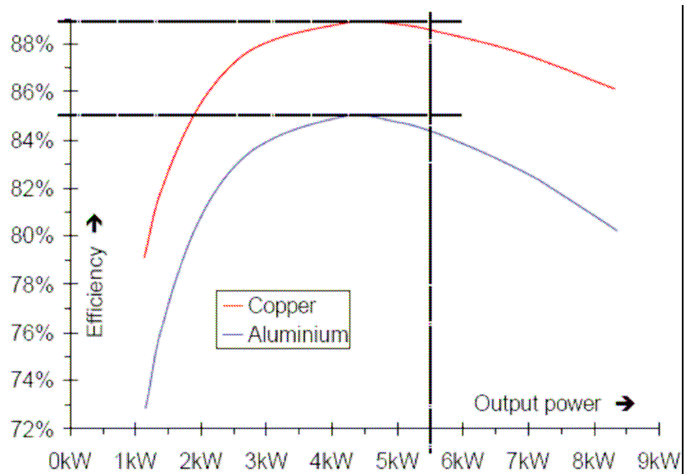


**Figure 6-8 Comparison of the efficiency of an aluminium rotor motor and a copper rotor efficiency optimized 5.5 kW motor [37]**

Because of the higher efficiency of the copper rotor, the length of the rotor, and therefore the motor, can be smaller than in an aluminium motor for the same power and efficiency rating. This can make possible to meet standard frame sizes with high efficiency motors, which would otherwise be extremely difficult.

The higher melting point of copper (1083ºC versus 660ºC for aluminium) was initially a barrier in the large-scale production of copper die-cast rotors, due to the short lifetime of the dies. This problem has been successfully overcome and several manufacturers are now producing cost-effective copper rotor induction motors.

## *6.3 Summary*

Three-phase induction motors have been subject to technological advances that lead to large efficiency improvements due to a reduction of the losses in the range 30 to 50%. Advances in motor design, tighter tolerances, the use of superior magnetic materials, larger copper/aluminium cross-section in the stator and rotor to reduce resistance are just some of the techniques that contribute to lowering the losses in induction motors. At component level, the use of copper rotors can also lead to high efficiency and/or power density gains due to its excellent conductivity.

Brushless/Electronically Commutated Permanent Magnet Motors technology, that has surfaced recently, has the potential to achieve a significant market penetration. These motors have less rotor losses than induction motors and can lead to efficiency improvements of 10-15% in the low power range when compared with variable speed induction motors.

Speed control can also produce large savings, typically in the range 15-35%, in applications with variable load profiles. Since motors with integrated VSD can also be considered a product, they were also addressed.

# 7 Improvement potential

The improvement potential of adopting induction motors with IE3 efficiency levels is analysed as BAT. However in the EU there are not yet available motors in this efficiency class for all power levels, and it may be difficult to manufacture motors in this class in the low power range [0,75-7,5kW], using the same frame sizes.

Although IE2/EFF1 motors are a substantially better technology than the currently largely dominating IE1/EFF2 motors, they are not strictly considered BAT. However, their improvement potential in terms of environmental impact and LLC is also analysed here to provide better insight on how those values evolve with improved motor efficiency.

In a similar way to the BaseCase, four scenarios will be analysed for four different annual operating hours: 2000, 4000, 6000 and 8000.

For the environmental impact and LCC assessment of BAT, the motor efficiencies presented in Table 7.1 are considered. These efficiencies are drawn from the proposed IEC 60034-30 standard.

**Table 7-1 Efficiency values for best available electric motor technology, IEC 60034-30 standard.**

| | Motor Rated Power | | |
|---|---|---|---|
| | **1,1 kW** | **11 kW** | **110 kW** |
| IE2 (EFF1 adjusted) Full-load Efficiency(%) | 82,7 | 90,2 | 94,5 |
| IE3 Full-load Efficiency(%) | 85,3 | 91,7 | 95,4 |

## *7.1 Environmental impact*

Again, for the sake of clarity, the main results are presented in this chapter in summary form. A more complete set of results is presented in Appendix II.

The material fractions for IE3 motors were estimated based on the provided BoMs of IE2/EFF1 and IE1/EFF2 motors and are presented in Table 7-2.

**Table 7-2 Estimated BoM for IE3 Motors**

| **Materials** | **Motor Rated Power** | | |
|---|---|---|---|
| | **1,1 kW** | **11 kW** | **110 kW** |
| Electrical steel (kg/kW) | 9,02 | 6,11 | 4,0 |
| Other steel (kg/kW) | 1,64 | 1,05 | 0,77 |
| Cast iron (kg/kW) | 2,50 | 1,30 | 3,00 |
| Aluminium (kg/kW) | 2,12 | 1,11 | 0,25 |
| Copper (kg/kW) | 2.26 | 1,08 | 0.7 |
| Insulation material (kg/kW) | 0,05 | 0,02 | 0,01 |
| Packing material (kg/kW) | 1,00 | 0,90 | 0,50 |
| Impregnation resin (kg/kW) | 0,30 | 0,10 | 0,05 |
| Paint (kg/kW) | 0,10 | 0,05 | 0,01 |

Table 7-3 presents the environmental impact per product of IE2 motors for the proposed power ratings.

**Table 7-3 Summary of the loss-based environmental impacts of BAT (IE2), 4000 h scenario.**

| | Motor Rated Power | | |
|---|---|---|---|
| **Main Life-Cycle Indicators** | **1,1 kW** | **11 kW** | **110 kW** |
| Total Energy, GER (MJ) | 70886 | 460.974 | 3.286.297 |
| Of which, electricity *(in primary* MJ) | 69.742 | 452.794 | 3.233.236 |
| Water, process (ltr) | 4.797 | 31.063 | 221.799 |
| Waste, non-hazardous/landfill (g) | 145.162 | 1.101.015 | 7.712.153 |
| Waste, hazardous/incinerated (g) | 1.962 | 11.656 | 80.565 |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 (kg $CO_2$ eq.) | 3.127 | 20.328 | 144.908 |
| Ozone Depletion, emissions (mg R-11 eq.) | | negligible | |
| Acidifying Agents, AP (g $SO_2$ eq.) | 18.873 | 124.907 | 888.058 |
| Volatile Organic Compounds, VOC (g) | 29 | 197 | 1.382 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | 837 | 5.206 | 37.199 |
| Heavy Metals, HM (mg Ni eq.) | 1.711 | 11.546 | 81.638 |
| Polycyclic Aromatic Hydrocarbons, PAH (mg Ni eq.) | 192 | 1.327 | 7.758 |
| Particulate Matter, PM, dust (g) | 677 | 6.042 | 35.797 |
| **Emissions to the Water** | | | |
| Heavy Metals, HM (mg Hg/20) | 685 | 4.389 | 31.006 |
| Eutrophication, EP (g $PO_4$) | 13 | 69 | 439 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | | negligible | |

**Table 7-4 Summary of the loss-based environmental impacts of BAT (IE3), 4000 h scenario.**

| | Motor Rated Power | | |
|---|---|---|---|
| **Main Life-Cycle Indicators** | **1,1 kW** | **11 kW** | **110 kW** |
| Total Energy, GER (MJ) | 56.890 | 389.383 | 2.746.014 |
| Of which, electricity *(in primary* MJ) | 55.645 | 379.273 | 2.680.748 |
| Water, process (ltr) | 3.860 | 26.197 | 185.481 |
| Waste, non-hazardous/landfill (g) | 136.834 | 1.187.556 | 8.082.552 |
| Waste, hazardous/incinerated (g) | 1.637 | 9.964 | 67.822 |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 (kg $CO_2$ eq.) | 2.518 | 17.245 | 121.650 |
| Ozone Depletion, emissions (mg R-11 eq.) | | negligible | |
| Acidifying Agents, AP (g $SO_2$ eq.) | 15.345 | 108.342 | 758.854 |
| Volatile Organic Compounds, VOC (g) | 24 | 174 | 1.202 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | 784 | 5.227 | 37.985 |
| Heavy Metals, HM (mg Ni eq.) | 1.505 | 10.971 | 77.048 |
| Polycyclic Aromatic Hydrocarbons, PAH (mg Ni eq.) | 168 | 1.270 | 7.002 |
| Particulate Matter, PM, dust (g) | 612 | 6.263 | 34.685 |
| **Emissions to the Water** | | | |
| Heavy Metals, HM (mg Hg/20) | 605 | 4.079 | 28.954 |
| Eutrophication, EP (g $PO_4$) | 13 | 71 | 459 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | | negligible | |

## *7.2 Life Cycle Cost of BAT*

Tables 7-5 to 7-7 present the Life Cycle Cost (LCC), for the three analysed IE2 motors.

**Table 7-5 LCC for 1,1 kW IE2 motors (Lifetime 12 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 125 € | 125 € | 125 € | 125 € |
| Electrical energy | 1.273 € | 2.545 € | 3.818 € | 5.090 € |
| **LCC (new product)** | **1.398 €** | **2.670 €** | **3.943 €** | **5.215 €** |

**Table 7-6 LCC for 11 kW IE2 motors (Lifetime 15 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 563 € | 563 € | 563 € | 563 € |
| Electrical energy | 14.164 € | 28.329 € | 42.493 € | 56.657 € |
| Repair & Maintenance | 145 € | 289 € | 434 € | 578 € |
| **LCC (new product)** | **14.872 €** | **29.181 €** | **43.490 €** | **57.683 €** |

**Table 7-7 LCC for 110 kW IE2 motors (Lifetime 20 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 5.400 € | 5.400 € | 5.400 € | 5400 € |
| Electrical energy | 172.211 € | 344.422 € | 516.634 € | 688.845 € |
| Repair & Maintenance | 1.150 € | 2.290 € | 3.449 € | 4.599 € |
| **LCC (new product)** | **178.761 €** | **352.122 €** | **525.483 €** | **697.924 €** |

Tables 7-8 to 7-10 present the Life Cycle Cost (LCC), for the three analysed IE3 motors.

**Table 7-8 LCC for 1,1 kW IE3 motors (Lifetime 12 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 154 € | 154 € | 154 € | 154 € |
| Electrical energy | 1.228 € | 2.456 € | 3.684 € | 4.912 € |
| **LCC (new product)** | **1.382 €** | **2.610 €** | **3.838 €** | **5.066 €** |

**Table 7-9 LCC for 11 kW IE3 motors (Lifetime 15 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 675 € | 675 € | 675 € | 675 € |
| Electrical energy | 13.951 € | 27.902 € | 41.854 € | 55.805 € |
| Repair & Maintenance | 145 € | 289 € | 434 € | 578 € |
| **LCC (new product)** | **14.771 €** | **28.867 €** | **42.962 €** | **57.058 €** |

**Table 7-10 LCC for 110 kW IE3 motors (Lifetime 20 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 6.300 € | 6.300 € | 6.300 € | 6.300 € |
| Electrical energy | 170.584 € | 341.168 € | 511.751 € | 682.335 € |
| Repair & Maintenance | 1.150 € | 2.290 € | 3.449 € | 4.599 € |
| **LCC (new product)** | **178.033 €** | **349.767 €** | **521.500 €** | **693.234 €** |

## *7.3 Comparison between BaseCase and BAT*

Table 7-11 presents the improvement potential (in percentage) of BAT in terms of the environmental impact, considering only the use phase.

**Table 7-11 Loss-based environmental impact variation (BAT vs. base-cases), 4000 h scenario.**

| | Motor Rated Power | | | | | |
|---|---|---|---|---|---|---|
| | 1,1 kW | | 11 kW | | 110kW | |
| **Main Indicators** | **IE2** | **IE3** | **IE2** | **IE3** | **IE2** | **IE3** |
| Total Energy | -36,38% | -48,94% | -22,65% | -34,67% | -18,53% | -31,88% |
| Of which, electricity | -36,90% | -49,65% | -23,17% | -35,64% | -18,77% | -32,65% |
| Water (process) | -36,12% | -48,61% | -22,60% | -34,72% | -18,27% | -31,65% |
| Waste, non-hazardous/landfill | -15,57% | -20,42% | -2,83% | 7,73% | -11,08% | -1,81% |
| Waste, hazardous/incinerated | -32,39% | -43,58% | -21,25% | -32,68% | -17,62% | -30,64% |
| Emissions to the Air | | | | | | |
| Greenhouse Gases in GWP100 | -36,04% | -48,48% | -22,38% | -34,16% | -18,34% | -31,39% |
| Acidification Agents, AP | -35,17% | -47,29% | -20,88% | -31,40% | -17,88% | -29,48% |
| Volatile Organic Compounds, VOC | -33,62% | -45,18% | -20,33% | -29,73% | -16,53% | -27,34% |
| Persistent Organic Pollutants, POP | -16,69% | -22,02% | -7,81% | -7,36% | -6,76% | -4,53% |
| Heavy Metals, HM | -26,25% | -35,14% | -13,48% | -17,58% | -13,03% | -16,87% |
| Polycyclic Aromatic Hydrocarbons, PAH | -26,77% | -35,85% | -15,37% | -18,91% | -27,89% | -34,60% |
| Particulate Matter, PM, dust | -22,13% | -29,61% | -14,53% | -11,37% | -10,89% | -13,31% |
| Emissions to the Water | | | | | | |
| Heavy Metals, HM | -25,57% | -34,27% | -14,07% | -20,09% | -13,67% | -19,08% |
| Eutrophication, EP | -4,55% | -5,90% | -1,24% | 1,61% | -2,75% | 2,91% |

The results indicate that if high efficiency motors, either IE2 or IE3 motors, replace IE2/EFF2 motors significant reductions in the environmental impact will be achieved. Table 7-12 presents the reduction in LCC.

**Table 7-12 LCC reductions (BAT vs. BaseCase).**

| | 1,1 kW | | 11 kW | | 110 kW | |
|---|---|---|---|---|---|---|
| | **IE2** | **IE3** | **IE2** | **IE3** | **IE2** | **IE3** |
| **LCC Reduction for 2000 hour/year** | 6,7 % | 7,7 % | 2,1 % | 2,7 % | 0,7 % | 1,2 % |
| **LCC Reduction for 4000 hour/year** | 7,9 % | 10,0 % | 2,5 % | 3,5 % | 1,0 % | 1,7 % |
| **LCC Reduction for 6000 hour/year** | 8,3 % | 10,8 % | 2,6 % | 3,8 % | 1,1 % | 1,8 % |
| **LCC Reduction for 8000 hour/year** | 8,6 % | 11,2 % | 2,7 % | 3,9 % | 1,1 % | 1,9 % |

Figure 7-1 shows the evolution of the LCC for the three power levels, considering different efficiency levels and number of operating hours. As it would be expected, the results show very significant reduction of the LCC for the low power motors, with savings reaching more moderate levels as the motor power increases. Most of the improvement occurs when the efficiency level moves from IE1/EFF2 to IE2, but a noticeable improvement can still be seen when the efficiency level reaches the IE3 level.

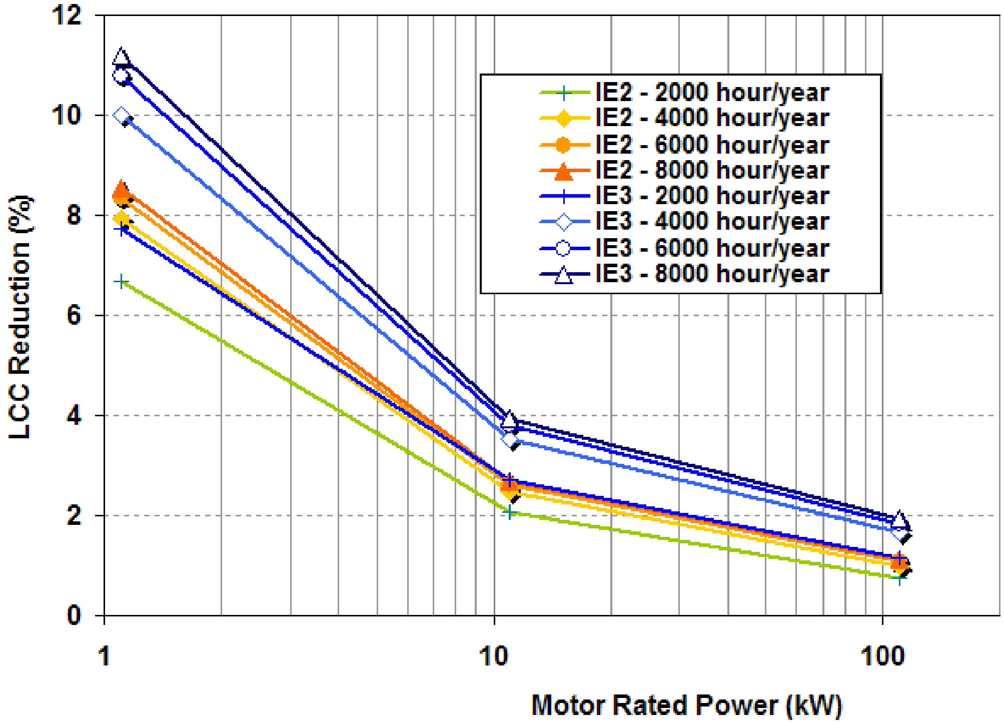


**Figure 7-1 LCC reduction (BAT vs. BaseCase).**

## 7.4 Brushless Permanent Magnet Motors (EC motors) environmental and LCC analysis

The previous analysis was made considering changes in efficiency without altering the basic technological aspects of the motor. However, as discussed in previous chapters, Brushless Permanent Magnet (EC) Motors can be used in some of the applications where induction motors are the common technologies in use today presenting some potential for improvement.

This section will analyse this potential for improvement in both environmental impact and LCC.

EC motors are only widely available in small powers (0,75-5 kW) so only the 1,1 kW motor will be analysed here.

### 7.4.1 Product specific inputs

#### *7.4.1.1 Bill of Materials (BoM)*

Bills of materials for EC motors were provided by stakeholders. The average BoM of a 1,1 kW EC motor is presented in Table 7-13.

**Table 7-13 BoM for 1,1 kW EC Motor**

| Materials | Motor Rated Power |
|---|---|
| | **1,1 kW** |
| Steel (kg/kW) | 1,8 |
| Aluminium die-cast (kg/kW) | 2,1 |
| Ferrite (kg/kW) | 1,0 |
| Copper (kg/kW) | 0,75 |
| Plastic (kg/kW) | 0,26 |
| PWB (kg/kW) | 0,09 |
| Electronic components (kg/kW) | 0,1 |

#### *7.4.1.2 Use-Phase*

The inputs for the use-phase are:

**Table 7-14 Use-Phase inputs**

| Variable | Motor Rated Power |
|---|---|
| | **1,1 kW** |
| Lifetime (years) | 12 |
| Efficiency (%) | 88,75 |
| Operating hours | 2000/4000/6000/8000 |

### 7.4.2 Environmental impact

The next table shows a summary of the environmental impact of a EC motor, for 4000 operating hours/year. Only losses are considered in the use-phase.

**Table 7-15 Summary of the loss-based environmental impacts of 1,1kW EC motor, 4000 h scenario.**

| | Motor Rated Power |
|---|---|
| **Main Life-Cycle Indicators** | **1,1 kW** |
| Total Energy, GER (MJ) | 43706 |
| Of which, electricity *(in primary* MJ) | 42735 |
| Water, process (ltr) | 2986 |
| Waste, non-hazardous/landfill (g) | 75600 |
| Waste, hazardous/incinerated (g) | 1534 |
| **Emissions to the Air** | |
| Greenhouse Gases in GWP100 (kg $CO_2$ eq.) | 1932 |
| Ozone Depletion, emissions (mg R-11 eq.) | negligible |
| Acidifying Agents, AP (g $SO_2$ eq.) | 11553 |
| Volatile Organic Compounds, VOC (g) | 25 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | 471 |
| Heavy Metals, HM (mg  Ni eq.) | 919 |
| Polycyclic Aromatic Hydrocarbons, PAH (mg Ni eq.) | 146 |
| Particulate Matter, PM, dust (g) | 1357 |
| **Emissions to the Water** | |
| Heavy Metals, HM (mg Hg/20) | 321 |
| Eutrophication, EP (g $PO_4$) | 3 |
| Persistent Organic Pollutants, POP (ng i-Teq.) | negligible |

Table 7-16 presents the improvement potential (in percentage) of BAT in terms of the environmental impact, considering only the use phase.

**Table 7-16 Loss-based environmental impacts variation (EC motor vs. BaseCase), 4000 h scenario.**

| | Motor Rated Power |
|---|---|
| **Main Life-Cycle Indicators** | **1,1 kW** |
| Total Energy, GER (MJ) | -61,10% |
| Of which, electricity *(in primary* MJ) | -61,34% |
| Water, process (ltr) | -60,24% |
| Waste, non-hazardous/landfill (g) | -61,65% |
| Waste, hazardous/incinerated (g) | -56,13% |
| **Emissions to the Air** | |
| Greenhouse Gases in GWP100 (kg $CO_2$ eq.) | -60,92% |
| Acidifying Agents, AP (g $SO_2$ eq.) | -60,55% |
| Volatile Organic Compounds, VOC (g) | -56,45% |
| Persistent Organic Pollutants, POP (ng i-Teq.) | -53,25% |
| Heavy Metals, HM (mg  Ni eq.) | -60,79% |
| Polycyclic Aromatic Hydrocarbons, PAH (mg Ni eq.) | -48,87% |
| Particulate Matter, PM, dust (g) | -50,02% |
| **Emissions to the Water** | |
| Heavy Metals, HM (mg Hg/20) | -65,16% |
| Eutrophication, EP (g $PO_4$) | -76,38% |

### 7.4.3 Life Cycle Cost

Table 7-17 presents the Life Cycle Cost of an EC motor for the different analysed scenarios.

**Table 7-17 LCC for 1,1 kW EC motor (Lifetime 12 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 288 € | 288 € | 288 € | 288 € |
| Electrical energy | 1.185 € | 2.370 € | 3.555 € | 4.740 € |
| **LCC (new product)** | **1.473 €** | **2.658 €** | **3.843 €** | **5.028 €** |

Figure 7-2 shows the LCC reduction for a 1,1 kW EC Motor when compared to the BaseCase.

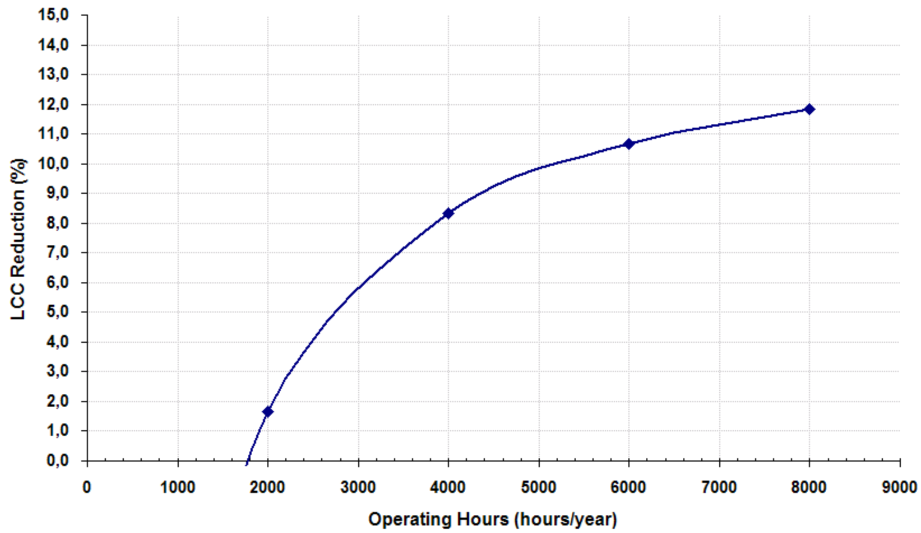


**Figure 7-2 LCC reduction as a function of the number of operating hours, 1,1 kW EC motor vs. BaseCase**

## *7.5 VSD environmental and LCC analysis*

Since VSDs can only produce savings in variable load applications they cannot be compared directly with other technologies. There is a very large number of applications which would benefit, both in terms of process improvement and in terms of energy savings) through the use of variable speed control. However previous studies [1] [27] have shown that the variable flow fluid motion applications (pumps, fans and compressors) have the largest savings potential.

Therefore, as a typical example for the analysis of the environmental impact and life cycle cost a comparison is to be made between two systems: one using a conventional approach with an IE1 motor coupled to a throttle valve to control flow in a pumping systems versus using a Variable Speed Drive with an IE1 motor.

Figure 7-3 shows the comparative performance of the two systems, with the inefficient throttling system inducing large losses for part-load operation.

In the low power range (up to 22 kW, but soon up to 45 kW) there are available integrated VSD-Motor units which can be purchased as a component, leading to much simpler installation and to a decrease in the costs.

Generally speaking variable flow pumping, ventilation and compressor applications, present a huge savings potential through the use of VSDs. The same can be said in motion control in which there are variable speed and frequent start/stop cycles. However, it must be stated that not all motor applications can benefit from VSDs, since for constant speed operation a VSD, not only does not save energy but leads to extra losses and capital expenses.

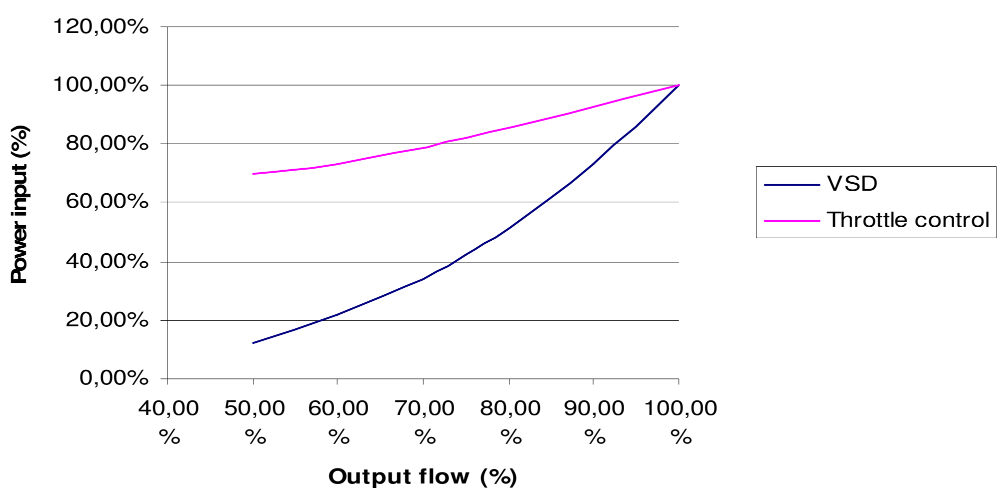


**Figure 7-3 Part-load power as a function of percent flow for a typical pumping system with throttle vs. a pumping system using a motor + VSD**

### 7.5.1 Product specific inputs

#### *7.5.1.1 Bill of Materials (BoM)*

Integrated Motor + VSD for power levels over 7.5 kW are not common. Therefore their Bill of Materials were estimated based on the small integrated units and the material fractions for separated VSDs and motors provided by stakeholders for the larger units.

**Table 7-18 Estimated BoM for Integrated Motor + VSD**

| Materials | Motor Rated Power | | |
|---|---|---|---|
| | 1,1 kW | 11 kW | 110 kW * |
| Electrical steel (kg/kW) | 5,4 | 3,6 | 3,1 |
| Other steel (kg/kW) | 1,5 | 0,95 | 0,7 |
| Cast iron (kg/kW) | 2,5 | 1,3 | 3 |
| Aluminium (kg/kW) | 2,7 | 1,0 | 0,3 |
| Copper (kg/kW) | 1,2 | 0,64 | 0,6 |
| Insulation material (kg/kW) | 0,05 | 0,02 | 0,01 |
| Packing material (kg/kW) | 1,2 | 1 | 0,5 |
| Impregnation resin (kg/kW) | 0,05 | 0,1 | 0,05 |
| Plastic (kg/kW) | 0,3 | 0,05 | 0,03 |
| PWB (kg/kW) | 0,2 | 0,03 | 0,01 |
| Electronics small (SMD, IC,...) (kg/kW) | 0,2 | 0,07 | 0,04 |
| Electronics big (IGBT, Thrysistors,...) (kg/kW) | 0,05 | 0,02 | 0,03 |

* Separated VSD and motor units

In the following analysis throttle valve materials and price are considered negligible compared with a VSD (conservative assumption). The BoM for the BaseCase IE1 motor is considered.

#### *7.5.1.2 Load Profile*

The following load (based on the EuP Pump study) profile is used:

**Table 7-19 Load Profile**

| % of flow | % of time |
|---|---|
| 50% | 25% |
| 75% | 50% |
| 100% | 25% |

Again, four scenarios are considered for four different annual operating hours: 2000, 4000, 6000 and 8000.

#### *7.5.1.3 Efficiency*

Motors are considered to have the same efficiency as the BaseCase motors (IE2). An average efficiency of 95% is considered for the VSD over the operating speed range (50-100%).

### 7.5.2 Environmental impact

When using a VSD the majority of the impact is, again, in the use phase.

**Table 7-20 Percentage of use-phase impact of motor + VSD, considering only losses.**

| | Motor Rated Power | | |
|---|---|---|---|
| **Main Indicators** | **1.1 kW** | **11 kW** | **110 kW** |
| Total Energy, (GER) | 98,55% | 98,70% | 98,62% |
| Of which, electricity *(in primary* MJ) | 99,65% | 99,40% | 99,36% |
| Water (process) | 93,94% | 94,75% | 93,43% |
| Waste, non-hazardous/landfill | 72,60% | 76,38% | 74,85% |
| Waste, hazardous/incinerated | 77,28% | 88,25% | 89,22% |
| **Emissions to the Air** | | | |
| Greenhouse Gases in GWP100 | 97,69% | 98,00% | 97,82% |
| Acidification Agents, AP | 96,65% | 96,98% | 96,81% |
| Volatile Organic Compounds, VOC | 85,78% | 87,62% | 83,75% |
| Persistent Organic Pollutants, POP | 66,15% | 70,68% | 72,86% |
| Heavy Metals, HM | 74,92% | 80,27% | 79,99% |
| PAHs | 64,36% | 80,74% | 82,17% |
| Particulate Matter, PM, dust | 59,38% | 76,62% | 65,36% |
| **Emissions to the Water** | | | |
| Heavy Metals, HM | 59,41% | 69,75% | 62,63% |
| Eutrophication, EP | 25,12% | 34,80% | 31,03% |

Table 7-21 shows the environmental impact variation associated with the replacement of BaseCase motor + throttle with BaseCase motor +VSD is shown in Table 7-15 for a 4000h/year scenario. Again, only losses are considered in the use-phase.

**Table 7-21 Environmental impact variation (VSD vs. throttle), 4000 h scenario**

| | Motor Rated Power | | |
|---|---|---|---|
| | **1,1 kW** | **11 kW** | **110kW** |
| **Main Indicators** | | | |
| Total Energy | -37,40% | -37,63% | -37,47% |
| Of which, electricity | -37,79% | -37,62% | -37,59% |
| Water (process) | -34,75% | -35,27% | -34,23% |
| Waste, non-hazardous/landfill | -29,38% | -44,55% | -37,60% |
| Waste, hazardous/incinerated | -26,16% | -32,94% | -32,38% |
| Emissions to the Air | | | |
| Greenhouse Gases in GWP100 | -37,05% | -37,43% | -37,16% |
| Acidification Agents, AP | -36,74% | -37,99% | -37,26% |
| Volatile Organic Compounds, VOC | -30,12% | -33,21% | -28,96% |
| Persistent Organic Pollutants, POP | -24,18% | -29,55% | -30,13% |
| Heavy Metals, HM | -27,17% | -35,25% | -32,51% |
| Polycyclic Aromatic Hydrocarbons, PAH | -14,19% | -36,30% | -34,51% |
| Particulate Matter, PM, dust | -17,50% | -50,52% | -29,57% |
| Emissions to the Water | | | |
| Heavy Metals, HM | -11,12% | -25,05% | -14,64% |
| Eutrophication, EP | -10,25% | -28,83% | -3,72% |

### 7.5.3 Life Cycle Cost of VSDs

Tables 7-18 to 7-20 present the Life Cycle Cost for the three analysed motors + VSD.

**Table 7-22 LCC for Integrated 1,1 kW Motor + VSD (Lifetime 12 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 288 € | 288 € | 288 € | 288 € |
| Electrical energy | 1.210 € | 2.420 € | 3.631 € | 4.841 € |
| **LCC (new product)** | **1.498 €** | **2.708 €** | **3.919 €** | 5.129 € |

**Table 7-23 LCC for Integrated 11 kW Motor + VSD (Lifetime 15 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 1.350 € | 1.350 € | 1.350 € | 1.350 € |
| Electrical energy | 12.606 € | 25.212 € | 37.818 e | 50.424 € |
| Repair & Maintenance | 145 € | 289 € | 434 € | 578 € |
| **LCC (new product)** | **14.100 €** | **26.851 €** | **39.601 €** | 52.352 € |

**Table 7-24 LCC for Separated 110 kW Motor + VSD (Lifetime 20 years).**

| | Number of Operating Hours per Year | | | |
|---|---|---|---|---|
| Item | **2.000h** | **4.000 h** | **6.000 h** | **8.000 h** |
| Product price | 13.500 € | 13.500 € | 13.500 € | 13.500 € |
| Electrical energy | 150.617 € | 301.235 € | 451.852 € | 602.470 € |
| Repair & Maintenance | 1.150 € | 2.290 € | 3.449 € | 4.599 € |
| **LCC (new product)** | **165.267 €** | **317.034 €** | **468.801 €** | 620.568 € |

Figure 7-4 shows the LCC reduction when a VSD is used for flow control instead of a throttle.

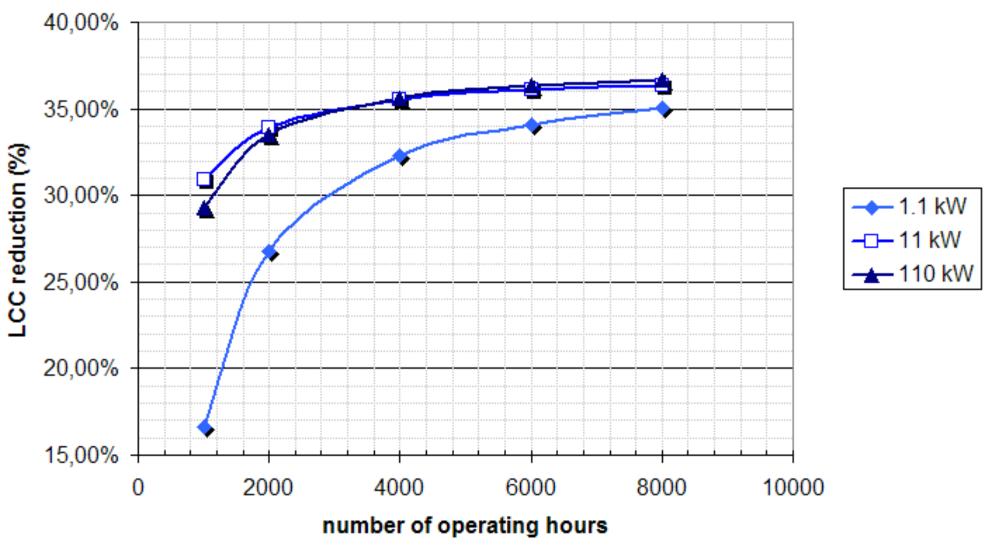


**Figure 7-4 LCC reduction as a function of the number of operating hours**

Although the VSD triples the initial price of the motor alone, a substantial reduction in LCC is achieved in variable flow pumping systems with high throttling losses where the consumed power is roughly proportional to the cube of the pump speed.

## *7.6 Long-term targets (BNAT)*

As mentioned earlier, the production of motors of the IE3 class in the low power range [0,75-7,5kW], using  the same frame sizes of lower efficiency motors  seems to pose major  challenges not yet solved. This is because of the additional material needed to achieve a higher efficiency, and the lack of fitting space available in those frame sizes.

In this sense, IE3 class motors in the low power range can be considered as a “best not available technology”.

Also, the proposed IEC 60034-30 classification standard includes, in its annex A, efficiency levels for a Super Premium (IE4) class that is envisaged for the next revision of the standard (earliest proposed date is 2013) since at this time there is no sufficient market and technological information to allow standardization.

The efficiency levels of this Super Premium class are believed to be too high to be achieved with standard induction motor technology, particularly for small motors. However, it is expected that advanced technologies (e.g.  Permanent Magnet motors) will enable manufacturers to design motors for this efficiency class with mechanical dimensions compatible to existing motors of lower efficiency classes, making this motors commodity products.

Since the IEC 60034-30 standard  is only directed at single speed three-phase induction motors, the next revision may expand its scope to new motor technologies which can be used to retrofit existing motors. Motors meeting these very high efficiency levels would greatly reduce the electricity consumption and environmental impact of electric motors once they are made available as commodity type products.

## *7.7 Summary*

This section analysed the improvement potential in terms of environmental improvement and lifecycle cost of the technologies presented in section 6.

The results show that if high efficiency motors replace the current IE1 motors, a significant reduction in environmental impact will be achieved.

A very significant reduction of the LCC for the low power motors, with savings reaching more moderate levels as the motor power increases is also achieved. Most of the improvement occurs when the efficiency level moves from IE1 to IE2, but a noticeable improvement can still be seen when the efficiency level reaches  the IE3 level.

In variable flow systems, the use of VSDs can produce a reduction in both environmental impact and LCC.

# 8 Scenario, policy, impact and sensitivity analysis

This chapter summarises the outcomes of all previous tasks relevant for this chapter and looks at suitable policy means to achieve the potential savings e.g. implementing LLCC as a minimum and BAT as a promotional target, using legislative or voluntary agreements, labelling and promotion. It draws up scenarios in the period 1998 – 2020 quantifying the improvements that can be achieved vs. a Business-as-Usual scenario. It makes an estimate of the impact on consumers as described in Appendix 2 of the Directive, explicitly. In a sensitivity analysis of key cost-effectiveness parameters, the robustness of different possible outcomes is analysed. Possible impacts in motor manufacturing industry are also presented.

## *8.1 Introduction*

The analysis carried out shows that the environmental and lifecycle cost impacts resulting from motor operation are, for the most part, attributable to the use-phase. The motor market is significantly affected by the split incentives market barrier – most motors are purchased by OEMs, who are mainly interested in the motor first cost, since they will not pay the operating expenses. Therefore regulatory measures focused on minimum efficiency motor standards seem appropriate to remove from the market inefficient products.

### 8.1.1 Product classification

The current effort from IEC to globally harmonize energy efficiency classes for three-phase induction motors that will result in the IEC 60034-30 international standard is a major step towards ensuring market transparency and the promotion of consistent regulatory measures around the world, and in particular in the EU.

This international standard specifies efficiency classes for general-purpose, single-speed, three-phase, 50 Hz and 60 Hz, cage-induction motors that:

- have a rated voltage *U*N up to 1000 V;

*NOTE - The standard also applies to motors rated for two or more voltages and/or frequencies*

- have a rated output *P*N between 0,75 kW and 370 kW;
- have either 2, 4 or 6 poles
- are rated on the basis of duty type S1 (continuous duty) or S3 (intermittent periodic duty) with an operation time of 80% or more;
- are constructed to degree of protection IP2x, IP4x, IP5x or IP6x according to IEC60034-5;
- are constructed with a cooling method IC0Ax, IC1Ax, IC2Ax, IC3Ax or IC4Ax according to IEC 60034-6;
- are intended for direct on-line connection;
- are rated for operating conditions according to IEC 60034-1, clause 6.

Motors covered by this standard may be used in variable-speed drive applications (see IEC 60034-17). In such applications the marked efficiency of the motor shall not be assumed to apply due to increased losses from the harmonic voltage content of the power supply.

Motors specifically built for operation in explosive atmospheres according to IEC 60079-0 and IEC 61241-1 are covered by this standard. However a lower classification may be required.

Geared motors and brake motors are included although special shafts and flanges may be used in such motors.

Excluded are:

- Motors specifically made for converter operation according to IEC 60034-25 with increased insulation.
- Motors completely integrated into a machine (pump, fan, compressor, …) which cannot be separated from the machine.
- All other non-general-purpose motors (like smoke-extraction motors built for operation in high ambient temperature environments according to EN12101-3 etc.).

The designation of the energy efficiency class consists of the letters “IE” (short for “International Energy Efficiency Class”), directly followed by a numeral representing the classification.

Four efficiency classes are defined:

- IE4 – Super Premium
- IE3 – Premium efficiency
- IE2 – High efficiency
- IE1 – Standard efficiency

Efficiency and losses shall be tested in accordance with IEC 60034-2-1 which describes methods for the determination of motor efficiency. The selected test method shall be associated with low uncertainty and shall be stated in the documentation of the motor.

The rated efficiency shall represent the average efficiency of a large (In USA a minimum of 5 units is used for that purpose) population of motors of the same design. The full-load efficiency of any individual motor, when operating at rated voltage and frequency, shall be not less than rated efficiency minus the tolerance of the total losses according to IEC 60034-1 (-15% of 1-$\eta$), but this individual efficiency must not decrease the average efficiency.

In this International Standard the terms and definitions given in IEC 60034-1, Rotating electrical machines – Part 1: Rating and Performance, apply.

### 8.1.2 Motor Market

The developments in power electronics in the last decades allowed induction motors to achieve the same or even better torque/speed performance of DC motors in high demand applications, but with much higher reliability, leading to a shift away from DC solutions in industry. Nowadays, AC motors completely dominate motors sales representing 96% of all motors sold in the EU. The AC market is, in its turn, dominated by three-phase induction motors which represent 87% of AC motors sold (83,5% of total motor markets).

Three-phase AC induction motors largely dominate the market not only in number of sales but also in terms of energy consumption. Therefore it seems adequate that any implementing measures should focus on that type of motors.

### 8.1.3 Labelling

The present market situation is characterized by the lack of a simple and clear way for the user to specify and inspect the motor efficiency. In accordance with IEC 60034-30, which is in the final stages of approval, the rated efficiency and the efficiency class shall be durably marked on or near the rating plate, for example 86% (IE2). For a motor with dual frequency rating, both 50 HZ and 60 Hz efficiencies shall be marked.

This standard will overcome the above mentioned information barrier. Because of the relatively narrow efficiency band in each class, no further labelling measures seem necessary.

### 8.1.4 Existing voluntary agreements and legislation around the world

Almost all the major economies have some kind of voluntary or mandatory regulatory scheme regarding motor efficiency. Some of these economies have mandatory minimum efficiency levels for motors sold in the respective countries and labelling schemes for the promotion of higher efficiency motors.

With the purpose of setting an international context for the proposed scenarios a brief outline of the current European and North American situations (USA and Canada are the leading market for energy efficient motors) is made here.

In the European Union, a voluntary agreement supported by CEMEP and the European Commission was established and signed in 1999 by 36 motor manufacturers, representing 80% of the European production of standard motors. In this agreement it was decided to define a motor classification scheme with three efficiency levels for three phase induction motors:

- EFF1 – High efficiency motors
- EFF2 – Medium efficiency motors
- EFF3 – Low efficiency motors

Based on the classification scheme there was a voluntary undertaking by motor manufacturers to reduce the sale of motors with the current standard efficiency (EFF3).

The CEMEP/EU agreement was a very important first step to promote motor efficiency classification and labelling, together with a very effective market transformation. Low efficiency motors (EFF3) have essentially been removed from the EU induction motor market which is now dominated by EFF2 motors (85% of motors sold). This has been a positive development, but the penetration of EFF1 motors is still very small (12% of motors sold).

However, other countries have achieved better results by the implementation of mandatory standards which introduced higher minimum efficiency levels leading to a more relevant market transformation (see section 1.3.3).

This is the case in North America which has been subject to mandatory policies regarding motor efficiency since 1997 has witnessed a much more effective market transformation. EPAct motors (equivalent to IE2 / EFF1 motors) and NEMA Premium motors (about 15% lower losses than IE2 /EFF1 motors) now account for 70% of the market.

The American Council for an Energy-Efficient Economy (ACEEE) and the National Electrical Manufacturers Association (NEMA) have agreed to a new set of proposed energy efficiency standards for industrial electric motors that has been submitted to the House Energy and Commerce Committee and the Senate Energy and Natural Resources Committee for their consideration in energy legislation now under development.

The proposal aims not only at setting higher minimum mandatory efficiency levels, but also to broaden the scope of existing standards (e.g. types of motors which can be considered as general purpose motors), reducing by about 50% the number of motors which are not subject to MEPs.

### 8.1.5 Environmental and LCC analysis

The environmental analysis showed that the use-phase completely dominates the life-cycle impact of electric motors (page 74). These results reinforce the need for minimum efficiency based regulation, as the best way to reduce the environmental impact of such products.

Figure 8-1 shows the LCC as a function of motor rated power, considering different efficiency classes and number of operating hours. As it would be expected, the results show very significant reduction of the LCC for the low power motors, with savings reaching more moderate levels as the motor power increases. Most of the improvement occurs when the efficiency level moves from IE1 to IE2.

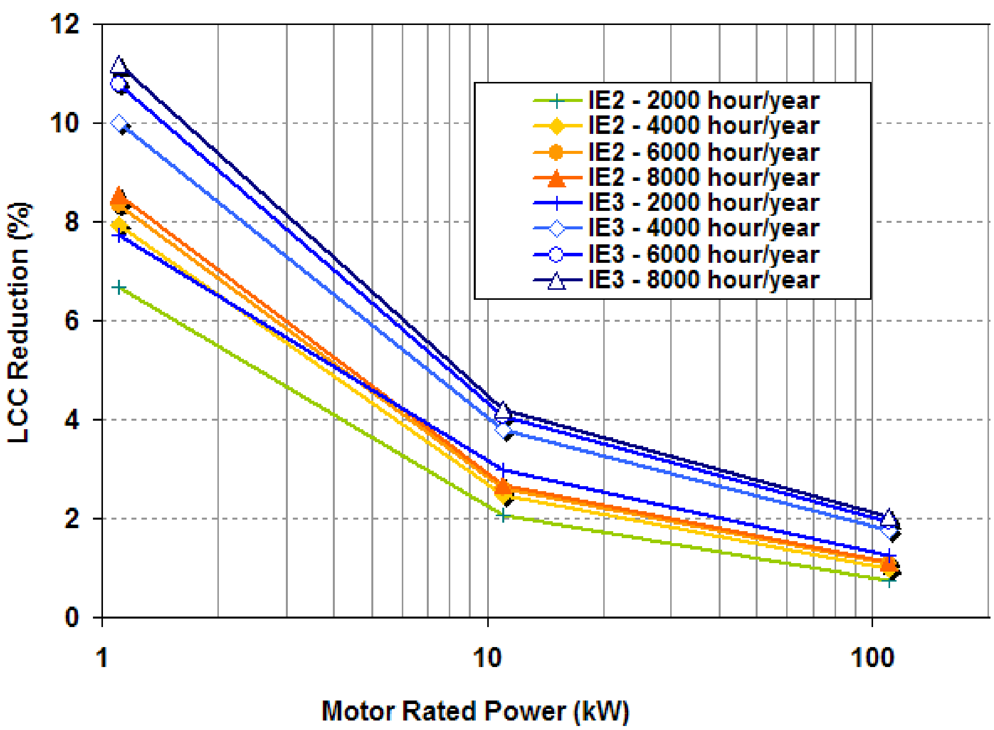


**Figure 8-1 LCC reduction (BAT vs. BaseCase)**

## *8.2 Product definition for possible Eco-design measures*

Implementation measures proposed hereafter will relate to single speed, three-phase 50 Hz or 60 Hz or 50/60 Hz, squirrel cage induction motors in accordance with IEC 60034-1 that:

- Have a rated voltage of $U_N$ up to 1000 V;
- have a rated output *P*N between 0,75 kW and 200 kW;
- have either 2, 4 or 6 poles;
- are rated on the basis of duty type S1 (continuous duty);
- are constructed to degree of protection IP4x or higher according to IEC60034-5;

Excluded are:

- Motors completely integrated into a machine (pump, fan, compressor, …) which cannot be separated from the machine;
- Motors specifically built for operation in explosive atmospheres according to IEC 60079-0 and IEC 61241-1;
- All other non-general-purpose motors (like smoke-extraction motors built for operation in high ambient temperature environments according to EN12101-3 etc.).

Motors shall be classified according to IEC 60034-30 Standard.

The present study is specifically about motors in the 0,75-200 kW power range, which was the power range initially considered for analysis.

However, due to the following very recent developments:

- MEPS in other countries already cover higher power motors (e.g. up to 370 kW in USA, up to 315 kW in China)

- recently approved IEC 60034-30 classification standard covers motors up to 370 kW,

a possible extension of the range up 370 kW of products covered by possible eco-design measures in Europe, was suggested to be considered, and is included in the scenario analysis.

## *8.3 Possible eco-design requirements*

In order to reduce the environmental impact of the products under study, a number of possible implementation measures are proposed here.

### 8.3.1 Generic eco-design requirements

Generic eco-design requirements aim at improving the environmental performance of EuPs, focusing on significant environmental aspects thereof without setting limit values.

#### *8.3.1.1 Design, manufacturing and end of life*

Some design recommendations can be made to improve the environmental impact of electric motors, namely:

- Motors should be easily assembled and disassembled;
- a reduction of the diversity of materials used should be sought;
- a reduction of non-recyclable parts, namely plastic, should be sought;
- windings should be easily removed.

None of these design recommendations should reduce the efficiency of the motor since the use-phase is clearly the one that causes the most environmental impact.

Electric motors are mainly built with materials that are recyclable and that have a very high value (e.g. steel, aluminium, copper). Therefore the majority of motor materials are recycled at the end-of-life.

#### *8.3.1.2 Installation, maintenance and use*

The optimization of the whole motor system has the largest potential for energy savings (20 - 30%) while reducing operating costs. Therefore, consumers should be made aware that the motor is only one part in a larger system designed to produce a desired effect, and that all parts should be properly dimensioned and integrated if they are to produce this effect efficiently. Therefore, system designers and operators should namely seek:

- The correct selection and sizing of an energy-efficient motor (be it new or upon replacement);
- The supply of good power quality;
- To avoid the use of inefficient components such as throttles valves and dampers. If the system has variable speed requirements, the use of VSDs is recommended for speed and/or torque control (See Annex III).
- The correct selection and sizing of efficient mechanical transmissions.
- The correct sizing of ducts, pipes and components (e.g. heat exchangers)
- To avoid leaks in air, water or vapour systems;
- Apply regular maintenance to all system components which are prone to wear.

Taking these aspects into consideration, there are available a series of educational materials and design aids (e.g. software such as MotorMaster or EuroDEEM) to assist motor system experts and factory engineers and Energy Management programs educating company staff.

Poor repair of old motors can further degrade their modest efficiency (most old motors are EFF3) if good practices are not undertaken. Therefore, the use of a good practice guide for motor repair and rewinding is also recommended [34].

Noise levels in electric motors are regulated by the IEC 60034-9 standard that specifies maximum A-weighted sound power levels, $L_{WA}$ in decibels, dB, for airborne noise emitted by rotating electrical machines.

### 8.3.2 Specific eco-design requirements

Specific eco-design requirements aim at improving a selected environmental aspect of the product by setting a limit to the consumption of a given resource. As demonstrated in previous chapters, the use-phase clearly has the most environmental impact when considering the life-cycle of electric motors. Therefore, specific eco-design requirements shall focus on motor efficiency.

The agreement between the European Commission and the CEMEP manufacturers has produced a major market change in lower efficiency range, but is clearly insufficient when compared with the results achieved by other countries (see Chapter 2). The introduction of mandatory minimum efficiency levels for motors sold in those countries has proven to be a much more successful approach to achieve an effective motor market transformation in the higher efficiency range.

Three possible scenarios are proposed for the introduction of MEPS in the EU, based on the classification scheme defined by the IEC 60034-30 standard:

1. Motors in the power range of 0,75-200 kW manufactured in or imported into the EU after January 1, **2011** must meet or exceed the **IE2** efficiency level.

2. Motors in the power range of 0,75-200 kW manufactured in or imported into the EU after January 1, **2011** must meet or exceed the **IE2** efficiency level.
   Motors in the power range of 7,5-200 kW manufactured in or imported into the EU after January 1, **2015** must meet or exceed the **IE3** efficiency level.

3. Motors in the power range of 0,75-200 kW manufactured in or imported into the EU after January 1, **2011** must meet or exceed the **IE2** efficiency level.
   Motors in the power range of 0,75-200 kW manufactured in or imported into the EU after January 1, **2015** must meet or exceed the **IE3** efficiency level.

**Table 8-1 Implementing dates for possible MEPS in the range 0,75-200 kW**

| | 2011 | 2015 |
|---|---|---|
| **Scenario I** | IE2 | - |
| **Scenario II** | IE2 | IE3 (Pn ≥ 7,5 kW) |
| **Scenario III** | IE2 | IE3 |

#### *8.3.2.1 CE Marking*

The compliance of MEPS for motors can be, at least in an initial period, based on self-verification by the manufacturers, using the related IEC standards for efficiency testing and classification, including the allowable tolerance levels.

Mechanisms can be developed (e.g. heavy fines applied per sub-standard product sold in the market, like in USA) to discourage non-compliance. Cross-checking of motor efficiencies by different manufacturers also acts as an additional discouragement.

The market can also be followed up by independent, qualified laboratories in order to check the compliance and tolerances of the products available in the market. A certification scheme for third-party testing laboratories, similar to the one currently in use in the USA, run by the US national Voluntary Laboratory Accreditation Program NVLAP, can be put in place.

## *8.4 Scenario analysis for possible market regulation*

Four scenarios for the motor market evolution, corresponding to the implementation of the specific eco-design measures stated above, will be analysed here.

1. **Business as Usual** (BAU) – based on the information collected in chapters 2 through 4 and the evolution of the electricity consumption in the EU-25 [38]. The 1998 (base year) installed base is conservatively assumed to be divided by efficiency level according to the sales in that year.

The motor stock in 1998 was based in previous studies [1] [30] and in the period 1998-2020 the evolution of motor sales in this scenario was made according to the evolution of the electricity consumption in the respective sectors [38]. In the period 1998-2005 the CEMEP sales by efficiency class were considered. After 2005 the sales by efficiency class are considered to remain stable.

2. **Scenario I** – Same as **BAU** until end of 2010. Motors in the power range of 0,75-200 kW manufactured in or imported into the EU after January 1, 2011 must meet or exceed the IE2 efficiency level as defined in the IEC 60034-30 standard. A residual number of sales (15%) of motors below the IE2 class is maintained to take into account special purpose motors that fall out of the product definition as stated in section 8.2[5]. IE3 class motors are considered not to have an important market penetration (constant 2% of new motors sold).

3. **Scenario II** – Same as **BAU** until end of 2010 and same as **Scenario I** until the end of 2014. Motors with a power rating over 7,5 kW (included) manufactured in or imported into the EU after January 1, 2015 must meet or exceed the IE3 efficiency level as defined in the IEC 60034-30 standard. A residual number of sales (15%) of motors under the IE3 class is maintained to take into account special purpose motors that fall out of the product definition as stated in section 8.2.

4. **Scenario III** – Same as **BAU** until end of 2010 and same as **Scenario I** until the end of 2014. Motors manufactured in or imported into the EU after January 1, 2015 must meet or exceed the IE3 efficiency level as defined in the IEC 60034-30 standard. A residual number of sales (15%) of motors under the IE3 class is maintained to take into account special purpose motors that fall out of the product definition as stated in section 8.2.

The evolution of the motor stock for the industrial and tertiary sectors was analysed for the different scenarios in the period 1998-2020 and is shown in Figures 8-2 to 8-9.

[5] Based on the North-American Motors' Market (Source: ACEEE)

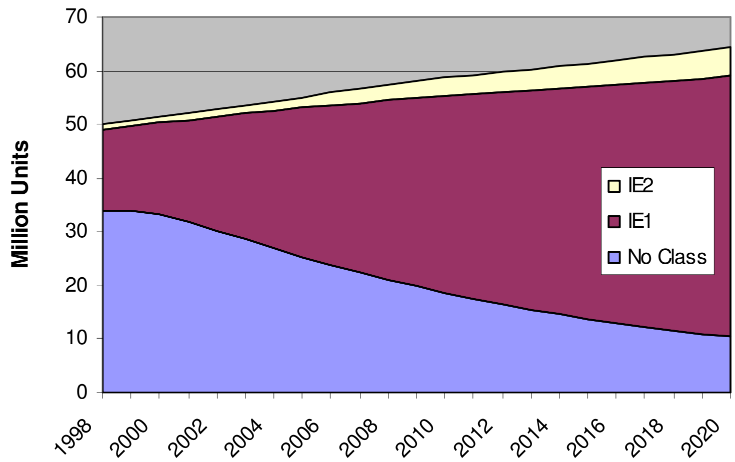


**Figure 8-2 Evolution of the motor installed base, by efficiency class, in the industry (BAU)**

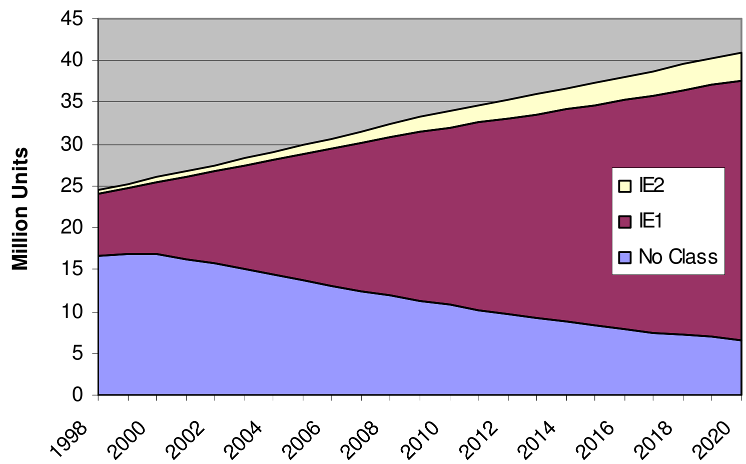


**Figure 8-3 Evolution of the motor installed base, by efficiency class, in the tertiary sector (BAU)**

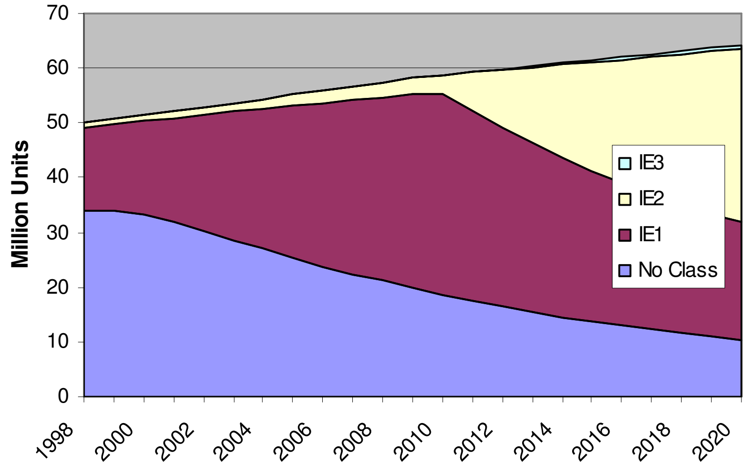


**Figure 8-4 Evolution of the motor installed base, by efficiency class, in the industry (Scenario I)**

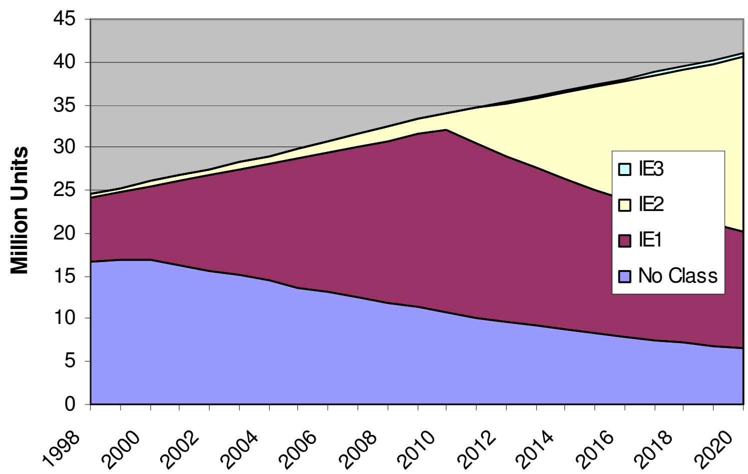


**Figure 8-5 Evolution of the motor installed base, by efficiency class, in the tertiary sector (Scenario I)**

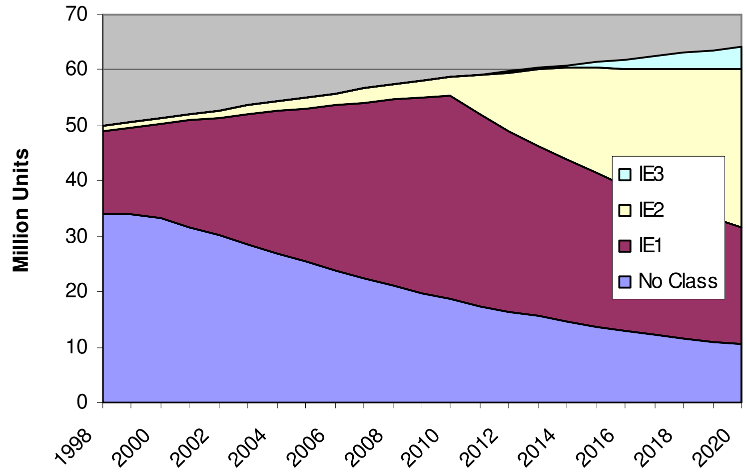


**Figure 8-6 Evolution of the motor installed base, by efficiency class, in the industry (Scenario II)**

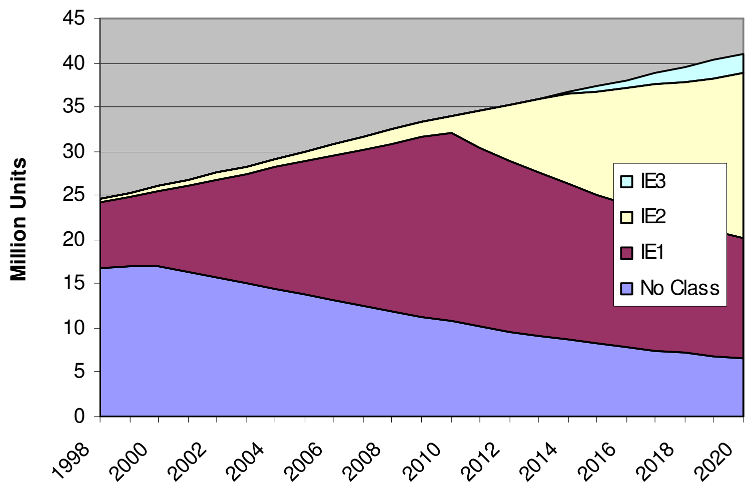


**Figure 8-7 Evolution of the motor installed base, by efficiency class, in the tertiary sector (Scenario II)**

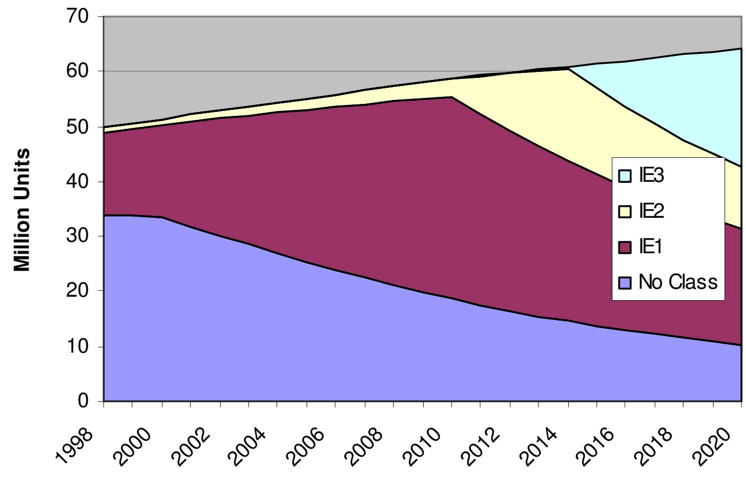


**Figure 8-8 Evolution of the motor installed base, by efficiency class, in the industry (Scenario III)**

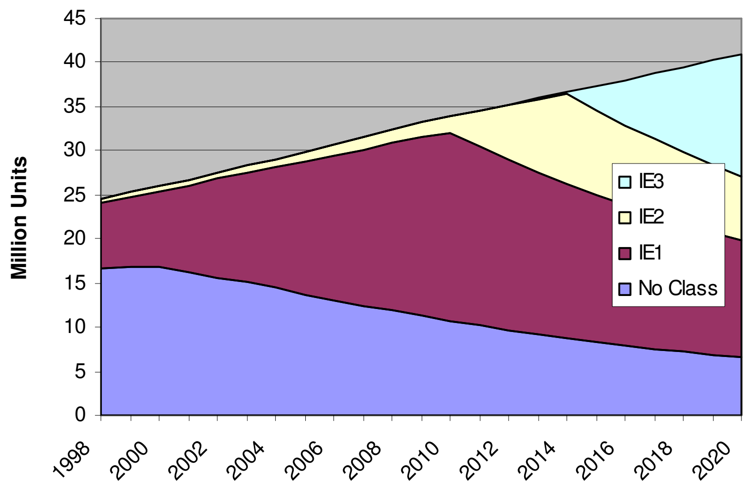


**Figure 8-9 Evolution of the motor installed base, by efficiency class, in the tertiary sector (Scenario III)**

The evolution of the electricity consumption, both for the industrial and tertiary sectors, for the three scenarios analysed, can be seen in the next figures.

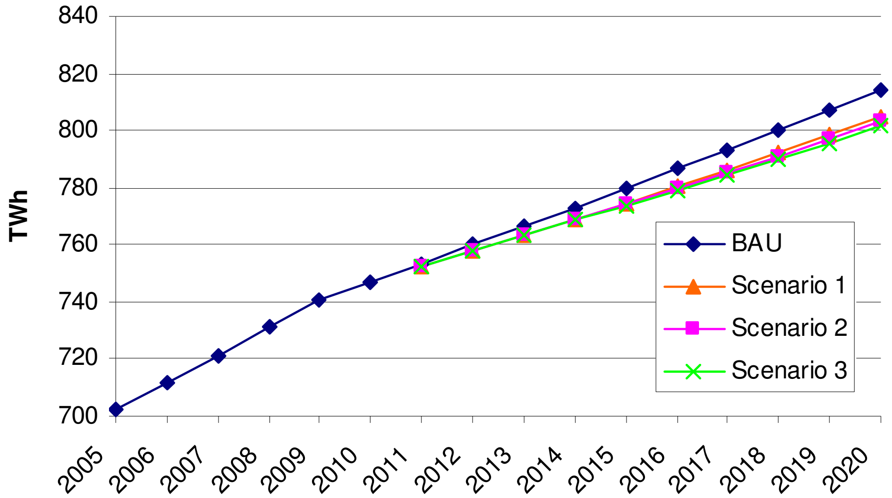


**Figure 8-10 Evolution of the electricity consumption in the industry sector**

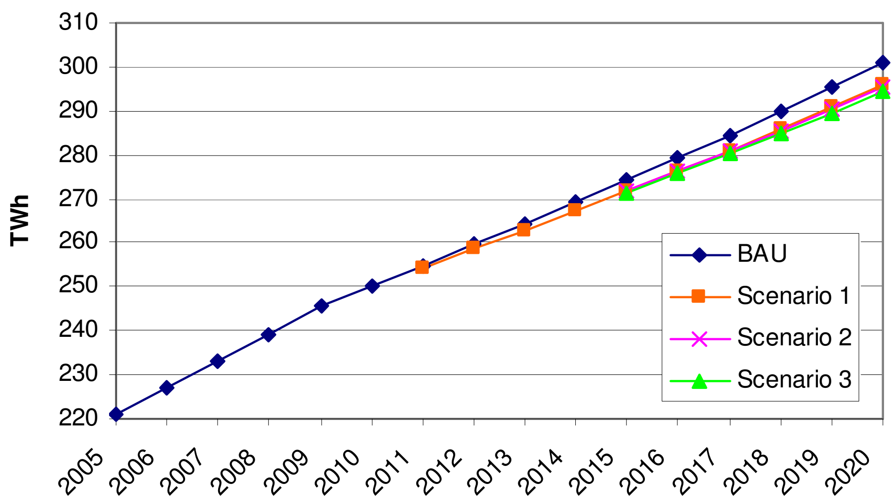


**Figure 8-11 Evolution of the electricity consumption in the tertiary sector**

The results show that the implementation of minimum efficiency levels for motors sold in the EU from 2011 forward would result in a saving of 14 TWh of electricity for Scenario I, of 17 TWh for scenario II and of 19 TWh for Scenario III, in the year 2020. This would represent cumulative savings of 84 TWh for Scenario I, 92 TWh for Scenario II and 101 TWh for Scenario III (2011-2020).

It should be emphasized that these figures do not show the total savings potential, since the full impact of MEPS with IE2 level would only be achieved in 2030, as the stock rotation initiated in 2011 will take 20 years to be completed. A similar reasoning can be applied to the potential impact of IE3 MEPS, which if initiated in 2015 would take an additional 20 years to be completed.

**Table 8-2 Proposed Scenarios vs. BAU electricity savings (industry plus tertiary), in TWh**

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario I** | 1,72 | 3,35 | 4,89 | 6,36 | 7,75 | 9,08 | 10,4 | 11,6 | 12,7 | 13,8 |
| **Scenario II** | 1,72 | 3,35 | 4,89 | 6,36 | 8,28 | 10,1 | 11,9 | 13,6 | 15,2 | 16,7 |
| **Scenario III** | 1,72 | 3,35 | 4,89 | 6,36 | 8,78 | 11,1 | 13,3 | 15,4 | 17,4 | 19,3 |

**Table 8-3 Proposed Scenarios electricity savings (industry plus tertiary), as a percentage of total BAU consumption**

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario I** | 0,18% | 0,34% | 0,49% | 0,63% | 0,76% | 0,88% | 0,99% | 1,09% | 1,19% | 1,28% |
| **Scenario II** | 0,18% | 0,34% | 0,49% | 0,63% | 0,79% | 0,95% | 1,10% | 1,24% | 1,37% | 1,50% |
| **Scenario III** | 0,18% | 0,34% | 0,49% | 0,63% | 0,83% | 1,04% | 1,23% | 1,41% | 1,57% | 1,73% |

If the current electricity production methods remain unchanged, this electricity savings would translate in the cumulative reduction of GWP emissions by 39 million tons of $CO_{2eq}$ in 2020 (8,8 million tons of $CO_{2eq}$ pa. in that year) for scenario.

**Table 8-4 Proposed Scenarios vs. BAU GWP reduction, in million tons of $CO_{2eq}$**

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario I** | 0,790 | 1,539 | 2,249 | 2,924 | 3,566 | 4,177 | 4,760 | 5,315 | 5,847 | 6,355 |
| **Scenario II** | 0,790 | 1,539 | 2,249 | 2,924 | 3,809 | 4,654 | 5,460 | 6,231 | 6,969 | 7,677 |
| **Scenario III** | 0,790 | 1,539 | 2,249 | 2,924 | 4,037 | 5,095 | 6,103 | 7,065 | 7,983 | 8,860 |

## *8.5 Additional scenario for the extension of the power range above 200 kW and up to 370 kW*

The extension of the scope of possible MEPS above 200 kW and up to 370 kW, would translate into additional electricity savings of 190 GWh for scenario I and 306 GWh for scenario II or III, in 2020. It should be emphasized that large motors have a slow stock rotation (about 20 years), which means that the savings potential in 2020 is minor fraction (about one quarter) of the total savings potential after the stock has been replaced. In any case, the modest savings potential associated with the efficiency improvements in the range above 200 kW and up to 370 kW, is due to the fact that large motors already have fairly high efficiency values. According to IEC 60034-30, IE1 motors above 200 kW must have a minimum efficiency of 94%. Therefore the potential for improvement in this upper range is limited.

## *8.6 Impact on consumers of possible MEPs regulation*

The environmental impact and LCC analysis carried out in the previous chapters clearly shows that in most applications there are large cost-effective savings potential for the implementation of measures regarding motor efficiency, with financial benefits to the consumers and leading to a large reduction in emissions. However, in applications with low operating time implementation measures can result in a negative impact for consumers which will be forced to buy motors at a higher price. These motors seem to represent only a very small percentage of the total motor market since the average operating hours for motors in the range considered are well above the cross-over point.

Both manufacturers and consumers will gain from the implementation of the IEC60034-30 standard that will hopefully end the confusion regarding differences and similarities of standards in different countries

### 8.6.1 Sensitivity analysis

#### *8.6.1.1 Electricity prices*

In order to analyse the impact of electricity prices variation on the Life Cycle Cost of the analysed products three scenarios were considered for three different electricity prices: 0,035€; 0,075€ (the EU average industrial electricity price) and 0,11€.

The next figures show the LCC reduction as a function of the number of operating hours for the different electricity prices.

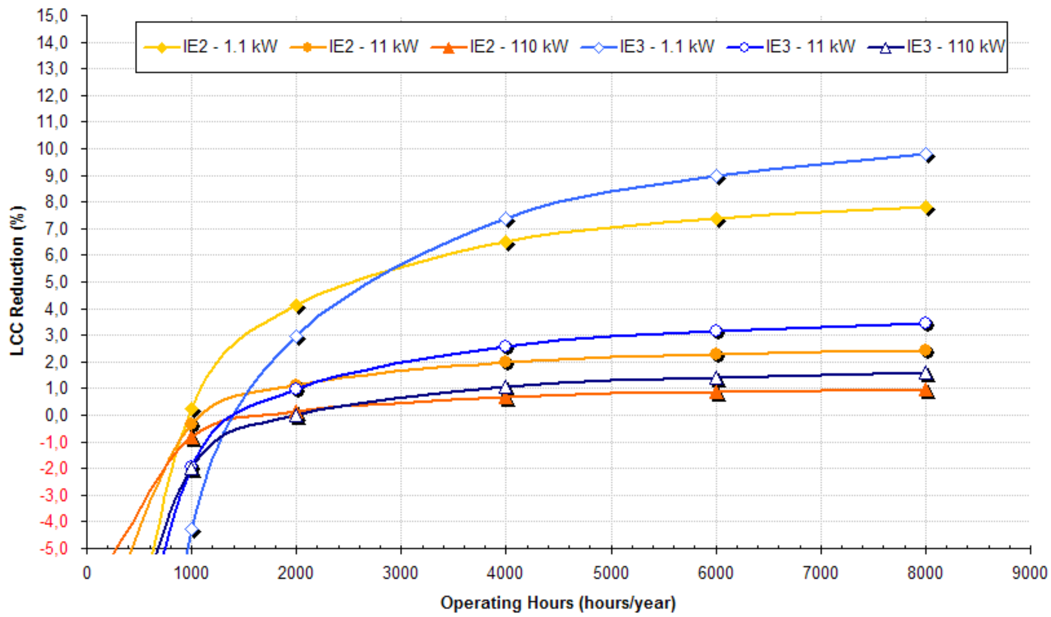


**Figure 8-12 LCC reduction as a function of the number of operating hours (0,035 €/kWh), BAT vs. BaseCase**

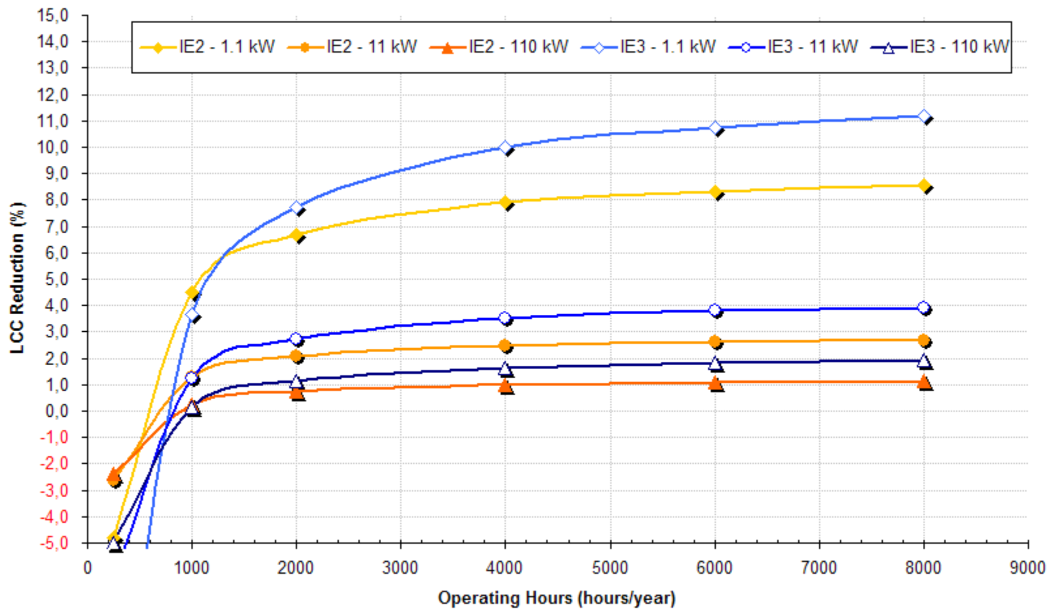


**Figure 8-13 LCC reduction as a function of the number of operating hours (0,075 €/kWh), BAT vs. BaseCase**

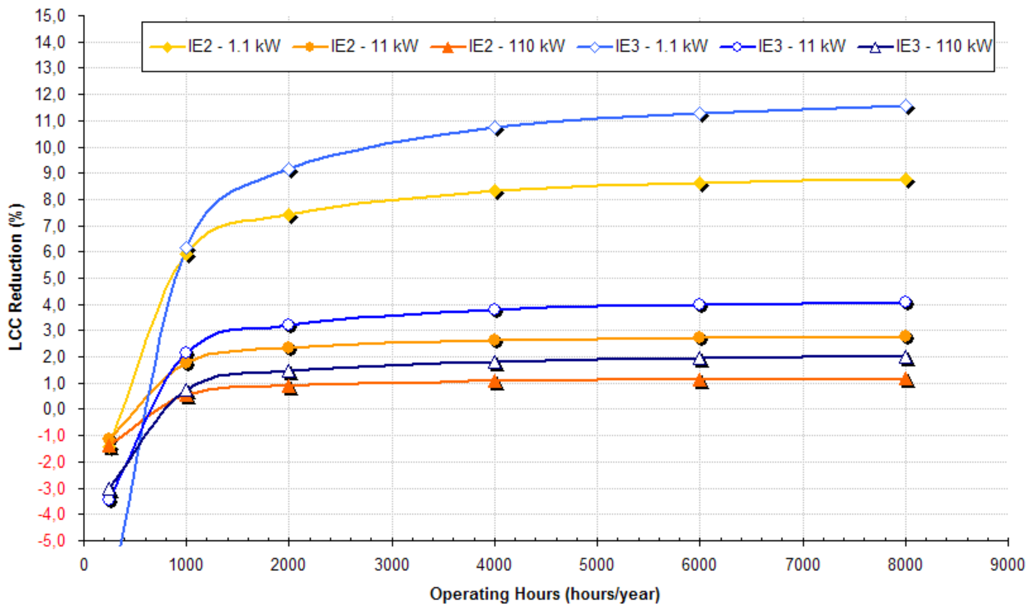


**Figure 8-14 LCC reduction as a function of the number of operating hours (0,11 €/kWh), BAT vs. BaseCase**

The results show that although the prices of IE2 and IE3 motors are considerably higher than those of IE1 motors, a reduction in LCC is achieved in all cases for a fairly reduced number of operating hours per year – around 2000 hours for the scenario of the lowest electricity prices.

## 8.7 Voluntary Labelling and Incentives

In order to consider the possible impact of incentives, it is useful to review the North American situation. In USA, motor manufacturers and the motor efficiency community created the voluntary labelling program NEMA Premium for motors with higher efficiency levels (equivalent to IE3). Seven years of promoting Premium motors through incentive programs, has resulted in a moderate market acceptance of these products, representing a significant programmatic success with most large industrial consumers. The USA federal government has also embraced these products. However, the shift of the motor marketplace to Premium appears to have stalled in recent years as the programs have been unable to significantly impact the original equipment manufacturers (OEMs) or many of the less sophisticated motor purchasers. Sales of these Premium motors stagnated at around 16% of sales, a modest number that demonstrates the limitations of such labelling programs even with rebate programs associated with them. This ineffectiveness can be associated mainly with two reasons:

-The first is lack of information on the importance of motor efficiency

-The second, and most relevant, is that the motor market is largely a OEM market that is cost-driven since the motor's operating costs will not be paid by the OEMs.

The North American experience in Canada and in USA has shown that financial incentives are an important first-step that plays an important role in transitioning the market towards more efficient motors. Those incentives also seem to encourage end-use consumers to replace (instead of repair) their older, inefficient and sometimes oversized motors with new motors, more efficient, and properly sized.

These incentives can also help in an anticipatory move prevent consumers from buying less efficient, but cheaper motors, before the enactment of the regulatory measures.

However, it is clear that the only way to ensure an effective market transformation is by the application of MEPS after which, the no direct financial incentives are required.

White Certificates schemes can also be adopted as a way to promote an earlier adoption of both IE2 and IE3 motors in new applications, before their use becomes mandatory. White Certificates can also encourage end-users to replace (instead of repair) their older, inefficient (mostly below IE1 class) and often oversized motors with new properly sized efficient motors.

## 8.8 Impact on motor manufacturers

The implementation of minimum efficiency levels for motors sold in the EU would result in a more regulated market where innovative manufacturers would profit from current and past R&D investments.

The adoption of MEPS for three-phase induction motors is not likely to cause a market shift towards another cheaper and/or less efficient technology since those technologies do not offer the same overall performance advantages as three-phase induction motors (see chapter 1). The previous adoption of MEPS in other countries proves this point since a market shift has not occurred there either.

The adoption of IE2 efficiency level in the short term does not seem to pose particular problems to the EU industry since most EU manufacturers are already producing this type of motors for whole power range under consideration.

However, the adoption of IE3 efficiency levels in the medium term can pose problems to the EU industry for the following reasons:

- Most EU manufacturers are not yet producing this type of premium efficiency motors. There is a need to invest in new designs and new manufacturing tools, which may represent a large amount of investment, particularly for small companies.

- IEC frame sizes may not allow to achieve IE3 efficiency levels for small motors (e.g. below 7.5 kW), without increasing the frame size, even if using more expensive copper rotor motors. This issue deserves to be further investigated.

### *8.9 Impact on Employment*

The possible implementing measures do not seem to pose an adverse impact on employment. On the opposite, it is expected that by removing from the market imported low performance motors, the share of market taken by the European manufacturers will increase. The increase in the use of variable speed drives, sold both as integrated units with the motors, as well as separate units, can lead to additional business and creation of new jobs.

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[38] Primes Energy Model, European Commission, 2006

# Appendix I

Relevant standards and legislation regarding motor use, design and safety

| Legislation | Scope |
|---|---|
| Low Voltage Directive 73/23/EEC | Seeks to ensure that electrical equipment within certain voltage limits both provides a high level of protection for European citizens and enjoys a Single Market in the European Union. The Directive covers electrical equipment designed for use with a voltage rating of between 50 and 1000 V for alternating current and between 75 and 1500 V for direct current. It should be noted that these voltage ratings refer to the voltage of the electrical input or output, not to voltages that may appear inside the equipment. For most electrical equipment, the health aspects of emissions of Electromagnetic Fields are also under the domain of the Low Voltage Directive. |
| Electromagnetic Compatibility Directive 89/336/EEC | Electric and electronic equipment to be sold in the EC must be constructed so that they do not cause excessive electromagnetic interference and are not unduly affected by electromagnetic interference. |
| IEC 60034-5 Rotating electrical machines – Degrees of protection | Gives definitions for standard degrees of protection provided by enclosures; protection of machines against harmful effects due to the ingress of water; protection of machines against ingress of solid foreign objects; Protection of persons against contact with or approach to live parts and against contact with moving parts. Gives designations for these protective degrees and tests to verify that the machines meet the requirements. |
| IEC 60034-9 Rotating electrical machines – Noise limits | The object of this standard is to determine maximum A-weighted sound power levels, *L*WA in decibels, dB, for airborne noise emitted by rotating electrical machines of standard design, as a function of power, speed and load, and to specify the method of measurement and the test conditions appropriate for the determination of the sound power level of the machines to provide a standardized evaluation of machine noise up to the maximum specified sound power levels. |
| IEC 60034-9 Rotating electrical machines – Built-in thermal protection | Specifies requirements relating to the use of thermal protectors and thermal detectors incorporated into the stator windings or placed in other suitable positions in induction machines in order to protect them against serious damage due to thermal overloads. |
| IEC 60034-14 Rotating electrical machines – Mechanical vibration of certain machines with shaft heights 56mm or higher | Specifies the factory acceptance vibration test procedures and vibration limits for certain electrical machines under specified conditions, when uncoupled from any load or prime mover. |

## Appendix II

### Table A - 1 Environmental Impact of Real-Life BaseCase 1.1 kW (4000h)

| Life cycle Impact per product: | Date | Author |
|---|---|---|
| Real-Life BaseCase 1.1 kW 3-Phase Ind. Motor | 0 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resources Use and Emissions | | Material | Manuf. | Total | BUTION | | Disposal | Recycl. | Total | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **385** | | | 347 | 39 | **385** | **0** |
| 3 | Ferro | g | | | **10340** | | | 517 | 9823 | **10340** | **0** |
| 4 | Non-ferro | g | | | **3234** | | | 162 | 3072 | **3234** | **0** |
| 5 | Coating | g | | | **110** | | | 6 | 105 | **110** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **14069** | | | 1031 | 13038 | **14069** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 729 | 171 | **900** | **79** | **110385** | 75 | 27 | **48** | **111412** |
| 9 | of which, electricity (in primary MJ) | MJ | 49 | 99 | **148** | **0** | **110377** | 0 | 0 | **0** | **110526** |
| 10 | Water (process) | ltr | 149 | 1 | **150** | **0** | **7360** | 0 | 0 | **0** | **7510** |
| 11 | Water (cooling) | ltr | 251 | 42 | **293** | **0** | **294339** | 0 | 1 | **-1** | **294632** |
| 12 | Waste, non-haz./ landfill | g | 41734 | 808 | **42542** | **64** | **128400** | 930 | 1 | **929** | **171936** |
| 13 | Waste, hazardous/ incinerated | g | 11 | 0 | **11** | **1** | **2543** | 347 | 0 | **346** | **2902** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 51 | 10 | **61** | **6** | **4817** | 6 | 2 | **4** | **4888** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 617 | 42 | **659** | **17** | **28428** | 11 | 2 | **9** | **29113** |
| 17 | Volatile Organic Compounds (VOC) | g | 2 | 0 | **2** | **0** | **42** | 0 | 0 | **0** | **44** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 252 | 20 | **272** | **0** | **726** | 6 | 0 | **6** | **1005** |
| 19 | Heavy Metals | mg Ni eq. | 350 | 48 | **398** | **3** | **1898** | 21 | 0 | **21** | **2320** |
| | PAHs | mg Ni eq. | 41 | 0 | **41** | **4** | **218** | 0 | 0 | **0** | **263** |
| 20 | Particulate Matter (PM, dust) | g | 88 | 6 | **94** | **69** | **608** | 98 | 0 | **98** | **869** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 200 | 0 | **200** | **0** | **714** | 6 | 0 | **6** | **920** |
| 22 | Eutrophication | g PO4 | 9 | 0 | **10** | **0** | **3** | 0 | 0 | **0** | **13** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 2 Environmental Impact of Real-Life BaseCase 11 kW (4000h)

| Life cycle Impact per product: | Date | Author |
|---|---|---|
| Real-Life BaseCase 11 kW 3-Phase Ind. Motor | Dec 2006 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **1320** | | | 1188 | 132 | **1320** | **0** |
| 3 | Ferro | g | | | **64350** | | | 3218 | 61133 | **64350** | **0** |
| 4 | Non-ferro | g | | | **34540** | | | 1727 | 32813 | **34540** | **0** |
| 5 | Coating | g | | | **550** | | | 28 | 523 | **550** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **100760** | | | 6160 | 94600 | **100760** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 6608 | 1057 | **7665** | **255** | **589098** | 459 | 118 | **341** | **597359** |
| 9 | of which, electricity (in primary MJ) | MJ | 272 | 607 | **880** | **0** | **588429** | 0 | 1 | **-1** | **589308** |
| 10 | Water (process) | ltr | 888 | 8 | **896** | **0** | **39237** | 0 | 0 | **0** | **40133** |
| 11 | Water (cooling) | ltr | 1007 | 258 | **1264** | **0** | **1569133** | 0 | 3 | **-3** | **1570394** |
| 12 | Waste, non-haz./ landfill | g | 585327 | 5096 | **590423** | **149** | **688144** | 6784 | 2 | **6782** | **1285498** |
| 13 | Waste, hazardous/ incinerated | g | 58 | 1 | **59** | **3** | **13560** | 1188 | 0 | **1188** | **14809** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 428 | 60 | **489** | **17** | **25730** | 34 | 8 | **26** | **26261** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 8676 | 262 | **8938** | **49** | **151654** | 67 | 11 | **57** | **160698** |
| 17 | Volatile Organic Compounds (VOC) | g | 10 | 1 | **11** | **3** | **231** | 2 | 0 | **2** | **247** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 1626 | 135 | **1760** | **1** | **3874** | 47 | 0 | **47** | **5682** |
| 19 | Heavy Metals | mg Ni eq. | 3120 | 316 | **3436** | **8** | **10259** | 132 | 0 | **132** | **13835** |
| | PAHs | mg Ni eq. | 315 | 0 | **315** | **9** | **1292** | 0 | 0 | **0** | **1616** |
| 20 | Particulate Matter (PM, dust) | g | 537 | 40 | **577** | **513** | **5447** | 597 | 0 | **597** | **7133** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 1320 | 0 | **1321** | **0** | **3807** | 38 | 0 | **38** | **5166** |
| 22 | Eutrophication | g PO4 | 50 | 0 | **50** | **0** | **19** | 2 | 0 | **2** | **71** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 3 Environmental Impact of Real-Life BaseCase 110 kW (4000h)

| **Life cycle Impact per product:** | Date | Author |
|---|---|---|
| Real-Life BaseCase 110 kW 3-Phase Ind. Motor | Dec 2006 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **6600** | | | 5940 | 660 | **6600** | **0** |
| 3 | Ferro | g | | | **744700** | | | 37235 | 707465 | **744700** | **0** |
| 4 | Non-ferro | g | | | **227700** | | | 11385 | 216315 | **227700** | **0** |
| 5 | Coating | g | | | **1100** | | | 55 | 1045 | **1100** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **980100** | | | 54615 | 925485 | **980100** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 54362 | 8869 | **63231** | **1544** | **3974434** | 3940 | 602 | **3339** | **4042548** |
| 9 | of which, electricity (in primary MJ) | MJ | 1829 | 5089 | **6918** | **3** | **3973269** | 0 | 3 | **-3** | **3980188** |
| 10 | Water (process) | ltr | 6369 | 69 | **6438** | **0** | **264944** | 0 | 2 | **-2** | **271380** |
| 11 | Water (cooling) | ltr | 5528 | 2149 | **7677** | **0** | **10595277** | 0 | 14 | **-14** | **10602940** |
| 12 | Waste, non-haz./ landfill | g | 5012808 | 43284 | **5056093** | **771** | **4657261** | 63451 | 10 | **63441** | **9777566** |
| 13 | Waste, hazardous/ incinerated | g | 323 | 7 | **329** | **15** | **91557** | 5940 | 2 | **5939** | **97841** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 3575 | 507 | **4082** | **93** | **173476** | 294 | 43 | **251** | **177901** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | | | | | negligible | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 72659 | 2200 | **74860** | **284** | **1023894** | 578 | 55 | **523** | **1099561** |
| 17 | Volatile Organic Compounds (VOC) | g | 103 | 10 | **113** | **23** | **1507** | 16 | 1 | **15** | **1658** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 12338 | 1170 | **13508** | **4** | **26178** | 437 | 0 | **437** | **40127** |
| 19 | Heavy Metals | mg Ni eq. | 24615 | 2740 | **27355** | **39** | **68569** | 1143 | 0 | **1143** | **97105** |
| | PAHs | mg Ni eq. | 3092 | 1 | **3093** | **51** | **7988** | 0 | 0 | **0** | **11132** |
| 20 | Particulate Matter (PM, dust) | g | 7225 | 335 | **7560** | **3761** | **24133** | 5127 | 1 | **5126** | **40580** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 10248 | 1 | **10249** | **1** | **25721** | 328 | 0 | **328** | **36299** |
| 22 | Eutrophication | g PO4 | 313 | 3 | **316** | **0** | **125** | 19 | 0 | **19** | **460** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | | | | | negligible | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 4 Environmental Impact of IE2 - 1.1 kW 3-Phase Ind. Motor (4000h)

| Life cycle Impact per product: | Date | Author |
|---|---|---|
| IE2 - 1.1 kW 3-Phase Ind. Motor | 0 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resources Use and Emissions | | Material | Manuf. | Total | BUTION | | Disposal | Recycl. | Total | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **385** | | | 347 | 39 | **385** | **0** |
| 3 | Ferro | g | | | **13310** | | | 666 | 12645 | **13310** | **0** |
| 4 | Non-ferro | g | | | **4290** | | | 215 | 4076 | **4290** | **0** |
| 5 | Coating | g | | | **110** | | | 6 | 105 | **110** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **18095** | | | 1232 | 16863 | **18095** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 954 | 227 | **1182** | **79** | **69564** | 89 | 28 | **61** | **70886** |
| 9 | of which, electricity (in primary MJ) | MJ | 57 | 131 | **188** | **0** | **69554** | 0 | 0 | **0** | **69742** |
| 10 | Water (process) | ltr | 157 | 2 | **159** | **0** | **4638** | 0 | 0 | **0** | **4797** |
| 11 | Water (cooling) | ltr | 252 | 56 | **308** | **0** | **185475** | 0 | 1 | **-1** | **185782** |
| 12 | Waste, non-haz./ landfill | g | 61564 | 1089 | **62654** | **64** | **81268** | 1177 | 1 | **1176** | **145162** |
| 13 | Waste, hazardous/ incinerated | g | 12 | 0 | **12** | **1** | **1603** | 347 | 0 | **346** | **1962** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 67 | 13 | **80** | **6** | **3036** | 7 | 2 | **5** | **3127** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 870 | 56 | **926** | **17** | **17919** | 13 | 3 | **11** | **18873** |
| 17 | Volatile Organic Compounds (VOC) | g | 2 | 0 | **2** | **0** | **26** | 0 | 0 | **0** | **29** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 341 | 28 | **369** | **0** | **460** | 8 | 0 | **8** | **837** |
| 19 | Heavy Metals | mg Ni eq. | 418 | 67 | **484** | **3** | **1198** | 25 | 0 | **25** | **1711** |
| | PAHs | mg Ni eq. | 51 | 0 | **51** | **4** | **138** | 0 | 0 | **0** | **192** |
| 20 | Particulate Matter (PM, dust) | g | 100 | 9 | **108** | **69** | **384** | 116 | 0 | **116** | **677** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 227 | 0 | **227** | **0** | **451** | 7 | 0 | **7** | **685** |
| 22 | Eutrophication | g PO4 | 10 | 0 | **10** | **0** | **2** | 0 | 0 | **0** | **13** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 5 Environmental Impact of IE2 - 11 kW 3-Phase Ind. Motor (4000h)

| Life cycle Impact per product: | Date | Author |
|---|---|---|
| IE2 - 11 kW 3-Phase Ind. Motor | 0 | ISR |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **1320** | | | 1188 | 132 | **1320** | **0** |
| 3 | Ferro | g | | | **78100** | | | 3905 | 74195 | **78100** | **0** |
| 4 | Non-ferro | g | | | **40348** | | | 2017 | 38331 | **40348** | **0** |
| 5 | Coating | g | | | **550** | | | 28 | 523 | **550** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **120318** | | | 7138 | 113180 | **120318** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 7795 | 1313 | **9108** | **255** | **452282** | 526 | 121 | **405** | **462050** |
| 9 | of which, electricity (in primary MJ) | MJ | 320 | 754 | **1074** | **0** | **451721** | 0 | 1 | **-1** | **452794** |
| 10 | Water (process) | ltr | 930 | 10 | **940** | **0** | **30123** | 0 | 0 | **0** | **31063** |
| 11 | Water (cooling) | ltr | 1012 | 319 | **1330** | **0** | **1204573** | 0 | 3 | **-3** | **1205901** |
| 12 | Waste, non-haz./ landfill | g | 703723 | 6390 | **710113** | **149** | **530833** | 7982 | 2 | **7980** | **1249076** |
| 13 | Waste, hazardous/ incinerated | g | 61 | 1 | **62** | **3** | **10409** | 1188 | 0 | **1188** | **11662** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 506 | 75 | **581** | **17** | **19755** | 39 | 9 | **31** | **20384** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 10249 | 326 | **10575** | **49** | **116458** | 77 | 11 | **66** | **127148** |
| 17 | Volatile Organic Compounds (VOC) | g | 13 | 1 | **14** | **3** | **178** | 2 | 0 | **2** | **197** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 2028 | 172 | **2200** | **1** | **2983** | 55 | 0 | **55** | **5239** |
| 19 | Heavy Metals | mg Ni eq. | 3515 | 402 | **3917** | **8** | **7893** | 152 | 0 | **152** | **11970** |
| | PAHs | mg Ni eq. | 361 | 0 | **361** | **9** | **997** | 0 | 0 | **0** | **1368** |
| 20 | Particulate Matter (PM, dust) | g | 595 | 50 | **645** | **513** | **4255** | 684 | 0 | **684** | **6097** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 1468 | 0 | **1468** | **0** | **2927** | 44 | 0 | **44** | **4439** |
| 22 | Eutrophication | g PO4 | 53 | 0 | **53** | **0** | **14** | 2 | 0 | **2** | **70** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 6 Environmental Impact of IE2 - 110 kW 3-Phase Ind. Motor (4000h)

| Life cycle Impact per product: | Date | Author |
|---|---|---|
| IE2 - 110 kW 3-Phase Ind. Motor | 0 | ISR |

| Nr | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **6600** | | | 5940 | 660 | **6600** | **0** |
| 3 | Ferro | g | | | **803000** | | | 40150 | 762850 | **803000** | **0** |
| 4 | Non-ferro | g | | | **217030** | | | 10852 | 206179 | **217030** | **0** |
| 5 | Coating | g | | | **1100** | | | 55 | 1045 | **1100** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **1027730** | | | 56997 | 970734 | **1027730** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 51999 | 9710 | **61709** | **1544** | **3226698** | 4103 | 617 | **3486** | **3293437** |
| 9 | of which, electricity (in primary MJ) | MJ | 1986 | 5574 | **7560** | **3** | **3225676** | 0 | 3 | **-3** | **3233236** |
| 10 | Water (process) | ltr | 6619 | 75 | **6694** | **0** | **215107** | 0 | 2 | **-2** | **221799** |
| 11 | Water (cooling) | ltr | 5556 | 2355 | **7911** | **0** | **8601679** | 0 | 14 | **-14** | **8609576** |
| 12 | Waste, non-haz./ landfill | g | 4791761 | 47292 | **4839053** | **771** | **3788291** | 66370 | 10 | **66360** | **8694476** |
| 13 | Waste, hazardous/ incinerated | g | 312 | 7 | **320** | **15** | **74330** | 5940 | 2 | **5939** | **80604** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 3530 | 555 | **4084** | **93** | **140841** | 306 | 44 | **262** | **145280** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | | | | negligible | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 68356 | 2408 | **70764** | **284** | **831337** | 602 | 57 | **546** | **902930** |
| 17 | Volatile Organic Compounds (VOC) | g | 111 | 11 | **122** | **23** | **1224** | 16 | 1 | **15** | **1384** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 14381 | 1273 | **15654** | **4** | **21299** | 457 | 0 | **457** | **37414** |
| 19 | Heavy Metals | mg Ni eq. | 24518 | 2983 | **27501** | **39** | **55718** | 1191 | 0 | **1191** | **84449** |
| | PAHs | mg Ni eq. | 1502 | 1 | **1503** | **51** | **6474** | 0 | 0 | **0** | **8028** |
| 20 | Particulate Matter (PM, dust) | g | 7115 | 367 | **7482** | **3761** | **19580** | 5339 | 1 | **5338** | **36160** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 10094 | 2 | **10095** | **1** | **20899** | 341 | 0 | **341** | **31336** |
| 22 | Eutrophication | g PO4 | 322 | 4 | **325** | **0** | **102** | 19 | 0 | **19** | **447** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | | | | negligible | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 7 Environmental Impact of IE3 - 1.1 kW 3-Phase Ind. Motor (4000h)

| Life cycle Impact per product: | Date | Author |
|---|---|---|
| IE3 - 1.1 kW 3-Phase Ind. Motor | 0 | vhk |

| | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **385** | | | 347 | 39 | **385** | **0** |
| 3 | Ferro | g | | | **14470** | | | 724 | 13747 | **14470** | **0** |
| 4 | Non-ferro | g | | | **4703** | | | 235 | 4468 | **4703** | **0** |
| 5 | Coating | g | | | **110** | | | 6 | 105 | **110** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **19668** | | | 1311 | 18357 | **19668** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 1043 | 249 | **1292** | **79** | **55453** | 95 | 28 | **67** | **56890** |
| 9 | of which, electricity (in primary MJ) | MJ | 60 | 143 | **203** | **0** | **55442** | 0 | 0 | **0** | **55645** |
| 10 | Water (process) | ltr | 160 | 2 | **162** | **0** | **3698** | 0 | 0 | **0** | **3860** |
| 11 | Water (cooling) | ltr | 252 | 61 | **313** | **0** | **147843** | 0 | 1 | **-1** | **148156** |
| 12 | Waste, non-haz./ landfill | g | 69313 | 1199 | **70512** | **64** | **64985** | 1273 | 1 | **1273** | **136834** |
| 13 | Waste, hazardous/ incinerated | g | 12 | 0 | **12** | **1** | **1278** | 347 | 0 | **346** | **1637** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 73 | 14 | **87** | **6** | **2420** | 7 | 2 | **5** | **2518** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 969 | 62 | **1031** | **17** | **14286** | 14 | 3 | **11** | **15345** |
| 17 | Volatile Organic Compounds (VOC) | g | 2 | 0 | **2** | **0** | **21** | 0 | 0 | **0** | **24** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 376 | 32 | **407** | **0** | **367** | 9 | 0 | **9** | **784** |
| 19 | Heavy Metals | mg Ni eq. | 444 | 74 | **518** | **3** | **956** | 27 | 0 | **27** | **1505** |
| | PAHs | mg Ni eq. | 55 | 0 | **55** | **4** | **110** | 0 | 0 | **0** | **168** |
| 20 | Particulate Matter (PM, dust) | g | 105 | 9 | **114** | **69** | **306** | 123 | 0 | **123** | **612** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 237 | 0 | **237** | **0** | **360** | 8 | 0 | **8** | **605** |
| 22 | Eutrophication | g PO4 | 10 | 0 | **10** | **0** | **2** | 0 | 0 | **0** | **13** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 8 Environmental Impact of IE3 - 11 kW 3-Phase Ind. Motor (4000h)

| Nr | Life cycle Impact per product: | Date | Author |
|---|---|---|---|
| 0 | IE3 - 11 kW 3-Phase Ind. Motor | 0 | ISR |

| Nr | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **1320** | | | 1188 | 132 | **1320** | **0** |
| 3 | Ferro | g | | | **93141** | | | 4657 | 88484 | **93141** | **0** |
| 4 | Non-ferro | g | | | **41297** | | | 2065 | 39232 | **41297** | **0** |
| 5 | Coating | g | | | **550** | | | 28 | 523 | **550** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **136308** | | | 7937 | 128371 | **136308** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 8377 | 1594 | **9971** | **255** | **378701** | 580 | 124 | **456** | **389383** |
| 9 | of which, electricity (in primary MJ) | MJ | 346 | 914 | **1260** | **0** | **378013** | 0 | 1 | **-1** | **379273** |
| 10 | Water (process) | ltr | 975 | 12 | **987** | **0** | **25210** | 0 | 0 | **0** | **26197** |
| 11 | Water (cooling) | ltr | 1017 | 385 | **1402** | **0** | **1008014** | 0 | 3 | **-3** | **1009413** |
| 12 | Waste, non-haz./ landfill | g | 725043 | 7805 | **732848** | **149** | **445598** | 8963 | 2 | **8961** | **1187556** |
| 13 | Waste, hazardous/ incinerated | g | 61 | 1 | **63** | **3** | **8711** | 1188 | 0 | **1188** | **9964** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 555 | 91 | **646** | **17** | **16549** | 43 | 9 | **34** | **17245** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 10334 | 395 | **10730** | **49** | **97489** | 85 | 11 | **74** | **108342** |
| 17 | Volatile Organic Compounds (VOC) | g | 14 | 2 | **16** | **3** | **152** | 2 | 0 | **2** | **174** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 2448 | 212 | **2660** | **1** | **2504** | 62 | 0 | **62** | **5227** |
| 19 | Heavy Metals | mg Ni eq. | 3642 | 497 | **4139** | **8** | **6656** | 168 | 0 | **168** | **10971** |
| | PAHs | mg Ni eq. | 382 | 0 | **382** | **9** | **878** | 0 | 0 | **0** | **1270** |
| 20 | Particulate Matter (PM, dust) | g | 643 | 60 | **704** | **513** | **4291** | 755 | 0 | **755** | **6263** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 1577 | 0 | **1577** | **0** | **2453** | 48 | 0 | **48** | **4079** |
| 22 | Eutrophication | g PO4 | 55 | 1 | **56** | **0** | **12** | 3 | 0 | **3** | **71** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 9 Environmental Impact of IE3  - 110 kW 3-Phase Ind. Motor (4000h)

| Nr | Life cycle Impact per product: | Date | Author |
|---|---|---|---|
| 0 | *** Star/Premium - 110 kW 3-Phase Ind. Motor | 0 | ISR |

| Nr | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **6600** | | | 5940 | 660 | **6600** | **0** |
| 3 | Ferro | g | | | **946613** | | | 47331 | 899283 | **946613** | **0** |
| 4 | Non-ferro | g | | | **210644** | | | 10532 | 200112 | **210644** | **0** |
| 5 | Coating | g | | | **1100** | | | 55 | 1045 | **1100** | **0** |
| 6 | Electronics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **1164957** | | | 63858 | 1101099 | **1164957** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 55724 | 12348 | **68072** | **1544** | **2672482** | 4572 | 656 | **3916** | **2746014** |
| 9 | of which, electricity (in primary MJ) | MJ | 2373 | 7079 | **9453** | **3** | **2671295** | 0 | 3 | **-3** | **2680748** |
| 10 | Water (process) | ltr | 7235 | 95 | **7330** | **0** | **178153** | 0 | 2 | **-2** | **185481** |
| 11 | Water (cooling) | ltr | 5624 | 2982 | **8606** | **0** | **7123286** | 0 | 14 | **-14** | **7131878** |
| 12 | Waste, non-haz./ landfill | g | 4800611 | 60680 | **4861291** | **771** | **3145718** | 74782 | 10 | **74772** | **8082552** |
| 13 | Waste, hazardous/ incinerated | g | 303 | 9 | **312** | **15** | **61555** | 5940 | 2 | **5939** | **67822** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 3895 | 706 | **4601** | **93** | **116662** | 341 | 47 | **294** | **121650** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 66320 | 3065 | **69386** | **284** | **688574** | 671 | 60 | **611** | **758854** |
| 17 | Volatile Organic Compounds (VOC) | g | 131 | 14 | **145** | **23** | **1017** | 18 | 1 | **17** | **1202** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 18100 | 1660 | **19760** | **4** | **17706** | 515 | 0 | **515** | **37985** |
| 19 | Heavy Metals | mg  Ni eq. | 25541 | 3888 | **29429** | **39** | **46252** | 1328 | 0 | **1328** | **77048** |
| | PAHs | mg  Ni eq. | 1542 | 1 | **1544** | **51** | **5408** | 0 | 0 | **0** | **7002** |
| 20 | Particulate Matter (PM, dust) | g | 7532 | 467 | **7999** | **3761** | **16977** | 5949 | 1 | **5948** | **34685** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 11236 | 2 | **11238** | **1** | **17335** | 380 | 0 | **380** | **28954** |
| 22 | Eutrophication | g PO4 | 348 | 4 | **352** | **0** | **86** | 22 | 0 | **22** | **459** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

## Table A - 10 Environmental Impact of 1,1 kW EC Motor (4000h)

| Nr | Life cycle Impact per product: | Date | Author |
|---|---|---|---|
| | 1,1 kW EC Motor | 0 | ISR |

| Nr | Life Cycle phases --> | | PRODUCTION | | | DISTRI- | USE | END-OF-LIFE* | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Resources Use and Emissions** | | Material | Manuf. | **Total** | **BUTION** | | Disposal | Recycl. | **Total** | |
| | **Materials** | **unit** | | | | | | | | | |
| 1 | Bulk Plastics | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 2 | TecPlastics | g | | | **293** | | | 264 | 29 | **293** | **0** |
| 3 | Ferro | g | | | **3123** | | | 156 | 2967 | **3123** | **0** |
| 4 | Non-ferro | g | | | **3170** | | | 159 | 3012 | **3170** | **0** |
| 5 | Coating | g | | | **0** | | | 0 | 0 | **0** | **0** |
| 6 | Electronics | g | | | **214** | | | 107 | 107 | **214** | **0** |
| 7 | Misc. | g | | | **0** | | | 0 | 0 | **0** | **0** |
| | **Total weight** | g | | | **6800** | | | 685 | 6115 | **6800** | **0** |
| | | | | | | | | | see note! | | |
| | **Other Resources & Waste** | | | | | | | debet | credit | | |
| 8 | Total Energy (GER) | MJ | 772 | 111 | **883** | **92** | **42345** | 48 | 29 | **19** | **43339** |
| 9 | of which, electricity (in primary MJ) | MJ | 357 | 49 | **406** | **0** | **42340** | 0 | 13 | **-13** | **42734** |
| 10 | Water (process) | ltr | 170 | 3 | **173** | **0** | **2824** | 0 | 11 | **-11** | **2986** |
| 11 | Water (cooling) | ltr | 72 | 29 | **101** | **0** | **112897** | 0 | 3 | **-3** | **112995** |
| 12 | Waste, non-haz./ landfill | g | 25232 | 397 | **25629** | **71** | **49342** | 417 | 36 | **381** | **75423** |
| 13 | Waste, hazardous/ incinerated | g | 194 | 1 | **195** | **1** | **977** | 371 | 14 | **357** | **1531** |
| | **Emissions (Air)** | | | | | | | | | | |
| 14 | Greenhouse Gases in GWP100 | kg CO2 eq. | 47 | 7 | **54** | **7** | **1848** | 4 | 2 | **2** | **1911** |
| 15 | Ozone Depletion, emissions | mg R-11 eq. | negligible | | | | | | | | |
| 16 | Acidification, emissions | g SO2 eq. | 532 | 31 | **563** | **19** | **10907** | 7 | 10 | **-3** | **11486** |
| 17 | Volatile Organic Compounds (VOC) | g | 2 | 1 | **3** | **1** | **16** | 0 | 0 | **0** | **19** |
| 18 | Persistent Organic Pollutants (POP) | ng i-Teq | 179 | 8 | **187** | **0** | **279** | 3 | 0 | **3** | **470** |
| 19 | Heavy Metals | mg Ni eq. | 146 | 20 | **166** | **4** | **728** | 14 | 2 | **12** | **910** |
| | PAHs | mg Ni eq. | 47 | 1 | **48** | **4** | **84** | 0 | 1 | **-1** | **134** |
| 20 | Particulate Matter (PM, dust) | g | 30 | 6 | **36** | **103** | **233** | 63 | 1 | **62** | **434** |
| | **Emissions (Water)** | | | | | | | | | | |
| 21 | Heavy Metals | mg Hg/20 | 50 | 0 | **50** | **0** | **273** | 4 | 7 | **-3** | **321** |
| 22 | Eutrophication | g PO4 | 2 | 0 | **2** | **0** | **1** | 0 | 0 | **0** | **3** |
| 23 | Persistent Organic Pollutants (POP) | ng i-Teq | negligible | | | | | | | | |

***=Note: Recycling credits only relate to recycling of plastics and electronics (excl. LCD/CRT). Recycling credits for metals and other fractions are already taken into account in the production phase.**

# Appendix III

## Variable Speed Drives

A variable speed drive is an electronic system designed to control the speed of the motor's shaft by varying the frequency and voltage applied to the stator windings in order to meet the application speed and /or torque requirements. The typical configuration of a VSD is shown in

Figure A - 1.

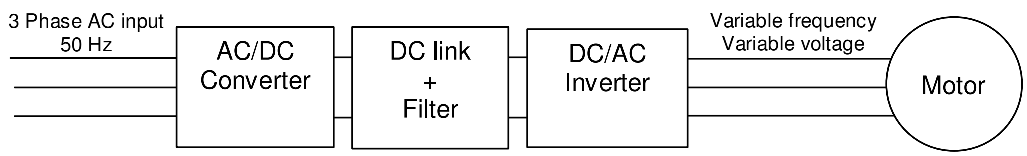



**Figure A - 1 Typical configuration of VSD**

The adjustment of the motor speed through the use of VSDs can lead to better process control, less wear in the mechanical equipment, less acoustical noise, and significant energy savings.

As previously mentioned, the speed of the rotating field created by the induction motor stator windings is directly linked with the frequency of the voltage waveforms applied to the windings. Electronic Variable Speed Drives can produce variable frequency, variable voltage waveforms. If these waveforms are applied to the stator windings there will be a shift of torque-speed curve, maintaining a constant pull-out torque, and the same slope of the linear operation region of the curve. In this way, the motor speed is going to be proportional to the applied frequency generated by the VSD (Figure A - 2).

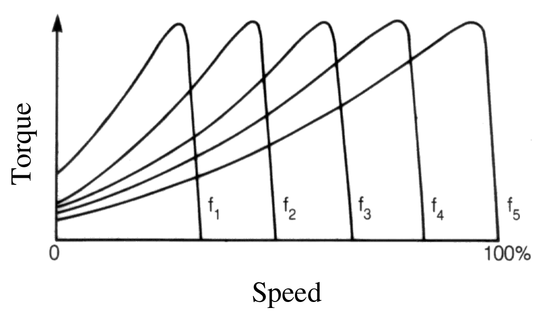



**Figure A - 2 Speed-Torque Curves for an Induction Motor ($f_1<f_2<f_3<f_4<f_5$ and $f_5$=50Hz)**

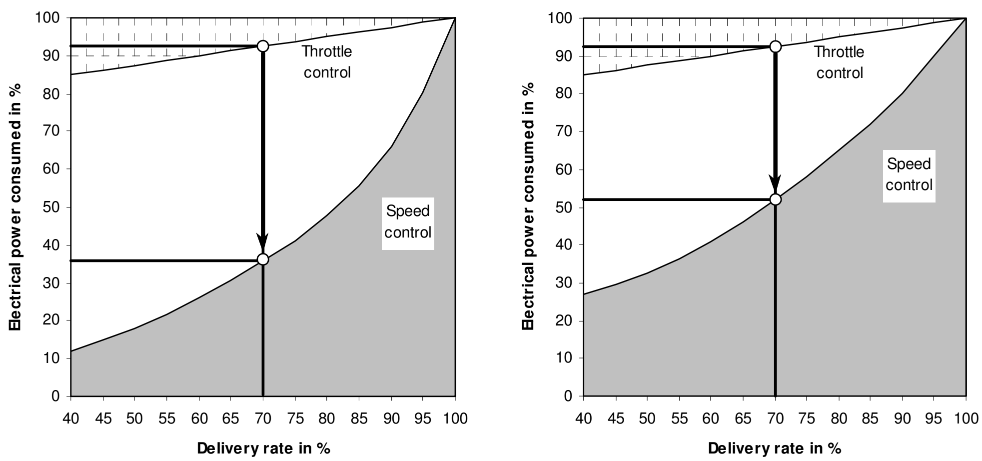
### *Applications*

VSDs can be applied to a wide variety of loads. Although the use of a VSD reduces the overall efficiency at full-load, because of the internal losses of the VSD (about 3-5% depending on size and load) it has a large potential for savings in loads with variable speed requirements. Examples of loads in which significant energy savings can be achieved are described next.

## Single Pumps

The centrifugal pumps without lift (e.g., closed-loop circuit) respect the cube power law, i.e., the consumed power is proportional to the cube of the speed, as shown in Figure A - 3 (a). If the user wants to reduce the flow in the process, a control valve can be used, or alternatively speed control can be applied using a VSD. Although both techniques fulfil the desired objective, the consumed energy is significantly higher when valve throttle control is used.

If there is a system head associated with providing a lift to the fluid in the pumping system, the pumps must overcome the corresponding static pressure, as shown in Figure A - 3 (b).




**(a) (b)**

**Figure A - 3 Electrical power input of a pump with throttle control vs. one with speed control: (a) without static pressure head (e.g. recirculation systems); (b) with static pressure head.**

In this last pumping system the mechanical energy is used to overcome the friction in the pipes, plus the mechanical work associated with lifting the fluid against the gravity as shown in Figure A - 4. If the percentage of the power associated with overcoming the pipe friction is relevant, energy savings can still be achieved although typically less than in systems without static pressure head.

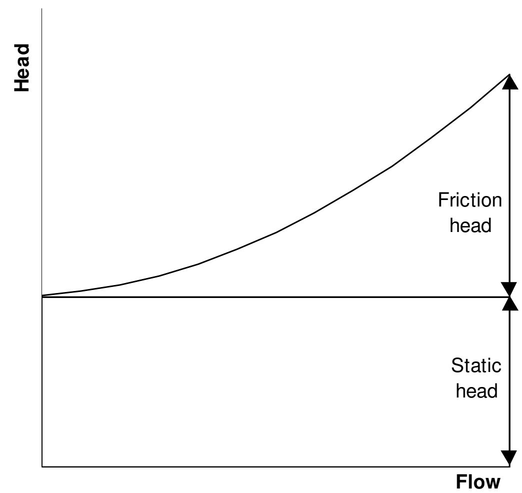



**Figure A - 4  Total system resistance from frictional losses plus static head losses.**

### Fans

Savings from adding variable speed control to fans can be significant even with fairly heavily loaded motors. Figure A - 5 illustrates the savings potential with a VSD versus common throttling methods.

High amounts of energy are wasted by throttling the air flow versus using adjustable speed. The worst method is outlet dampers, followed by inlet vane control. The energy consumption in these loads is so sensitive to the speed that the user can achieve large savings with even modest speed adjustments.

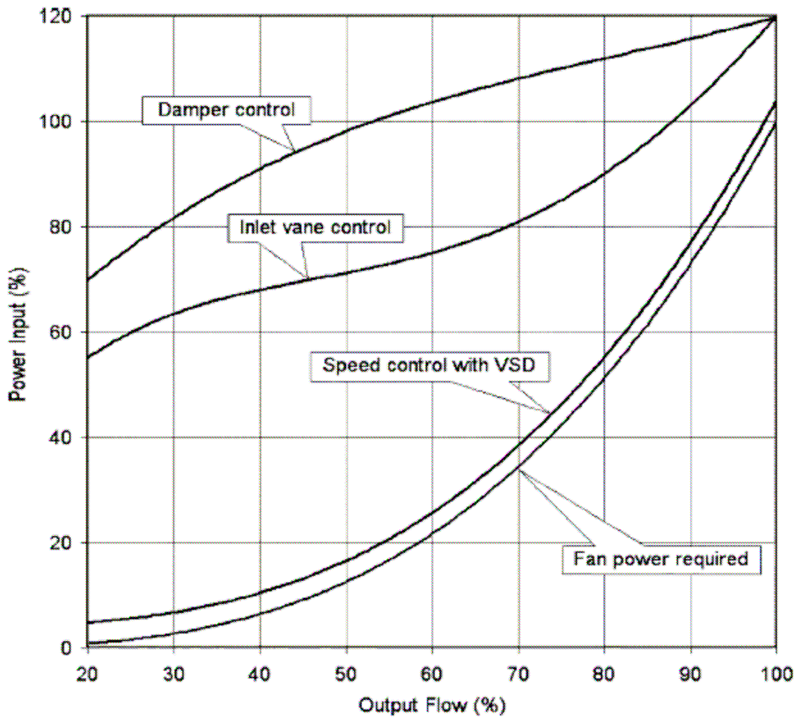



**Figure A - 5 Relative power consumption of different air flow control methods.**

**Refrigeration and Chillers**

Another example of VSD application in compressors is for refrigeration purposes (Figure A - 6). The use of VSD for temperature control (floating head operation) in the refrigeration pumps/compressors (e.g. Walk-in Freezer) can eliminate the on/off cycling, with large energy savings. The temperature control can also be improved, in terms of differential between internal and external temperatures.

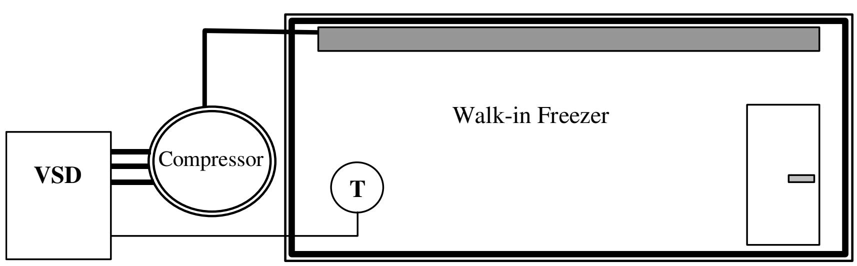



**Figure A - 6 Variable speed refrigeration compressor.**

In air conditioning systems substantial savings can also be achieved due to the variable load requirements. For example, in a rooftop chiller system (Figure A - 7), VSDs can be applied to modulate the pump speed, based on zone temperature control, and/or to control the fan speed, based on the coolant return temperature. The result, compared with an on/off cycling control, is a more stable temperature in the controlled space and more efficient operation, by typically decreasing the fan energy in the range 25%–50%.

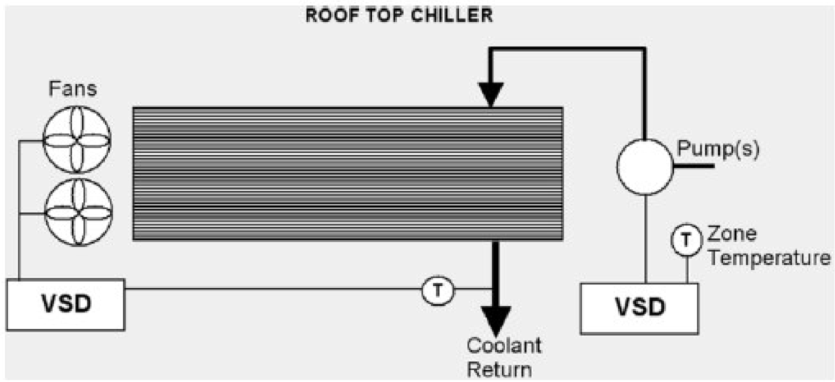



**Figure A - 7 Application of a VSD to a roof-top chiller**

## Compressors

Rotary screw and piston air compressors are essentially constant torque loads and can also benefit from the application of variable speed control. The savings related to the use of variable speed control are dependent on the control system that is being replaced. In Figure A - 8 the energy savings achieved by fitting a VSD to a rotary screw compressed air unit, compared to other methods of flow control at partial load, can be seen. In a compressor, with modulating control, if the demand is 50% of rated capacity, the energy savings associated with the VSD integration is about 38%.

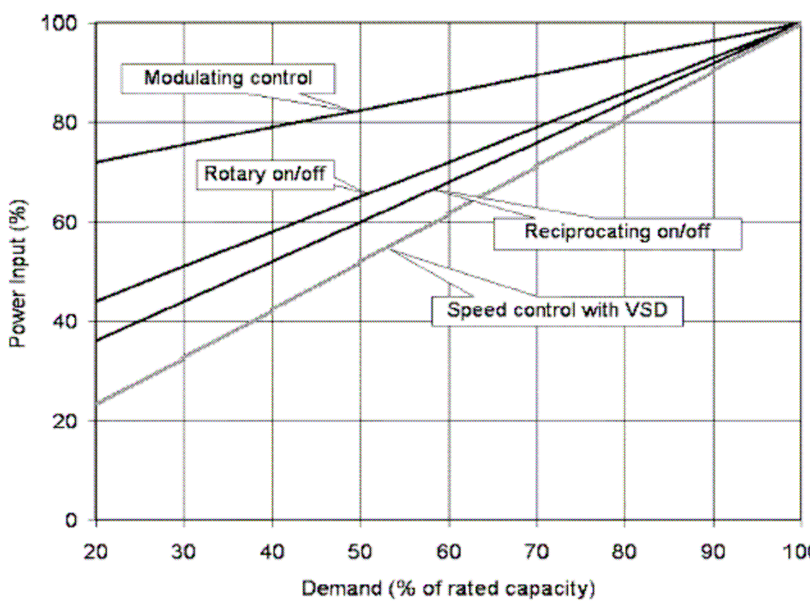



**Figure A - 8 Energy saved by using a VSD on a rotary screw air compressor**

Energy savings with constant torque loads is typically considerably less than with centrifugal pumps or fans which obey the power cube law, and so to retrofit a VSD to a compressor it is less likely to be economic on the grounds of energy savings alone. However, the introduction of screw compressors with integral speed control has enabled the additional price of variable speed control to be significantly reduced. These machines therefore deserve to be considered for all new applications with long running hours, when there is a widely varying demand.

### Conveyors

In the constant torque devices (ex.: horizontal conveyors), the torque is approximately independent of the transported load (is only friction dependent). Typically, the materials handling output of a conveyor is controlled through the regulation of input quantity, and the torque and speed are roughly constant. But, if the materials input to the conveyor can be changed, it is possible to reduce the speed (the torque is the same), and, as it can be seen in Figure A - 10, significant energy savings will reached, proportional to the speed reduction.

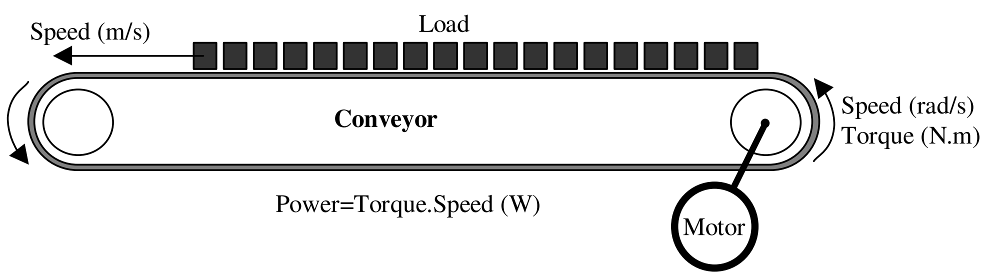



**Figure A - 9 Power required by a conveyor.**

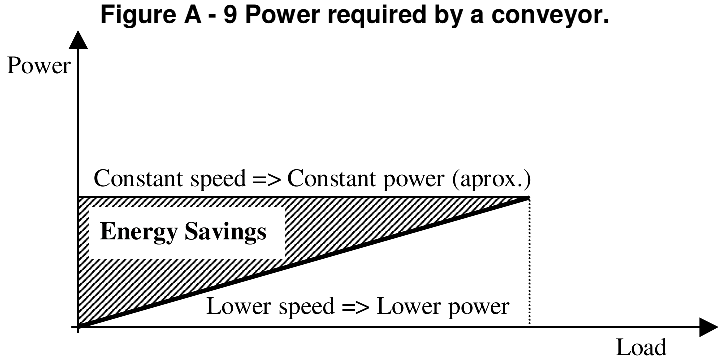



**Figure A - 10 Energy savings in a conveyor using speed control, in relation to the typical constant speed.**