Energy Using Product (EuP) Directive
Preparatory Study

Results of EuP Lot 11: Motors

MEPSA 09, Australia

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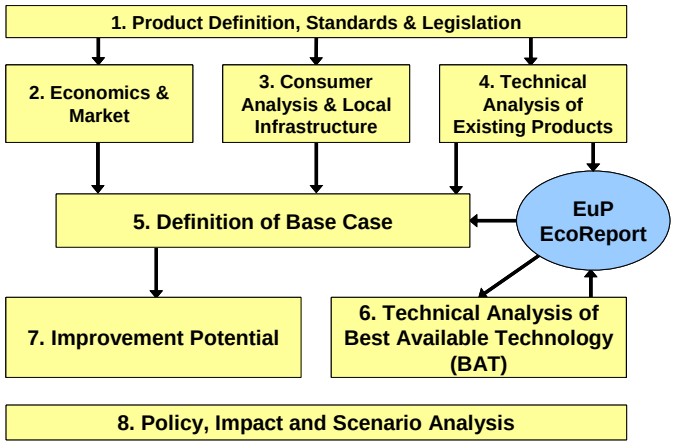
METHODOLOGY OUTLINE



Performance Parameters

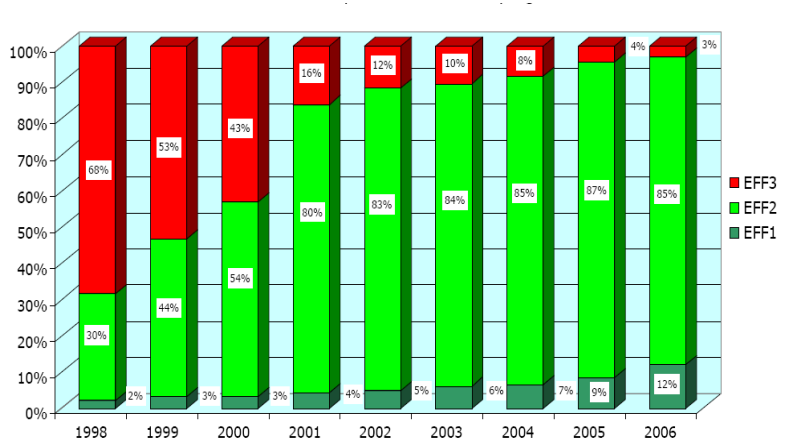
The proposed primary functional parameters are:

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

The proposed secondary functional parameters are:

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

Efficient Motors Market trends – EU



Technical analysis of existing products

- BaseCase models as being IE1 efficiency class.
- Best available technology (BAT) was defined as IE3 efficiency class. IE2 motors are also analysed.

CEMEP agreed to collect data from manufactures and produced Bill-of-Materials (BoMs) for the following different motors:

- IE1 and IE2 in the power range of 1.1 kW, 11 kW and 110 kW to cover the considered power range

Definition of BaseCase

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;
- 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.

End-of-life behaviour

Scenario for recycling at end-of-life for:

- Landfill (fraction of products not recovered) – **default 5%**
- Plastics
  - Re-used/Closed loop recycling – default 1%
  - Material Recycling – default 9%
  - Thermal Recycling (non hazardous incineration optimised for energy recovery) – default 90%
- Metals recycling percentage – 95% **(default value)**

Production Phase

BoMs for IE1 motors

1,1 kW Motor IE1/EFF2	Average kg (per kW)	11 kW Motor IE1/EFF2	Average kg (per kW)	110 kW Motor IE1/EFF2	Average kg (per kW)
Electrical steel	5,40	Electrical steel	3,60	Electrical steel	3,10
Other steel	1,50	Other steel	0,95	Other steel	0,67
Cast iron **	0,0 - 5,0	Cast iron **	0,0 - 2,0	Cast iron	3,00
Aluminium **	0,5 - 2,5	Aluminium **	0,2 - 1,5	Aluminium	0,18
Copper	1,24	Copper	0,64	Copper	0,54
Insulation material	0,05	Insulation material	0,02	Insulation material	0,01
Packing material	1,00	Packing material	0,90	Packing material	0,50
Impregnation resin	0,30	Impregnation resin	0,10	Impregnation resin	0,05
Paint	0,10	Paint	0,05	Paint	0,01

Production Phase

Bill of Materials (consideration of spare parts of usage phase)

The VhK EcoReport assumes 1% of the total weight as spare parts. This is thought highly inadequate.

Replacement windings and bearings were considered in the BoM as 2.5 times the weight of the original corresponding parts.

Real-Life BaseCase inputs

Variable	Motor Rated Power		
	1,1 kW	11 kW	110 kW
Lifetime (years)	12	15	20
Load Factor (%)	60	60	60
Efficiency (%)	75,1	87,6	93,3
Operating hours per year (4 scenarios)	2000/4000/6000/8000	2000/4000/6000/8000	2000/4000/6000/8000
Distance covered over motor life (km)	250	250	250
Average volume (m^3)	0,02	0,15	1,1
Price (with discount)	96 €	450 €	4500 €

Average electricity price in Industry for EU-25 – **0,0754 €**
(SMEs-2000 MWh/year)
(excluding VAT)

Best Available Technologies

State-of-the-art at product level:

- High Efficiency Induction Motors
- Brushless DC Motors

State of the art at component level (prototype, test and field trial level).

- Copper rotors

BAT Inputs

Variable	Motor Rated Power		
	1,1 kW	11 kW	110 kW
Lifetime (years)	12	15	20
Load Factor (%)	60	60	60
Operating hours per year (4 scenarios)	2000/4000/6000/8000	2000/4000/6000/8000	2000/4000/6000/8000
Distance covered over motor life (km)	250	250	250
Average volume (m^3)	0,02	0,15	1,1

Replacement windings and bearings were considered in the BoM as 2 times the weight of the original corresponding parts.

Motor prices/discounts

Motor prices early this decade showed a tendency a tend to decrease, but recent increase in the price of raw materials may reverse that trend.

IE2 prices are typically 20-30% above IE1 motors price.

IE3 prices are typically 40-60% above IE1 motors price.

A 40% discount over list price is assumed.

BAT – Environmental Impact and LCC Analysis

For the environmental impact and LCC assessment of BAT, the motor efficiencies are drawn from the proposed IEC 60034-30 standard.

	Motor Rated Power		
	1,1 kW	**11 kW**	**110 kW**
IE2 Efficiency(%)	81,4	89,8	94,5
IE3 Efficiency(%)	84,1	91,4	95,5

BoM – IE2/EFF1 Induction motor

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

BoM – IE3/Premium Induction motor

The material fractions for IE3/Premium motors were estimated based on the provided BoMs of IE2 and IE1 motors.

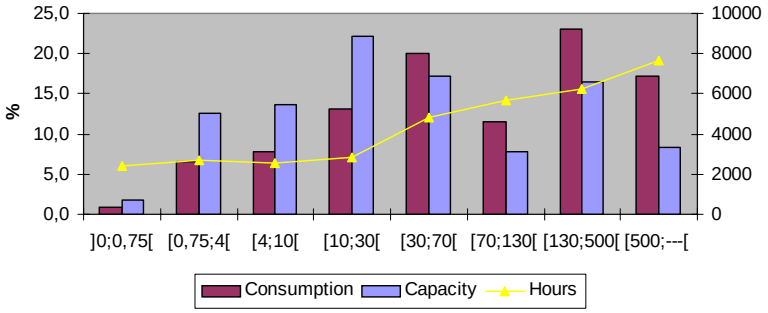
Materials	Motor Rated Power		
	1,1 kW	11 kW	110 kW
Electrical steel (kg/kW)	9,02	6,11	4,0
Other steel (kg/kW)	1,64	1,05	0,77
Cast iron (kg/kW)	2,50	1,30	3,00
Aluminium (kg/kW)	2,12	1,11	0,25
Copper (kg/kW)	2.26	1,08	0.7
Insulation material (kg/kW)	0,05	0,02	0,01
Packing material (kg/kW)	1,00	0,90	0,50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

Improvement Potential in Relation to BaseCase

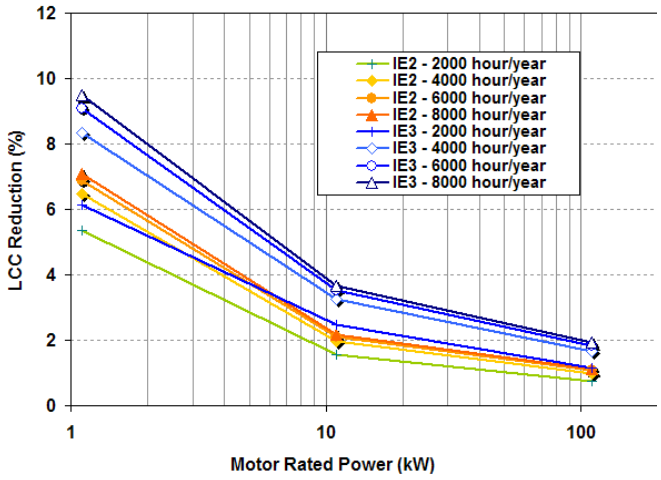
	Motor Rated Power					
	1,1 kW		11 kW		110kW	
Main Indicators	**IE2**	**IE3**	**IE2**	**IE3**	**IE2**	**IE3**
Total Energy	-30,49%	-42,60%	-19,17%	-32,45%	-18,53%	-31,88%
Of which, electricity	-30,97%	-43,27%	-19,64%	-33,40%	-18,77%	-32,65%
Water (process)	-30,31%	-42,34%	-19,15%	-32,53%	-18,27%	-31,65%
Waste, non-hazardous/landfill	-11,15%	-15,66%	2,06%	9,12%	-11,08%	-1,81%
Waste, hazardous/incinerated	-27,19%	-37,98%	-18,02%	-30,62%	-17,62%	-30,64%
Emissions to the Air						
Greenhouse Gases in GWP100	-30,19%	-42,18%	-18,92%	-31,95%	-18,34%	-31,39%
Acidification Agents, AP	-29,38%	-41,05%	-17,52%	-29,24%	-17,88%	-29,48%
Volatile Organic Compounds, VOC	-28,01%	-39,14%	-17,17%	-27,71%	-16,53%	-27,34%
Persistent Organic Pollutants, POP	-12,42%	-17,41%	-5,31%	-5,83%	-6,76%	-4,53%
Heavy Metals, HM	-21,40%	-29,93%	-10,58%	-15,87%	-13,03%	-16,87%
Polycyclic Aromatic Hydrocarbons, PAH	-21,85%	-30,55%	-12,63%	-17,25%	-27,89%	-34,60%
Particulate Matter, PM, dust	-17,98%	-25,14%	-12,87%	-10,34%	-10,89%	-13,31%
Emissions to the Water						
Heavy Metals, HM	-20,98%	-29,33%	-11,39%	-18,42%	-13,67%	-19,08%
Eutrophication, EP	-3,04%	-4,28%	0,09%	2,20%	-2,75%	2,91%

Use phase

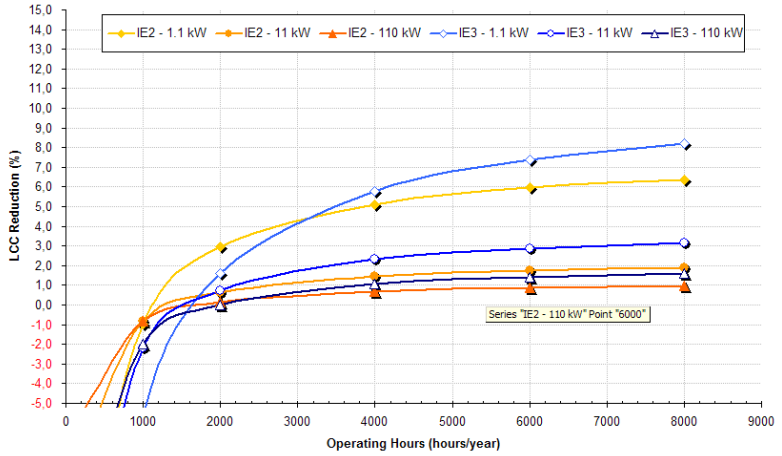
Installed motor capacity, electricity consumption and average operating hours by power range in the industrial sector



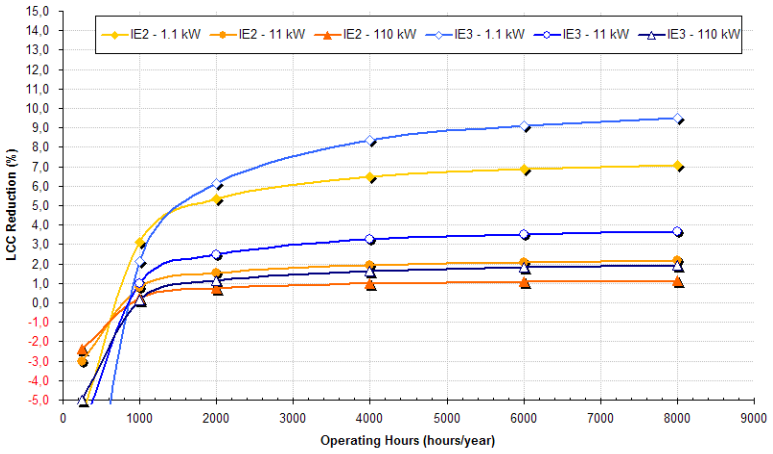
LCC reduction (in relation to basecase)



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



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



Product Definition for the introduction of MEPS

Implementation measures proposed will relate to general purpose, single speed, three-phase 50 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;

Product Definition for the introduction of MEPS

Excluded are all non-general purpose motors where it is recognized that efficiency is impaired by special design constraints (IEC 60034-30). These include motors that are specifically designed for:

- converter operation
- integration into a machine (for example pump, fan and compressor) or gear that cannot be tested separately from the machine
- special ambient conditions (e.g. very high or low ambient temperature, high altitudes of installation) e.g. like smoke-extraction motors
- special requirements of the driven machine (e.g. special torque stiffness and/or breakdown torque characteristics)
- a particular type of load with restrictions to the use in other applications.

Stock Model

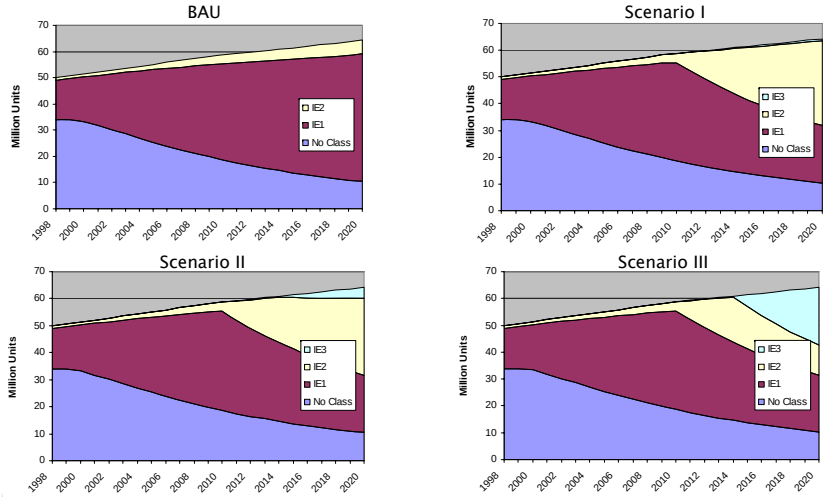
ASSUMPTIONS

- Stock in 1998 by efficiency class as sales percentage in that year
- 1998-2005 use of CEMEP data for 100% of market sales (CEMEP data refers to 80% of the data)
- Extrapolate market trends in the period 2006-2010
- Apply different penetration scenarios after 2011 for motor market transformation

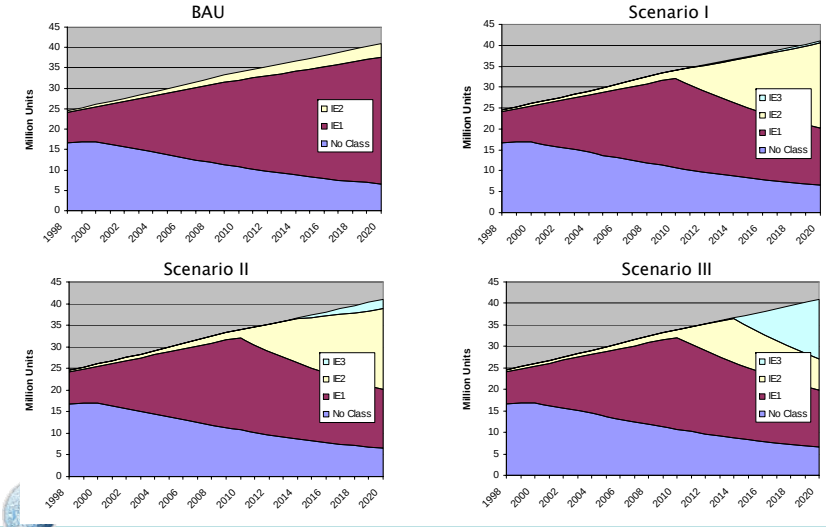
Scenarios analysed

- ***Business as Usual***
- ***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
- ***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
- *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

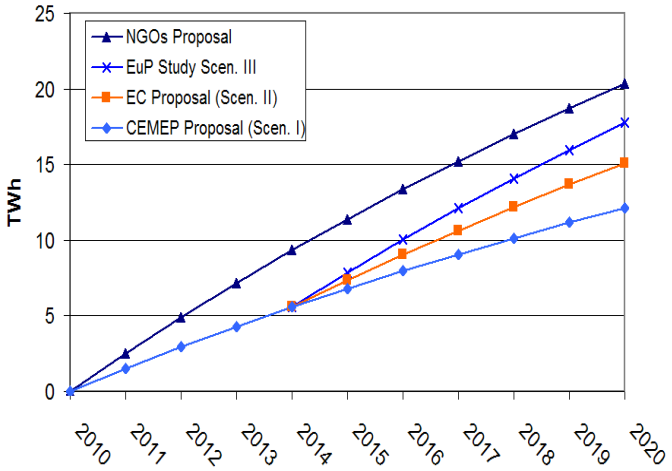
Stock Evolution in Industry



Stock Evolution in Tertiary



Energy savings for Different Scenarios



Proposed Scenarios vs. BAU electricity savings, in TWh

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Scenario I	1,51	2,93	4,29	5,57	6,80	7,96	9,08	10,1	11,2	12,1
Scenario II	1,51	2,93	4,29	5,57	7,34	9,03	10,6	12,2	13,7	15,1
Scenario III	1,51	2,93	4,29	5,57	7,86	10,04	12,11	14,09	15,98	17,78

Note: Stock rotation is not complete

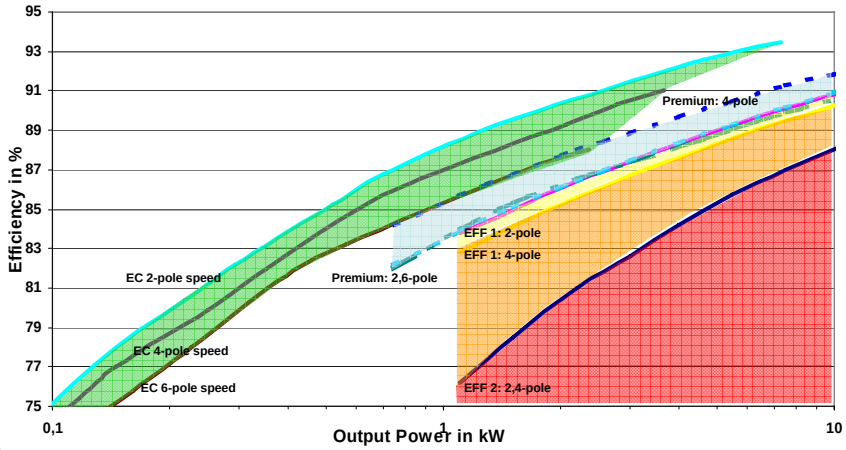
Extension of the power range above 200 kW and up to 375 kW

The extension of the scope of possible MEPS above 200 kW and up to 375 kW, would translate into additional electricity savings of 190 GWh for scenario I and 306 GWh for scenario II or III, in 2020

BLDC Motors

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].

BLDC Efficiency

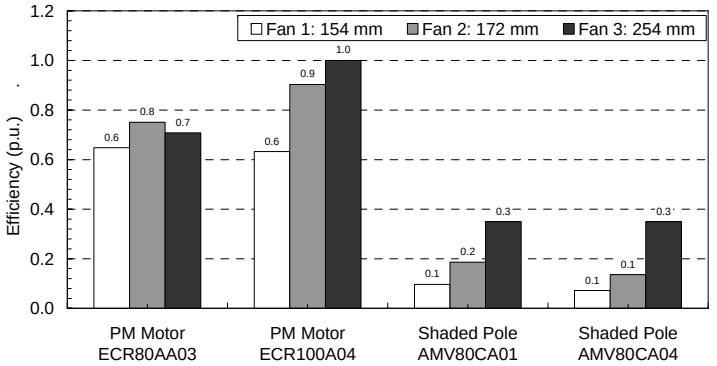


Source: EBM-Papst

COMPARISON BETWEEN SMALL EC PM MOTORS AND SHADED-POLE IM

Reference	**ECR80AA03**	**ECR100A04**	**AMV80CA01**	**AMV80CA04**
Type	PM-EC	PM-EC	Shaded-Pole	Shaded-Pole
Rated Power (W)	20 W	9 W	5 W	16 W
Rated Voltage (V)	231 V	231 V	220-240 V	220-240 V
Rated Current (A)	0.29 A	0.10 A	0.21 A	0.5 A
Speed (r/min)	1500	1250	1300-1500	1300-1500
Picture				

COMPARISON BETWEEN SMALL EC PM MOTORS AND SHADED-POLE IM



Approximate efficiency, obtained by dividing the input power by the estimated flow, in p.u., with the most efficient unit as the reference value.

EC/Brushless Permanent Magnet Motors

EC motors are only widely available in small powers (up to 5 kW) so only the 1,1 kW motor were analysed.

Bill-of-Materials

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

* No Rare-Earth Magnets in model

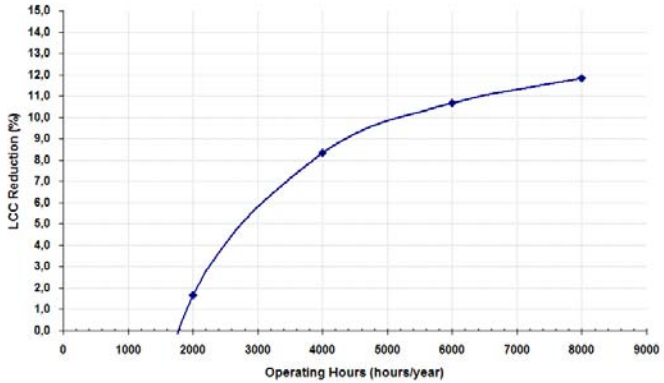
Use-Phase Inputs

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

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%
Policyclic 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%

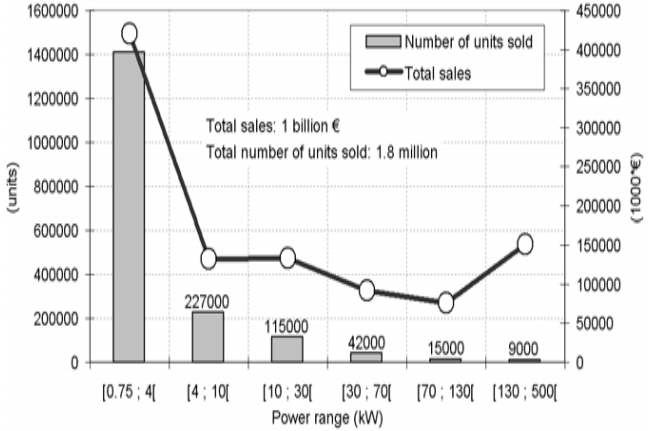
LCC reduction as a function of the number of operating hours,1,1 kW EC motor vs. BaseCase



Motor + Electronics price is considered to be the triple of the motor alone.

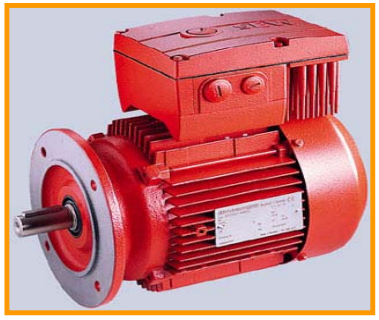
Variable Speed Drives – VSDs

Number of units sold in the EU and sales (2002) value per power range. (In 2005, in Germany 1 in every 3 new motors was fitted with a VSD)



Variable Speed Drives

Separated
1 Billion €



Integrated
Up to 22 kW
250 k€ ??

VSD Environmental and LCC analysis

VSDs can only produce savings in variable load applications

Previous studies show that the variable flow fluid motion applications (pumps, fans and compressors) have the largest savings potential.

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
- another using a Variable Speed Drive with an IE1 motor.

VSD Bill of Materials

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	0,3	0,05	0,03
PWB	0,2	0,03	0,01
Electronics small (SMD, IC,...)	0,2	0,07	0,04
Electronics big (IGBT, Thrysistors,...)	0,05	0,02	0,03

* Separated VSD and motor units

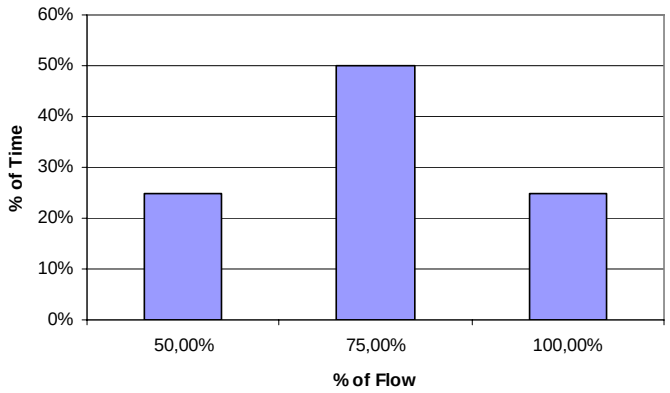
Integrated VSD Drive Use-phase Inputs

-Typical Load Profile of a Pumping System

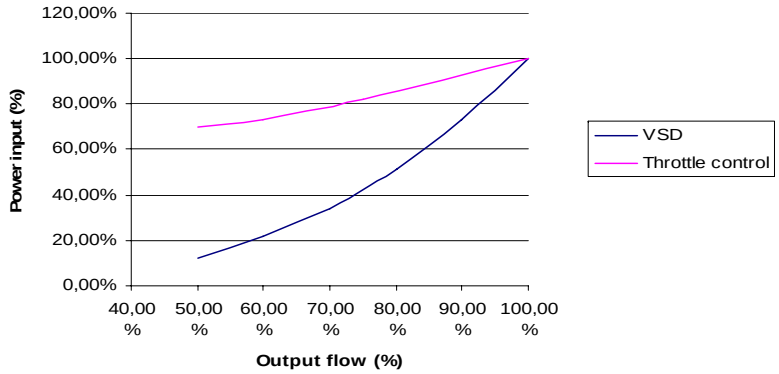
-Motors are considered to have the same efficiency as the BaseCase motors (IE1).

-An average efficiency of 95% is considered for the VSD over the operating speed range (50-100%).

Typical Load Profile for Pumping System
(Source: Pump EuP Study)



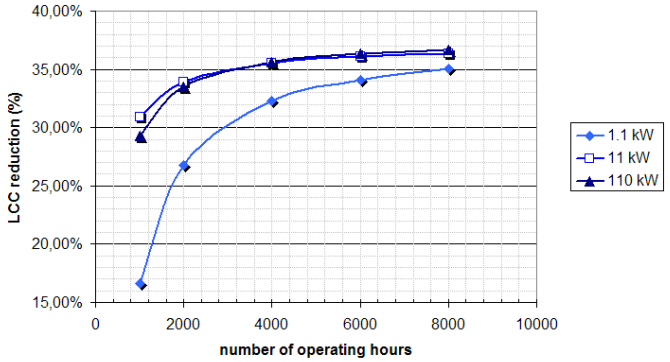
Part-load power as a function of percent flow for a typical pumping system with throttle vs. a pumping system using a motor + VSD



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%
Policyclic 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%

LCC reduction as a function of the number of operating hours



VSD + motor price is considered to be the triple of the motor alone.

Possible Regulation MEPS Steps

-2012 IE2 standards

-2015 IE3 OR IE2 + VSD

MEPS for VSDs?

Challenges
-No Motor + VSD Test Procedure
-Efficiency related to many factors (hardware+software)
-Impact on the supply