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Energy efficiency in electric motor systems: Technology, saving potentials and policy options for developing countries

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Energy efficiency in electric motor systems: Technology, saving potentials and policy options for developing countries

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1. Abstract

Electric motor systems account for about 60 percent of global industrial electricity consumption and close to 70 percent of industrial electricity demand. Electric motors drive both, core industrial processes, like presses or rolls, and auxiliary systems like compressed air generation, ventilation or water pumping. They are utilized throughout all industrial branches, though their main applications vary.

Studies show a high potential for energy efficiency improvement in motor systems, in developing as well as in developed countries. Specifically, system optimisation approaches which address the entire motor system demonstrate high potential. For most countries the saving potentials for energy efficiency improvements in motor systems with best available technology lie between 9 and 13 percent of the national industrial electricity demand. Many of the energy efficiency investments show payback times of a few years only. Still, market failures and barriers like the lack of capital, higher initial costs, lack of attention by plant managers and principal agent dilemmas hamper investment in energy efficient motor systems.

To overcome these barriers, policies were established in several countries. Examples include minimum energy performance standards (MEPS) which introduced a minimum efficiency level for electric motors to allow them to enter the national market. These have been implemented in many countries worldwide. Although MEPS can be a very effective means to improve the market share of energy efficient motors, they are not designed to address system optimization aspects of, for example, entire compressed air or pump systems.

Policies based on a system optimization approach combined with capacity development were, for example, implemented in many developed countries, but also in newly industrialized countries like China or Brazil. These can be auditing schemes or energy management standards. Often, both are combined with broad capacity building programmes as their success crucially depends on the skills of the energy manager or auditor.

2. Introduction

Electric motor systems account for about 60 to 70 percent of industrial electricity consumption and about 15 percent of final energy use in industry worldwide (IEA 2007). It is estimated that full implementation of efficiency improvement options could reduce worldwide electricity demand by about 7 percent (IEA 2008). Electric motors drive both, core industrial processes like presses or rolls, and auxiliary systems like compressed air generation, ventilation or water pumping. They are utilized throughout all industrial branches, yet the main applications vary. With only some exceptions, electric motors are the main source for the provision of mechanical energy in industry. Size classes vary between motors with less than one kW and large industrial motors with several MW rated power. In recent years, many studies have identified large energy efficiency potentials in electric motors and motor systems with many of the saving options showing very short payback times and high cost effectiveness.

Still, investments in improving energy efficiency of electric motor systems are often delayed or rejected in favour of alternative competing investments. Different barriers and market failures were found to be responsible for that. Among them are a lack of attention of the plant manager, principal agent dilemmas, higher initial cost for efficient motors, etc. In developing countries, in particular, access to capital and higher initial costs of energy efficient motors are a very relevant barrier. In many cases, broken motors are rewound and reused, although (poor quality) motor rewinding often reduces motor efficiency.

This opportunity of high energy efficiency potentials has also been recognized by policymakers, who have aimed at overcoming the barriers since the 1990s. Consequently, policies like minimum standards and motor labelling schemes were introduced in many countries of the world. Energy audit schemes and capacity development programmes that focus on system optimization were established as well.

However, after more than a decade of energy efficiency policy on motor systems, considerable energy efficiency potentials are still visible, e.g. investments in more efficient motors or the instalment of inverters to better control the motor. Market transformation programmes proved to successfully transform the motor market towards higher efficiency, while new emerging motors with even higher efficiency are just about to enter the market.

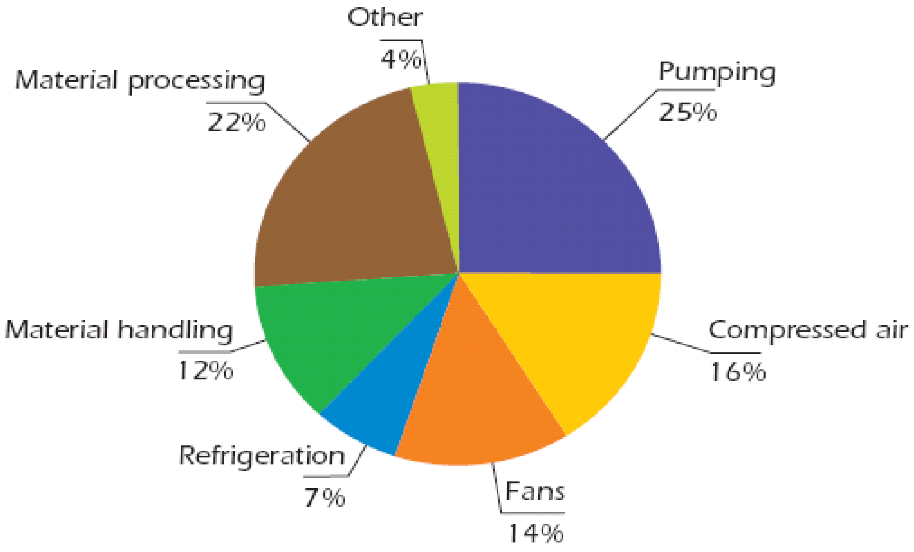
Although this report attempts to focus on developing countries, it is indispensable for some parts to use literature and data from developed countries due to data constraints. In these cases, however, the conclusions are also valid for developing countries as they mostly concern technical descriptions. In other cases, data from developed countries was added for comparison purposes, especially in the policy chapter. This report neither describes the situation in least developed countries, nor does it provide policy conclusions for these countries.

3. Motor system technology and options to improve energy efficiency

Electric motors are used in most industrial systems where mechanical energy is needed. They convert electrical energy into rotary mechanical energy which is then further converted to ultimately provide the needed use-energy.

Depending on the industrial structure, electric motor systems account for about 60 to 70 percent of industrial electricity consumption. A typical classification of motor systems is shown in Figure 1, denoting the share of each motor system in the total electricity consumption of all motor systems in the USA. Although the figures vary slightly by country, the general pattern is comparable in most countries. Pumping, compressed air and fan systems are some of the most electricity consuming motor systems. Also, material handling and processing consume a lot of electricity, although these systems are more heterogeneous and differ from each other.

Figure 1 **Electric motor electricity use by type of motor system in the USA**



Source: (IEA, 2007).

While most of the electric motors used are induction motors1 and thus relatively comparable, the systems in which they are used vary strongly in terms of complexity as well as efficiency. Pumping, compressed air and ventilation systems often enjoy special attention, as they represent a large share of industrial electricity consumption and, at the same time, relatively high saving potentials. The importance of each motor system differs between industries. For example, in the metal processing industry, most motors are used for materials processing and handling, while in the pulp and paper industry the share of motors used in pumping systems is remarkably high and the food industry shows high shares of motors for cooling appliances.

Consequently, the system perspective is essential for the exploitation of energy savings in motor systems. In this document, the system definition by Brunner et al. (2007) is used. They distinguish between three kinds of motor systems:

1. The (fully functioning) electric motor itself.
2. The core motor system, which can comprise a variable speed drive, the driven equipment like a fan, pump or compressor and the connection, like a gear or belt.
3. The total motor system, which also includes ducting or piping systems and all possible end-use equipment like compressed air tools. It may also entail uninterruptible power supply.

By moving from 1 to 3, the system boundaries are systematically expanded, which, in consequence, increases the complexity as well as the potentials for energy efficiency improvements. While the choice of high efficiency components may also improve the systems' efficiency, only a system-wide optimization with regard to control equipment and selecting components that fit together in terms of load and size can realize the full potential of energy efficiency improvements.

3.1 System efficiency improvement

Pump systems account for the highest share of industrial electricity consumption. They represent about one quarter of total electricity consumption of all motor systems in industry in the USA. In Europe, they account for about 20 percent of industrial electricity demand (ETSU et al., 2001). The use of pumps is highest in the petrochemical (51 percent), the pulp and paper (28 percent) and chemicals industry (18 percent), while the share of pumps of total electricity con-

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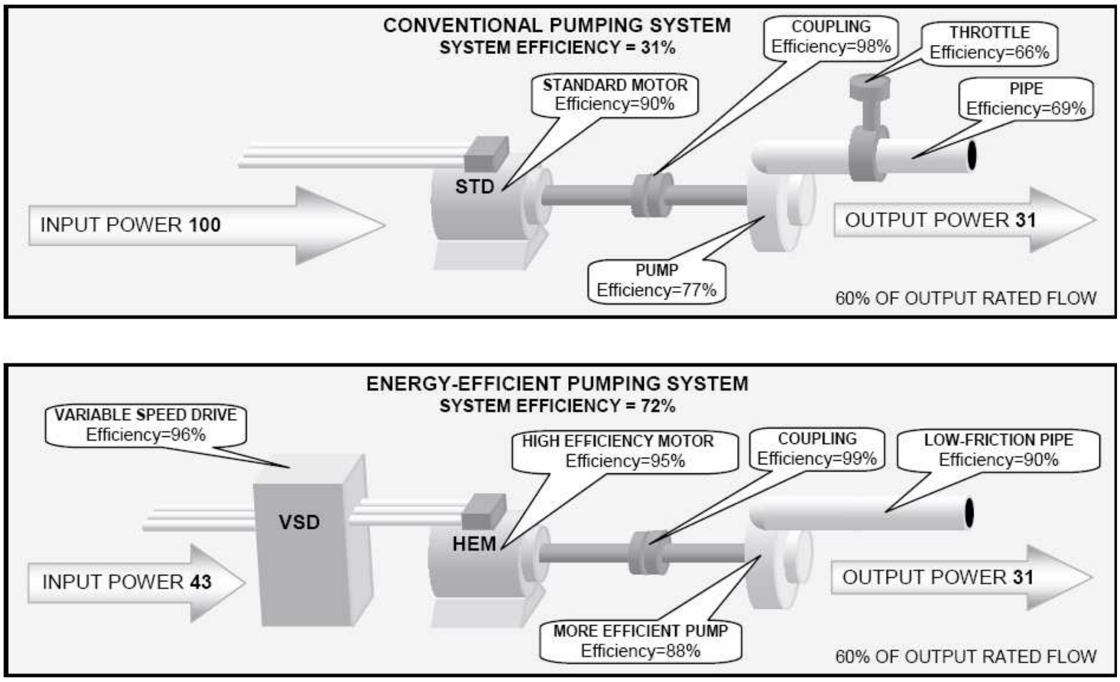
[1] There is a great variety of motors available on the market, however, induction motors account for the large part of electricity consumption. Most other motors are used for special applications.

sumption is well below 10 percent in many other industries (Elliot and Nadel 2003). Figure 2 presents a comparison between a typical pump system and an energy efficient one. The efficient pump system uses a variable speed drive instead of a throttle, more efficient components like a motor and pump, and shows reduced friction losses in the motor and pump coupling as well as in the pipe network.

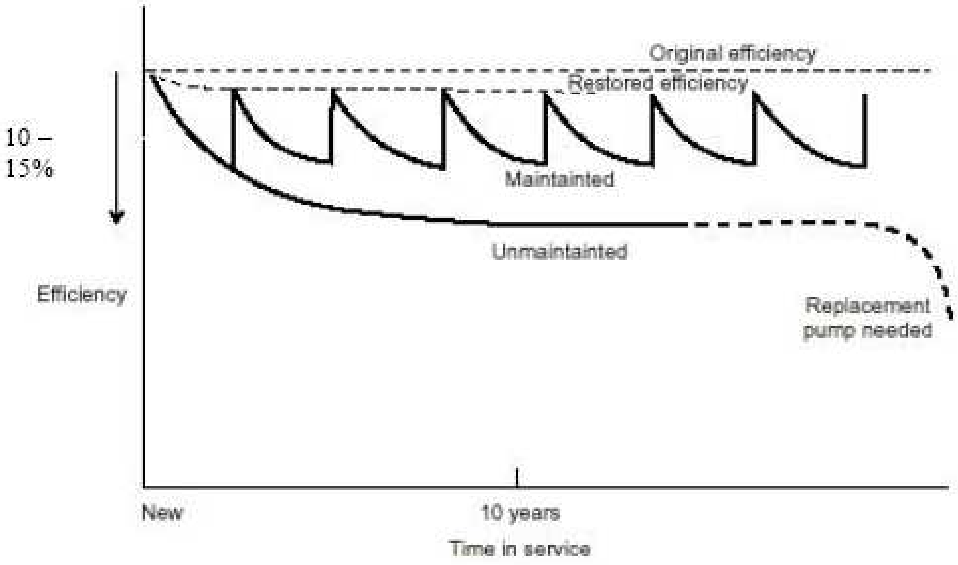
Figure 2 Comparison of a typical and an energy efficient pump system



Source: De Keulenaer H. et al. 2004.

Over time, pumps deteriorate and their efficiency can fall by up to 10-15 percent (ETSU et al., 2001). Gudbjerg (2007) mentions possible efficiency losses in centrifugal water pumps of around 5 percent after the first five years of operation. If the fluid contains solids or if temperature or speed is increased, the deterioration will accelerate. The drop in efficiency is strongest in the first years of utilization. Besides regular maintenance, coatings, e.g. with glass or resin, can improve the long-term durability as well as the efficiency of the pump (Gudbjerg, Andersen 2007).

Figure 3 **Effect of deterioration and maintenance on pump efficiency**



Source: (ETSU et al., 2001).

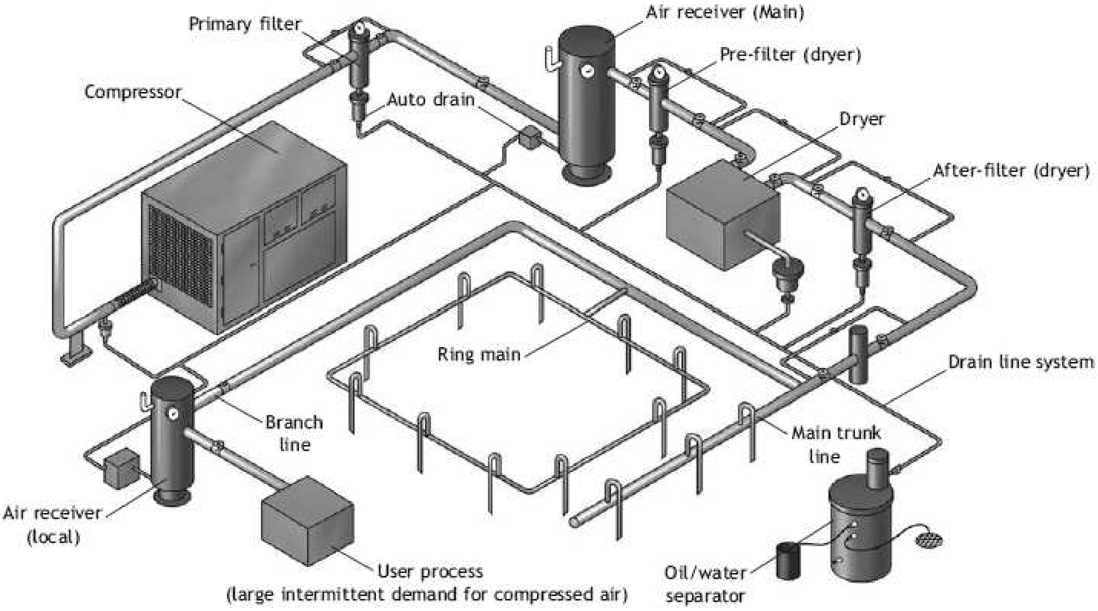
Fans are mostly used in heating, ventilation and air conditioning systems to provide the necessary air exchange, but they are applied in other processes like material handling and cleaning, drying or painting as well. Fans account for about 9.5 to 17.5 percent of the industrial sectors' total electricity consumption with the highest share of 17.5 percent in the pulp and paper industry (Radgen 2002).

Fans can typically be divided into centrifugal and axial fans, which have further sub-categories. Among these sub-categories, the fan's efficiency can vary between 55 percent and 88 percent, which demonstrates the great potential for efficiency improvements by choosing the appropriate fan alone, although not all fans can be applied to all purposes (Radgen et al. 2007). As for the other cross-cutting technologies, including the efficiency of fans, the system perspective is essential and most of the potential savings can only be realized by extending the system borders beyond the optimization of single components.

Refrigeration accounts for a high share of electricity use in both the food and chemicals industry. For food processing, many raw materials, intermediate products and final products need to be refrigerated to ensure product quality and lifetime and to comply with hygiene standards. The chemicals industry mostly needs very low temperature cooling for the liquefaction of gases, often down to several Kelvin only. Options for energy efficiency improvement exist along the entire cold chain, from better insulated cold storage houses in the food industry to more efficient compressors and cold generation systems.

Compressed air systems consume about 10 percent of industrial electricity consumption in the EU as well as in the USA (Radgen, Blaustein 2001; XEnergy 2001). They range in size from several kW to several hundred kW. In comparison to electric motor-driven systems, compressed air tools can often be designed smaller, lighter and more flexible. They allow for speed and torque control and show security advantages, because no electricity is used where pneumatic tools are applied. Consequently, compressed air systems are found in all industries, although they are considerably less energy efficient than direct motor-driven systems. While compressed air is used in the food industry for purposes like bottling, spraying coatings, cleaning or vacuum packaging, typical uses in the textiles industry are loom jet weaving, spinning or texturizing. In most industries, compressed air is used for conveying, controls and actors.

Figure 4 Typical compressed air system



Source: (The Carbon Trust, 2005).

In a typical compressed air system, a supply and a demand side can be distinguished. The supply side consists of compressors and air treatments and provides pressurized air, while the demand side consists of an air distribution system, storage tanks and mostly several end-uses like different pneumatic tools (see Figure 4). Controls adjust the compressed air supply to the actual demand. The compressor is often driven by an electric motor, but in plants with high electricity costs or high risk of blackouts, alternative drives like diesel, natural gas engines or steam turbines are also used to drive the compressor. A variety of different types and designs is available for the compressor, which converts mechanical energy into pressure. Many compressors are sold packaged with the motor already included and, thus, the design of the core motor system is already determined by the compressor producer. Before being transported to the place of use, the air is treated to improve its quality by, e.g. drying or filtering. These numerous energy conversion, storage and transportation steps lead to significant energy losses and inefficiencies. With a typical system efficiency of 10-15 percent, compressed air systems are among the least efficient industrial motor systems (IEA, 2007). Efficiency improvements are available practically everywhere in the system.

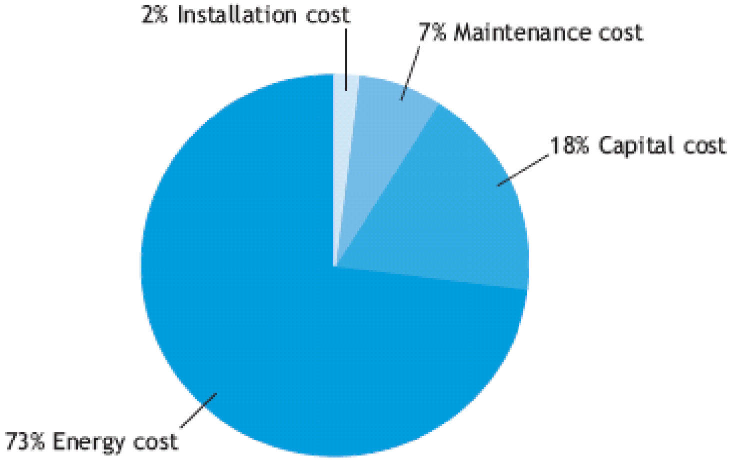
Consequently, replacing compressed air-driven tools by motor-driven ones can improve energy efficiency considerably. This option is of course not applicable to all compressed air systems. But with the constant improvement of electric motor drives the applications through which they can deliver the same services and quality, but at a lower cost increase as well. In fact, compressed air is regarded as the most expensive energy carrier available at a plant and its replacement can result in significant economic benefits, particularly for new plants. Determining whether compressed air is the appropriate energy carrier is important to achieve the highest energy efficiency levels.

Already small air leaks in compressed air systems can cause several thousand of dollars of additional annual costs. Leak prevention programmes can avoid these unnecessary expenses and increase energy efficiency.

A considerable improvement potential exists in cases where compressed air is still the most appropriate energy carrier. Radgen and Blaustain (2001) found a technically and economically feasible saving potential of about 33 percent of electricity consumption of all compressed air systems in Europe, exploitable within a period of 15 years. They identified 11 distinct measures to improve the energy efficiency of compressed air systems. Among these, the reduction of air leaks is by far the single most influential measure. Other measures with a comparably high impact are the use of multi-pressure systems, variable speed drives or the recovery of waste heat. Many of the improvement options can be implemented by replacing select components while other, like the avoidance of air leaks, require no system changes at all. Case studies in the USA showed average energy savings of 15 percent of compressed air system electricity use with payback times below 2 years (XEnergy, 2001). In Germany, the assessment of 40 compressed air plants revealed high saving potentials of mostly between 20 and 50 percent of total electricity consumption of the compressed air system

(Radgen, 2004). As energy costs account for the highest cost share of compressed air systems, many energy efficiency options demonstrate very short payback periods (see Figure 5).

Figure 5 Costs of a compressed air system with a 10-year lifetime



Source: (The Carbon Trust, 2005).

Material handling and material processing differ considerably between industries and processes. For example, in the paper industry, they are mostly rolls and conveyors, while in the cement industry, mills reveal an immense amount of electricity consumption. They are too heterogeneous to be described here and their improvement options are closely bound to the industrial process to which they are applied. Some of the general options that are applicable in most cases, like high efficiency motors, are described in the following chapter.

Optimization of the entire motor system goes a lot further than applying high efficiency components and avoiding stand-by time. System optimisation assures that the chosen components work together effectively and that saving potentials along the complete energy flow within a system are considered. For compressed air systems, this, for example, means that the first and highest ranked energy efficiency option should be to check if the provided amount of compressed air is actually needed in the process. In a next step, the compressed air system itself has to be optimized by choosing high efficiency components, but also by making the components fit together and by efficiently controlling and monitoring the entire system. In the final step of system optimization, the possibilities for energy recovery, such as the use of low temperature waste heat from air compressors, should be considered.

In contrast to the replacement of components by energy efficient ones, many of the system optimization options have fairly low investment costs, which makes them particularly attractive in developing countries where companies experience even stronger capital restrictions. However, system optimization that goes beyond switching off appliances when they are not being used is complex and requires in-depth knowledge about the installed processes. Therefore, the success of improved system optimization initiatives is closely linked to the capacity development of highly skilled system optimization experts (McKane et al., 2007b).

3.2 Component efficiency improvement

As a consequence of the enormous heterogeneity of motor systems, production systems and firms in industry, the options to improve energy efficiency are manifold and diverse. However, certain cross-cutting improvement possibilities can be observed among the majority of motor systems. These options also show the highest saving potential at industry level, although system-specific options might provide for higher energy savings at the level of single firms. Some of the options that indicate the highest potentials for efficiency improvement are related to the motor itself, the motor control and the core motor system, like the use of high efficiency pumps or fans or the correct sizing of these appliances. The following options are related to the electric motor itself and the core motor system.

Depending on the age and efficiency of the motors in place, the replacement of less efficient motors by **high efficiency ones** can capture considerable saving potentials with payback times of a few years only. For applications that have high annual running hours – mostly in firms with multi-shift operation – the replacement can be very profitable. Case studies have shown that motors which are older than 20 years are still being used in many companies – in developing as well as in developed countries. Even shorter payback times are achieved if, following the breakdown of a motor, investments in high efficient motors are chosen rather than standard motors. The price premium of a high efficient motor of about 20 percent often pays off after several months. The direct comparison of lifecycle costs of an energy efficient, permanent magnet motor with a standard asynchronous motor in Figure 6 shows that an annual running time of above 2000 h, the investment in the energy efficient motor is cost effective (Almeida et al., 2008).[2] For motors with very high annual running hours, the lifecycle cost can be reduced by more than 10 percent.

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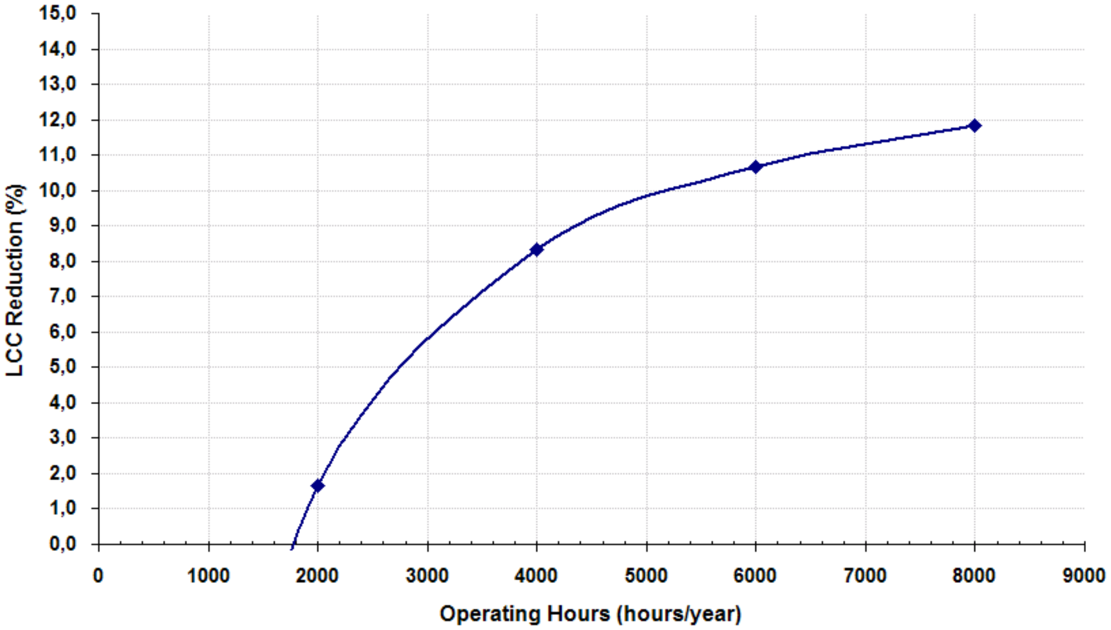
[2] The assumptions were as follows: Motor lifetime was assumed to be 12 years. The standard motor had an efficiency of 75.1 percent and a price of EUR 160, while the permanent magnet motor had an efficiency of 88.75 percent and a price of EUR 288. The underlying electricity price was 0.0754 euros/kWh.

Figure 6 **Lifecycle cost reduction when using a 1.1 kW energy efficient brushless permanent magnet motor instead of a standard motor (efficiency class IE1/Eff2)**



Source: (Almeida et al., 2008).

In case of a motor breakdown, companies often decide to **rewind** the broken motor to thus avoid the higher investment in a new motor. The main steps of motor rewinding are dismantling the motor and checking for damages, removing the old windings as well as insulation, cleaning the stator core, and finally, rewinding it with new wire and efficiency testing. According to Meyers et al. (1993), rewinding is even more common in developing countries due to the relatively low labour cost and the high price of a new motor. Some are rewound 5 to 6 times before they are finally scrapped. It is estimated that more than 50 percent of electric motors are rewound in some industrial sectors (UNEP, 2006).

From an efficiency (and a lifecycle cost) point of view, rewinding can be a bad decision for two reasons. The older less efficient motor will still be used for a decade or two and, furthermore, rewinding often comes with a loss of motor efficiency of 1 to 3 percent, which is substantial for electric motors. Others argue that rewinding can actually increase motor efficiency, if, for instance, the copper content of the windings is increased during rewinding by taking copper wire with a greater diameter (EASA, AEMT, 2003).

Rewinding broken motors is a common practice, particularly in developing countries, but rewound motors often lose efficiency by 1 to 3 percent. Consequently, rewinding should only be used for motors with low annual running hours (below 2000 hours per year).

Prakesh et al. (2008) determined that a rewound 3.7 kW induction motor with one less turn per coil, representing a badly rewound motor, showed a reduced efficiency of about 5 percent in comparison to a new motor with the same design. They also found that it was possible to correct this defect with professional rewinding and to increase efficiency to a level comparable with a new motor. Prakesh et al. estimate that if 10 percent of the industrial motors in India are poorly rewound, an energy saving potential of 650 GWh could be realized through professional rewinding, corresponding to about USD 45 million in energy cost savings per year.

Still, if motor efficiency is low so that rewinding has the potential to improve it (through increased copper content), the motor might just be very inefficient and buying a new one might significantly improve its efficiency. Furthermore, good rewinding requires reliable repair shops that use low temperature bake out ovens, high quality materials and a quality assurance programme to ensure that the motor’s efficiency is tested after rewinding and that it was not damaged during the whole process (EnerWise Africa, 2005).

Therefore, (high quality) rewinding may be a solution for motors in applications with low annual running hours (less than 2000 hours per year), where motor efficiency is not as crucial. Quality assurance and capacity development for proper motor rewinding is an effective means to improve the efficiency of the motor stock, particularly in developing countries.

The equipment of 20 percent of the induction motors stock in China with variable speed drives could reduce the capacity extension by around 9 GW until 2020 (Yang, 2007).

Another option for significantly improving motor system efficiency is the application of frequency converters to adjust motor speed according to the energy use needed. These **variable speed drives** show the highest saving potentials in flow systems, like pumping or ventilation systems with high output variations. Pumping systems are traditionally controlled by valves. These reduce the output flow while the motor is still running in full load and thus waste an enormous amount of energy, which is released as friction. Variable speed drives, in contrast, control the motor input frequency and voltage to adjust the motor rotation speed to the requirements. As a consequence, pump load or water flow are adjusted – without the use of an inefficient valve.

Depending on the system design, the efficiency improvement can be higher than 30 percent. These high savings are achieved because the consumed power is proportional to the cube of the flow in pumping or ventilation systems.

Variable speed drives have attracted increasing attention since the 1990s. However, their application and market diffusion still lags behind what is energetically and economically feasible, also in newly installed systems.

As for the electric motor, **the pump, the fan or the compressor**, substantial efficiency differences are evident. Radgen and Oberschmidt (2007) show that the efficiency of today's fans varies up to 25 percent within one fan class. They found an improvement potential of 8 percent (centrifugal backward curved fans) to 33 percent (axial fans) in comparison with the typical product of each product type. This implies that a focus on energy efficiency in designing a product allows for large efficiency gains to be realized. Similar observations are made for pumps (AEA Energy and Environment, 2008). Consequently, when choosing a pump or fan, its energy efficiency should be an important decision factor, which it often is not.

3.3 Outlook on technology development

Although electric motors are a mature technology, certain improvements in energy efficiency are still expected. Currently, a new generation of motors with copper die cast rotors is being produced that will increase efficiency by some percentage points in comparison to standard technology (Doppelbauer et al., 2005). The permanent magnet motor shows potential for even higher efficiencies, particularly for smaller motors of up to several kW.

Compared to electric motors, electronic motor controls that allow for variable speed drives (VSD) are a fairly new technology that still has considerable market potential in coming years. As the cost of power controls production is primarily determined by processing and packaging costs, further substantial decreases in VSD costs are expected (Mecrow and Jack, 2008). Together with the tendency towards more integrated and smaller motor controls, the application of VSD is expected to expand considerably.

In the very long-term, superconductivity may further reduce the losses of electric motors even more and thus reach efficiency levels of around 99 percent. However, this technology is only cost effective for very large motors (or generators) in applications with high annual running hours.

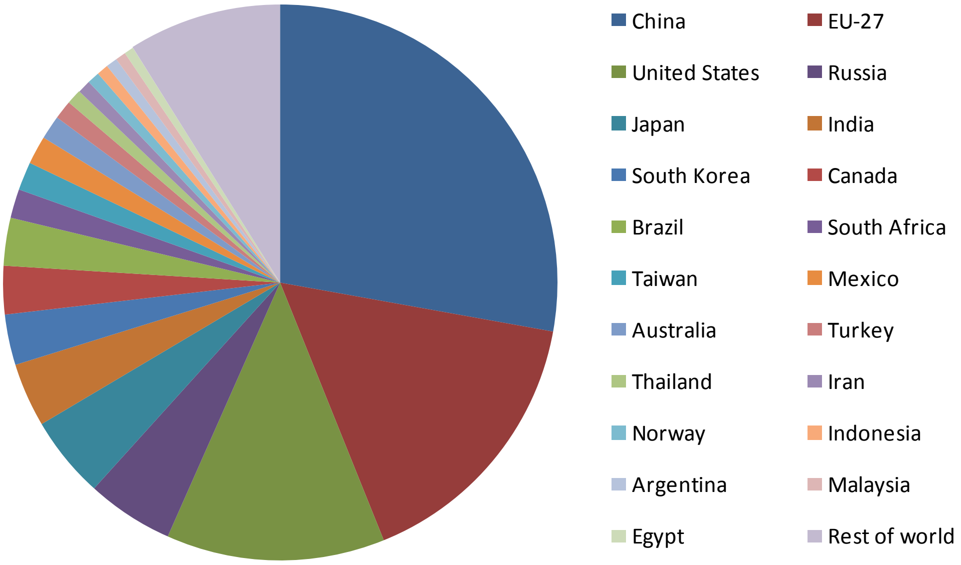
4. Quantitative assessment of costs and saving potentials

In order to give an idea of the importance of motor systems in industry's electricity consumption, this analysis aims to calculate motors' electricity consumption, saving potential and cost reduction potentials by country. The calculation comprises the following steps:

1. Using electricity consumption data by industrial sub-sector and typical shares of electric motor systems by sub-sector to calculate the total electricity consumption by motor system and country.
2. The typical saving potential by motor systems is used to calculate the total saving potential of motor systems for each country in GWh per year.
3. Average electricity tariffs for industry are used to calculate related cost-savings.

The analysis is conducted for the 21 countries or world regions with the highest industrial electricity consumption. Together these account for 91 percent of global industrial electricity consumption (see Figure 7). For the analysis, this data is divided into different industrial sub-sectors to consider structural distinctions between countries. For India, Malaysia, Indonesia, Argentina, Egypt and Iran, no sub-sector data is available. For these countries, the calculations were conducted at industry level and no differentiation was made between sub-sectors.

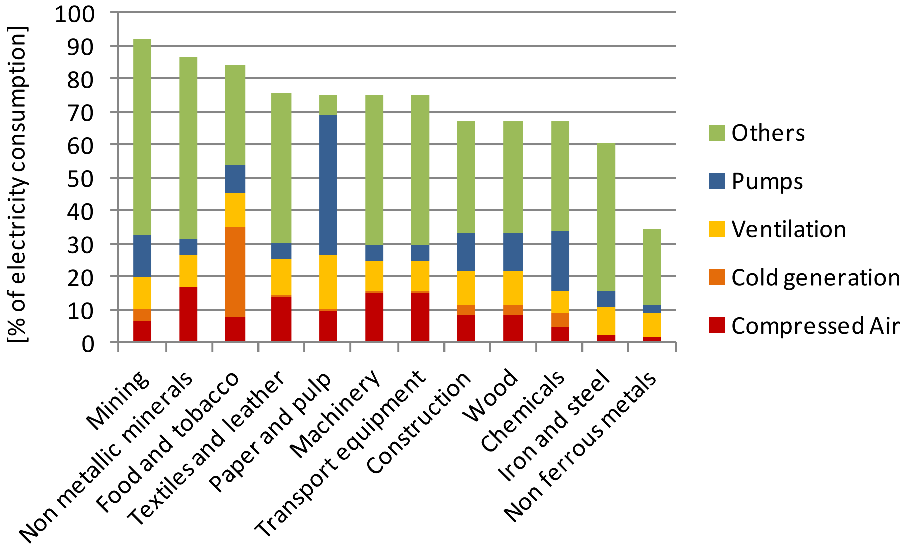
Figure 7 Global electricity consumption in industry by country for 2008



Source: Enerdata database.

As most countries do not publish electricity consumption statistics which differentiate between end-use type, like electric motor systems or lighting, these values have to be estimated. The estimation is carried out on a sub-sector basis by considering different motor system types by sub-sector. The assumed share of motor systems is presented in Figure 8. Although these values represent typical shares by sub-sector and were derived from several studies, the actual shares might differ, particularly for developing countries. Reasons for divergences might be the use of diesel engines where electricity supply is not secure, a generally lower level of mechanization and more manual labour or a different structure of the relevant sub-sector. As no better data is available, the given shares are used in this analysis. For the interpretation of results, these assumptions must be kept in mind and a direct comparison between, e.g., developing and developed countries is therefore not possible.

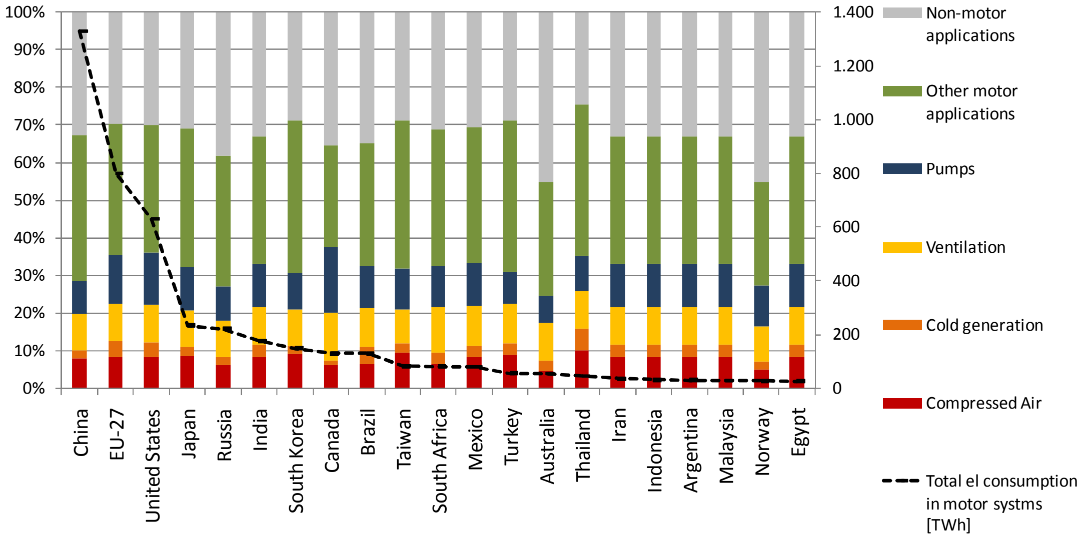
Figure 8 **Assumptions on the share of motor systems in total electricity consumption by sub-sector (values in percent)**



Source: Own estimations based on (Elliot and Nadel, 2003; ETSU et al., 2001; Radgen, 2002; Radgen and Blaustein, 2001; XEnergy, 2001).

Based on the above shares, total electricity consumption by motor system and country is calculated.

Figure 9 **Resulting share of electricity consumption by motor system (left axis) and total electricity consumption of motor systems in TWh (right axis)**



For a brief estimation of the extent of the saving potential by country, the figures from Table 1 are used. These figures represent the results of several studies from the US and the EU which estimated the saving potentials of these motor systems. They explicitly consider a row of single efficiency measures and also distinguish between system optimization and the implementation of more efficient components. For ventilation, for instance, it was estimated that the potential for system optimization is around 17 percent, while for more efficient fans it is only 5 percent. As the group of "other motor systems" is by definition very heterogeneous, the saving potential of 10 percent represents a conservative assumption. It is based on the consideration that some of these motor systems can be used in very energy intensive processes like cement grinding, where the remaining potential is lower than, for instance, in compressed air systems. The underlying saving potential represents various options that could be introduced in a cost effective manner over the next 10 to 20 years. Thus, the potential does not entail a premature replacement of capital stock, but respects the "natural" capital turnover. An overview of how realistic these values are is also provided in the following chapter on case studies.

Table 1 **Average saving potentials by motor system as assumed for the calculations**

Compressed Air	Cold generation	Ventilation	Pumps	Others motor systems
33%	20.0%	22.0%	20.0%	10.0%

Source: (Elliot and Nadel, 2003; ETSU et al., 2001; Radgen, 2002; Radgen and Blaustein, 2001).

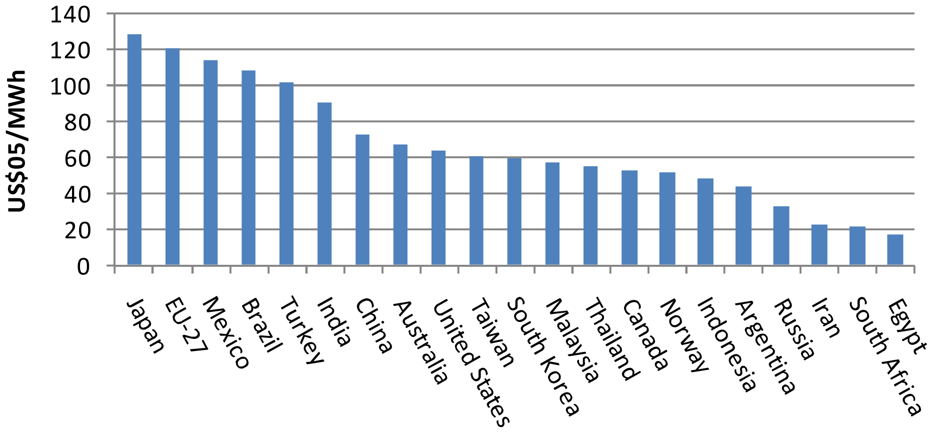
As for the share of electric motors as well as for the assumed saving potential, no explicit distinction is made between developed and developing countries. Future analyses must urgently address this factor once better data is available. It is very likely that the remaining efficiency potentials in developing countries are higher than presumed here. Potentials from high-quality rewinding or less motor rewinding in general are not at all considered, the motor stock in developing countries is expected to have lower average efficiency, and system optimization potentials in general are expected to be higher. The resulting saving potentials by country are given in Table 2. For motor systems as a whole, the saving potential lies between 9 and 13 percent of national electricity consumption.

Table 2 Resulting electricity saving potential by country and electric motor system type [GWh]

	Compressed Air	Cold generation	Ventilation	Pumps	Other motor systems	Sum	Share of total el con.
China	51,072	8,379	42,060	34,699	76,750	212,960	11%
EU-27	31,555	9,161	25,357	29,597	39,577	135,247	12%
United States	24,267	7,109	19,936	24,994	30,630	106,935	12%
Japan	9,562	1,656	7,151	7,858	12,487	38,715	11%
Russia	7,181	1,647	7,680	6,296	12,475	35,279	10%
India	7,263	1,718	5,721	6,060	8,959	29,721	11%
South Korea	6,339	901	4,429	4,094	8,493	24,256	12%
Canada	3,997	567	5,602	6,962	5,414	22,541	11%
Brazil	4,140	1,805	4,498	4,537	6,443	21,422	11%
Taiwan	3,691	550	2,379	2,495	4,616	13,730	12%
Mexico	3,150	735	2,645	2,693	4,184	13,407	12%
South Africa	2,567	683	3,181	2,618	4,329	13,378	11%
Turkey	2,254	475	1,830	1,323	3,133	9,015	12%
Australia	1,493	553	2,172	1,424	3,014	8,655	9%
Thailand	2,094	698	1,376	1,139	2,497	7,803	13%
Iran	1,495	354	1,178	1,247	1,844	6,118	11%
Indonesia	1,341	317	1,056	1,119	1,654	5,487	11%
Argentina	1,281	303	1,009	1,069	1,580	5,241	11%
Malaysia	1,187	281	935	990	1,464	4,855	11%
Norway	807	233	1,008	1,094	1,381	4,522	9%
Egypt	1,079	255	850	900	1,331	4,414	11%

To calculate the potential cost savings, average electricity tariffs by country as shown in Figure 10 were multiplied by their saving potential. The electricity tariffs represent average prices for industry including taxes. However, the definitions vary slightly by country, but are calculated as average revenues per MWh for most countries.

Figure 10 **Average electricity tariffs for industry in 2008 including taxes**



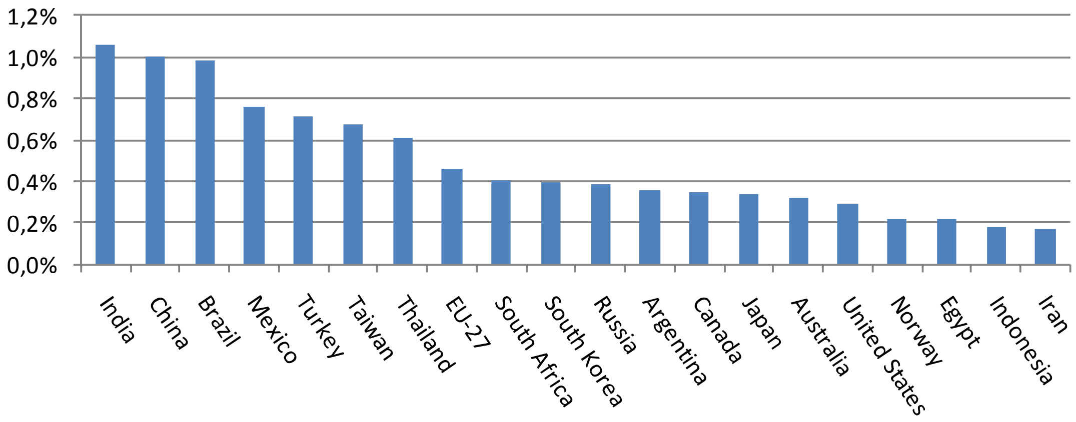
Source: Enerdata database.

Table 3 **Resulting potential annual electricity cost savings by country [million US$ 05]**

EU-27	16,254	Taiwan	838
China	15,601	Australia	579
United States	6,803	Thailand	432
Japan	4,976	South Africa	291
India	2,695	Malaysia	279
Brazil	2,328	Indonesia	267
Mexico	1,526	Norway	236
South Korea	1,430	Argentina	232
Canada	1,178	Iran	140
Russia	1,148	Egypt	77
Turkey	911		

The following table shows the electricity cost savings as share of industrial value added by country. These vary from 0.2 to above 1 percent, while electricity tariffs and level of industrial value added have the strongest effect on this indicator.

Table 4 **Cost reduction potential as share of value added of industry (2008)**



Source: Value added from Enerdata database.

However, the calculated cost saving potential through reduced electricity consumption in industry should not be interpreted without considering the necessary investment. Although the investment cannot be calculated within the scope of this study, the assumed saving potential only considers cost effective saving options. Cost effective in this case means a positive net present value while considering relatively high discount rates (of around 30 percent). Most of the necessary investments should have a payback time of several years at most, but many also have payback times below one year. On the other hand, most of the considered equipment has a lifetime of 10 to 20 years. The following section on the case studies also provides an overview of the typical payback times and investments.

For the interpretation of the results, the following aspects should be considered. They should, moreover, be understood as a list of further possible improvements for future analyses. Most of these issues relate to low data availability in developing and even in BRICs countries.

1. The use of more empirical and country-specific data on the shares of different motor systems in the sub-sectors would improve the analysis, particularly considering the structure in developing countries with a lower level of mechanization and probably more diesel engines for mechanical energy supply.
2. For the estimated saving potentials, the particular situation in developing countries would improve the reliability of results and allow comparing developing and developed countries. Issues include motor rewinding or a generally lower efficiency level of capital stock.

3. Electricity prices are averaged for the entire industry and also include taxes, while in reality firms' electricity tariffs differ due to their annual electricity consumption and the installed power. The tariffs can differ substantially between branches. Some countries even subsidize electricity tariffs (e.g. Egypt). In these countries, electricity savings would also result in financial savings for the government.
4. For India, Malaysia, Indonesia, Argentina, Egypt and Iran electricity consumption by sub-sector was not available, only for the industry as a whole. Thus, structural effects could not be considered for these countries.
5. Part of this saving potential will be realized due to some form of business-as-usual efficiency improvement – without the introduction of additional policies. However, the majority of projects will require considerable policy action to be realized.
6. A further aspect that could be improved in future analysis is the consideration of future economic growth. This step from a static to a dynamic analysis would also better capture the differences between developed and developing countries, because higher economic growth is expected for the latter, which would actually increase the saving potential. This additional saving potential is available at a very low cost, because it involves the building of new capital stock. In this case, efficiency improvement is a lot more cost effective compared to the replacement of already existing equipment.
7. Technical progress will even increase the future saving potential and improve its cost effectiveness.

The estimation presented gives an idea of the scope of potential savings as well as the total cost attributable to electricity consumption of industrial motor systems and potential savings.

5. Company case studies

This chapter aims to illustrate how energy efficiency improvements can be realized in companies. It should be noted that these case studies are not a representative sample, but success stories of profitable energy efficiency investments. Still, they show that certain measures were cost effectively implemented in companies and, moreover, give an idea of the energy savings that can be realized. Typical barriers that prevent energy efficiency improvements in motor systems are discussed in the next chapter.

Project	Country	Energy efficiency improvement	Cost effectiveness
Optimization of cooling water system in a pharmaceutical company by installing two new pumps, applying variable speed control and minimizing friction losses in the ductwork system	China	Reduction of electricity demand of cooling water system by 49%	Payback about 1.8 years (investment of US$ 145,000 and annual savings of US$ 80,000).
Installation of 34 variable speed drives in a petrochemical company	China	28% electricity demand reduction per tonne of crude oil refined	0.48 years static payback time.
Installation of 102 **variable speed drives** in one company (Yang, 2007)	Mexico	20% reduction of electricity demand of equipped motors	1.5 years static payback and investment of around US$ 400,000.
Electric motor replacement in aluminium production plant	India	Annual Electricity savings of 263 MWh (75% reduction of electricity for cooling water pump)	Annual electricity savings of US$ 13,900 and investment of US$ 375 (payback time less than two weeks).
Replacement of inefficient reciprocating compressors by **screw compressors** for compressed air generation in a pulp and paper mill	India	24% of electricity for compressed air generation.	About 1.5 years payback time and US$ 19,150.
Installation of **efficient screw compressors** with evaporative condensers for refrigeration in a chemical plant	India	60% of electricity for refrigeration (2,238 MWh/a)	Investment of US$ 250,000 and annual savings of US$ 195,000.
Reduction of air leaks and intake air temperature in **compressed air system**	Thailand	22% of compressed air electricity consumption or 130 MWh/a	US$ 1,500 investment and payback time of 2.5 months.
Compressed air system optimization in textile manufacturing plant	USA	4% reduction of compressed air electricity	The total investment of US$ 529,000 had

		demand and further reliability benefits	a payback time of 2.9 years.
Installation of 15 variable speed drives in a ventilation system in a textile plant	USA	59% reduction of ventilation system's electricity demand	1.3 years static payback time and US$ 130,000 investment.
Pump impeller size reduction, throttle replacement and motor replacement	UK	More than 30% of pump electricity consumption	11.5 weeks (investment of £2780)

Within the scope of the China Motor Systems Energy Conservation Program (collaboration of UNIDO, US Department of Energy, the Energy Foundation and the Chinese government), energy audits were conducted in Chinese firms to improve the energy efficiency of motor systems, namely compressed air, fan and pump systems. In total, 41 plants were assessed and investments in system optimization were made in most cases. The average estimated payback time was 1.4 years. Some projects had payback times of a few months only, while for others it was about 5 years. The projected savings were between 7 and 50 percent of the systems' electricity consumption. The projects that had already been realized when the project report was written, showed that the projected savings had for the most part been achieved or overachieved (Peters and Nadel, 2004).

The following energy efficiency project was initially described by Tutterow et al. (2004). It consists of an energy audit which was conducted in a **Chinese pharmaceutical firm** to identify improvement potentials of the plant's pumping system. Before optimization, the cooling system consumed over 2 million kWh per year, which was about 13 percent of the total plant's electricity consumption. The audit revealed several sources of unnecessary energy losses. Examples include the use of a valve to regulate the water flow or drastic changes in the diameter of a pipe that causes high friction losses. The optimization project implemented based on this evaluation included the installation of two new pumps, the use of variable speed control and the cleaning as well as optimization of the ductwork to minimize friction losses. In total, the US$ 145,000 investment had a payback time of 1.8 years and reduced electricity demand for the water cooling system by 49 percent.

Within the same programme, another project was carried out in a **petrochemical company** to reduce electricity consumption for crude oil refining. Thirty-four variable speed drives were installed which lead to a reduction of electricity consumption from 8016 to 5766 kWh/t crude oil refined, with a short payback time of only 0.5 years.

The **Indian Bureau of Energy Efficiency** (BEE), together with the German Society for Technical Cooperation (GTZ), compiled best practice case studies on energy efficiency projects in Indian companies and published them in a series of 10 reports, each containing around 100 case studies. The first compendium on "Greenhouse gas mitigation through energy efficiency in Indian Industry" was published in 2007 (BEE and GTZ, 2007). The examples demonstrate how to reduce greenhouse gas emissions by improving energy efficiency in a very cost effective manner. The projects described had a payback time of 0.8 years. Although the projects cover various possible areas to improve energy efficiency in a number of industrial sectors, like cement production, iron and steel, pulp and paper or the food industry, many projects focus on motor systems.

A very straightforward improvement was made in India's aluminium industry (BEE and GTZ, 2008). A **plant producing primary aluminium** and rolled aluminium goods since 1959 was able to reduce its annual electricity bill by US$ 13,900, while investing US$ 375 for a **new electric motor in the cooling water cycle**. Initially, the company used a 75 kW motor to cooling water pumping two different casting processes, of which one required considerably less cooling water. Thus, the 75 kW motor worked in a very inefficient partial load when only the second process was operating. The simple measure of adding a smaller 18.5 kW motor for cooling water pumping for the second process resulted in a reduction of around 75 percent of electricity consumption for cooling water pumping. Although the total savings of US$ 13,900 are rather small, the very short payback time of less than two weeks makes the project very attractive. The same company implemented several other energy efficiency projects such as the replacement of an inefficient impeller fan by an energy efficient backward-curved impeller fan or the use of a variable frequency drive for the exhaust blower of the cold rolling mill. Both projects had payback times of less than one year and the estimated total annual energy savings equalled about US$ 60,000. All the projects were developed and conducted by in-house energy experts.

An option that was frequently reported in the Indian energy efficiency compendium is the implementation of **variable frequency drives** to control motor speed. This typical energy efficiency investment was made, for example, by a tyre manufacturing company to control the flow in a hot water pump or by a cement producing company that equipped two cooling water pumps with variable speed drives and replaced a very inefficient throttle control. Most of these projects had short payback times of between one and two years.

Another measure that was implemented several times is the use of **screw compressors for compressed air systems** replacing less efficient compressors, mostly reciprocating compressors. One example of a pulp and paper mill reported the installation of two screw compressors that reduced power consumption by 40 kW and resulted in energy cost savings of US$ 19,000, while the investment was about US$ 30,000. Annual electricity consumption for compressed air generation was reduced from 1386 to 1050 MWh. In a chemical plant, the replacement of reciprocating compressors by screw compressors for refrigeration showed enormous electricity savings of around 2,200 MWh per year or 60 percent of electricity demand for refrigeration. The investment of US$ 250,500 came with an annual reduction of electricity and maintenance costs of around US$ 195,000 and thus, was highly profitable.

A further source of case studies is the “**Energy Efficiency Guide for Industry in Asia**”[3], developed under the United Nations Environment Programme (UNEP). The guide aims to help Asian companies improve their energy efficiency. It contains a long list of case studies of best practice energy efficiency projects.

According to the case studies presented, a Thai producer of surgical latex gloves managed to reduce its annual electricity costs by US$ 7,450 by carrying out low-cost investments to **improve the efficiency of the compressed air system**. Compressed air is predominantly used in the firm to test the produced gloves for impermeability. The company’s compressed air system consists of five compressors in the range from 30 to 60 kW installed power, of which two are continuously running. A survey found considerable pressure losses due to leaks in worn gaskets and rubber seals as well as broken pipes and joins. Also, the misuse of compressed air was reported, e.g. for cleaning of the staff’s clothes. Consequently, the auditors proposed replacing worn out equipment and modifying maintenance behaviour to prevent air leaks in the future. This measure alone had a payback time of two months only and required an investment of US$ 500. Furthermore, it was found that the compressor intake air was taken from the compressor room, where temperatures are generally higher than on the outside. As a matter of fact, reducing the intake air temperature significantly improves the compressor’s energy efficiency. Conse-

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[3] http://www.energyefficiencyasia.org/

quently, the auditors proposed using outdoor air which, on average, is 3 K colder. A payback time of four months was reported for this measure, with a total investment of US$ 1,000.

For comparative purposes, some interesting case studies from developed countries are described below.

A case study in a US **textile manufacturing** plant shows the impacts of **compressed air system optimization** on energy demand and productivity. The company has around 1,600 employees and manufactures diverse textile products. Compressed air is mainly used for air jet looms, spinning frames and blowguns. In total, 8 compressors were used, of which 6 were between 800 and 1000 hp. To extend the production by 60 additional air jet looms, the company planned to install an additional 800 hp compressor. Furthermore, to deal with the frequently occurring pressure drops, another capacity extension was foreseen. An energy survey revealed several weaknesses in the current system like an enormous pressure drop due to leaking, worn hoses, drains and valves and poorly functioning filters. Also, an excessive compressor blow off was identified, because the centrifugal compressor worked below its minimum stable flow. Moreover, the bypass valves were not working properly. Overheating as well as moisture carry-over in the compressors was found in addition. Worn end-use components were furthermore responsible for substantial air leaks. Many of the recommendations addressing all these weaknesses were implemented, such as the installation of a pressure/flow controller, storage, a filter, a dryer, repairing the end-use components, replacement of the smallest compressor by two new 350 hp compressors and some further improvements. The project resulted in energy savings of around 4 percent of the compressed air system’s electricity use, while production capacity was increased at the same time. Furthermore, the system worked far more reliably after the project implementation, which directly improved productivity and reduced the system’s maintenance costs (due to a 90 percent reduced shutdown rate). These results were achieved with an investment of US$ 528,000, which had a simple payback time of 2.9 years.

Another case study from the UK reveals very short payback times for a salt producing plant which **reduced the size of a pump impeller**. The salt is derived from the brine (a salt solution) by evaporating the water. To make use of the condensate, the company decided to transport it to a nearby power station where it was used for electricity production. For the condensate pumping, a 110 kW pump was used. An audit revealed that the pump created pressure that was considerably higher than needed. Reducing the impeller diameter from 320 to 280 mm corrected this inefficiency. As a result, the throttle was made dispensable and the improvements resulted in savings of around 30 percent of the initial pumping energy consumption. Following pump modifications, the old 110 kW motor was oversized and worked in partial load and it was thus replaced by a smaller motor that could work closer to its peak efficiency. The overall payback time of the two investments of £ 2780 in total was 11.5 weeks. If only the reduction of the impeller diameter is counted, the payback time was 11 days only, while it was 3.5 years for the motor replacement. Reducing the impeller size is a particularly cost effective option, as it requires very low investments only and can result in significant energy savings. In this case study, the investment amounted to £ 260, while the energy savings were around 30 percent.

The US Department of Energy (DOE) published several case studies on the implementation of energy efficiency measures in companies.[4] One of these projects from the textile industry is the **installation of 15 variable speed drives in a spinning and weaving plant** in the USA. The company is a medium-sized company with 300 employees that operates 24 hours per day and 348 days per year. This high annual operation time makes an investment in energy efficiency measures even more attractive, as the payback time tends to be shorter. The plant processes 45,000 lbs of raw cotton per day. As the cotton requires a certain temperature and humidity level in the production facility, a well functioning ventilation system is essential. An energy audit of the ventilation system recommended retrofitting 15 of the 18 fans with variable speed drives. The project resulted in a drastic reduction of the ventilation system’s electricity demand by 59 percent. This result could be realized because the fans initially ran in partial load and the replacement of inefficient dumper control by variable speed drive allowed a considerable reduction of the installed motor power. The payback time for an investment of US$ 130,000was 1.3 years and the project entailed further benefits like an easier and more precise control over air quality.

6. Barriers for energy efficiency

A number of different barriers and market failures may hamper the adoption of energy efficient technologies. Some of the barriers are particularly prevalent for electric motor systems. Among these are principal agent problems, lack of information, transaction costs or organizational structure.

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[4] Available online at http://www1.eere.energy.gov/industry/bestpractices/motors.html (Accessed on 12/20/2009).

Electric motor systems like compressed air, pumps and ventilation are mostly auxiliary systems, which are not the focus of firms' decisionmakers.

Motor markets often have a principal agent barrier: most electric motors are bought by original equipment manufacturers (OEMs) and incorporated into, e.g. pumps or fans. The end user, who is paying the electricity bill, often has no information about the motor that has been incorporated into the pump or fan and, thus, cannot base his or her investment decision on the efficiency of the electric motor. On the other hand, pump or fan manufacturers are primarily competing on the basis of product price, meaning that the least costly motor is also the most attractive one for them.

De Almeida (1998) demonstrates that the procurement process of new electric motors is a fairly standardized process in large firms, which reveals several barriers related to a lack of or even opposing incentives. For instance, the department responsible for the procurement of new motors is different from that in charge of the motor's electricity bill. In smaller companies, a motor breakdown represents an emergency, where the only thing that counts is the time to install a new motor. Furthermore, it is often observed that companies stock backup motors of the same type to prepare for a potential breakdown.

The investment decision is often dominated by the initial motor cost, and less weight is given to the motor's running costs, which are by far the most important cost component over a motor's lifetime. Thus, a typical price premium of 20 to 30 percent for high efficiency motors represents an obstacle for companies in choosing the more efficient motor (Almeida et al., 2008).

The knowledge and capacity of employees is crucial for a system operate efficiently. It is a prerequisite for system optimization. In developing countries it is even more difficult for companies to find experts on motor system optimization (Nadel et al., 2002).

As motor system optimization also includes the application of high efficiency equipment, the availability of such equipment at reasonable prices is a prerequisite for an investment. However, in developing countries the most efficient equipment is often not produced locally but has to be imported at relatively high prices. Nadel et al. (2002) describe the case of variable speed drives in China. Hence, imports had a market share of about 90 percent around 2000, mainly because Chinese products lacked the quality or features demanded by the purchaser.

7. Policies to improve energy efficiency

Several policy options exist to overcome these barriers and to expand the use of energy efficient equipment. The following chapter first discusses minimum energy performance standards (MEPS) and product labelling, which aim at increasing the efficiency of products on the market, and the second chapter focuses on ways to move beyond the use of efficient components and to improve the entire system's efficiency.

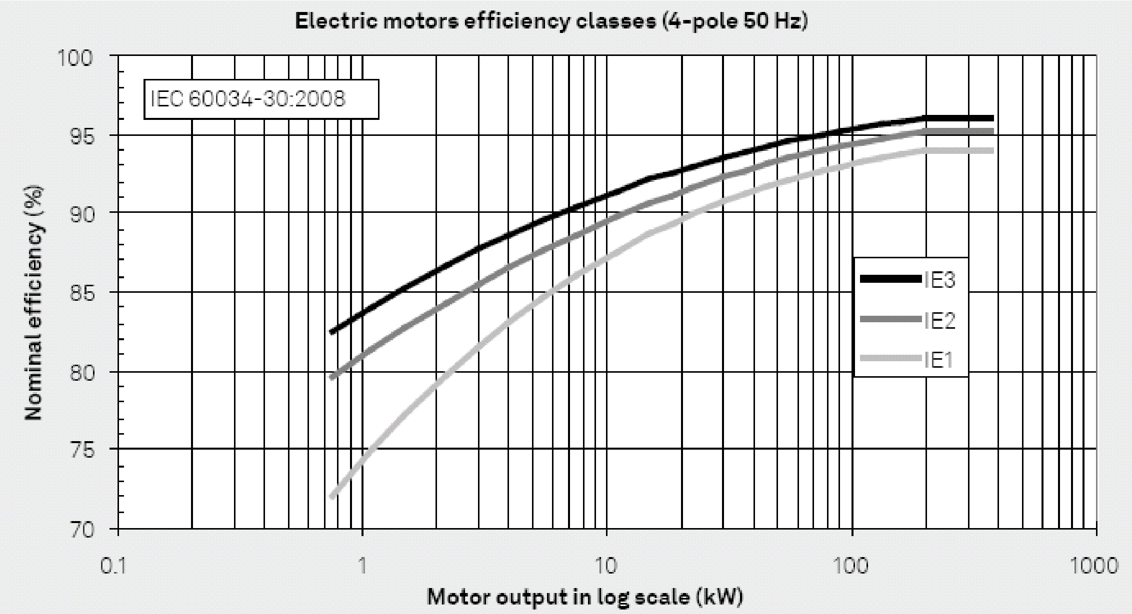
7.1 Minimum standards and labelling

For more than a decade, many countries have begun implementing labelling and minimum energy performance standard (MEPS) schemes to improve the efficiency of motors on the market. MEPS aim at phasing out the least efficient motor classes by setting minimum standards for the efficiency of motors being sold in a country. By labelling motors, policymakers try to overcome the information barrier that made it impossible for company decisionmakers to invest in high efficiency motors. Labelling provides the necessary information in a transparent way and allows for easy comparisons of motor efficiency among producers. Thus, it reduces transaction costs and contributes to transforming the motor market towards high efficiency motors. Therefore, MEPS and labelling often go hand in hand. While MEPS reduce the market share of least efficient motors, labelling fosters the use of very efficient motors, probably in applications where they are most cost effective.

One necessary prerequisite for both labelling and MEPS is that motor efficiency classes need to be defined. This has already been done in many countries, resulting in several different national standards. Unfortunately, the varying definitions of efficiency classes that were established in different countries turned out to be a considerable trade barrier and made comparisons of motor markets difficult, and the International Electrotechnical Commission (IEC) therefore developed an international efficiency classification, test standards and labels for electric motors (Boteler et al., 2009). The IEC classification distinguishes between four efficiency levels with the label IE1 for the least efficient motors and IE4 for the highest efficiency motors. These classes are now being increasingly used as a basis for national labelling and MEPS schemes.

The scope of the IEC scheme covers AC, three-phase, induction motors between 0.75 and 375 kW[5]. Although this definition only covers a certain type of the many different motor types available on the market, this general purpose motor accounts for the larger share of global electricity consumption by electric motors (around 70 percent). Smaller motors are mostly integrated into other products, like refrigerators or circulation pumps, which can be subject to won standards or labelling schemes. The defined efficiency classes are presented in Figure 11 for 50 Hz motors. The IE4 class has not yet been defined, but is expected to demand a further 15 percent reduction of losses in comparison to IE3. Figure 11 shows that the efficiency differences – and the expected savings – are particularly high for smaller motors and that the gap closes with increasing motor size to only about 2 percent difference from IE1 to IE3 for 375 kW motors.

Figure 11 Efficiency classes for 50 Hz 4-pole motors according to IEC 60034-30



Source: (Boteler et al., 2009).

Several countries have already introduced MEPS for motors or have decided to introduce them. Among them are large electricity consumers like Brazil, China, USA, Europe, Mexico, Australia or Taiwan.

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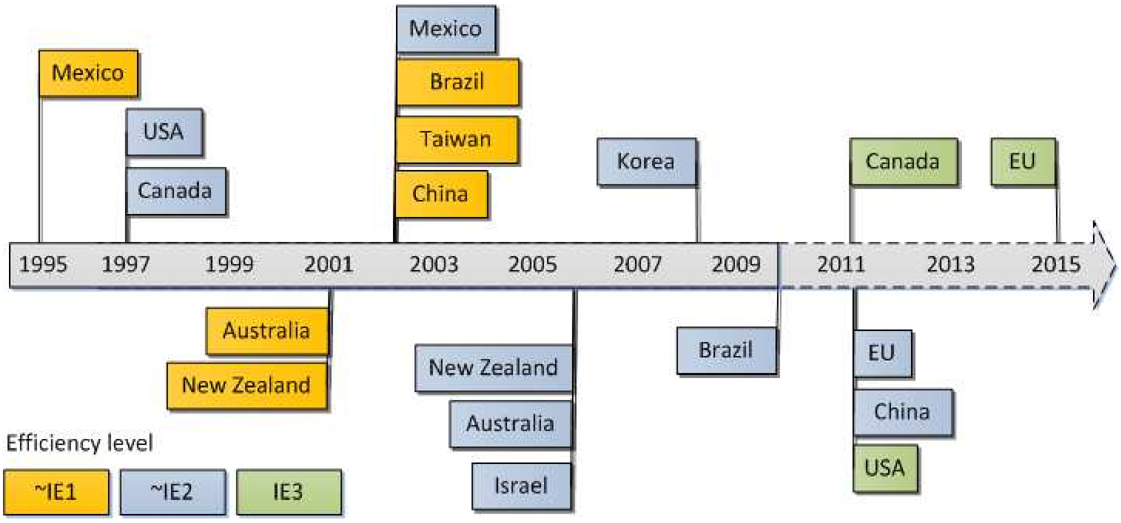
[5] Further requirements of the cited standard IEC 60034-30 are 2-, 4- or 6-poles, a voltage below 1000 V, 50 or 60 Hz, and the motor should be a general purpose motor. Motors which are fully integrated into, e.g. pumps or fans and motors exclusively built for converter operation are explicitly excluded.

The first country to introduce ambitious MEPS for electric motors was the USA. MEPS were passed into law as early as 1992, but it was not until 1997 when the standards were applied. This gave motor manufacturers a five-year period to adapt to the standards and redesign their motors. This so-called EPAct 92 standard is comparable to the international IE2 definition from the IEC. More ambitious MEPS were discussed in 2007 and were implemented as law in December 2010. The USA, together with Canada, are the first countries to base MEPS on IE3 (Boteler, 2009).

Figure 12 provides an overview of the implementation dates of the different standards by country. It should be noted that the implemented standards do not fully correspond to the IEC testing and classification standards in most cases. For example, the standard in Taiwan, which was introduced in 2003, is considerably higher than IE1 for smaller motors and relatively close to IE1 for larger motors (Yang et al., 2009). Large developing countries like Brazil, Mexico and China have also implemented MEPS.

Figure 12 Implementation of mandatory MEPS for electric motors worldwide (simplified illustration; not all countries included)



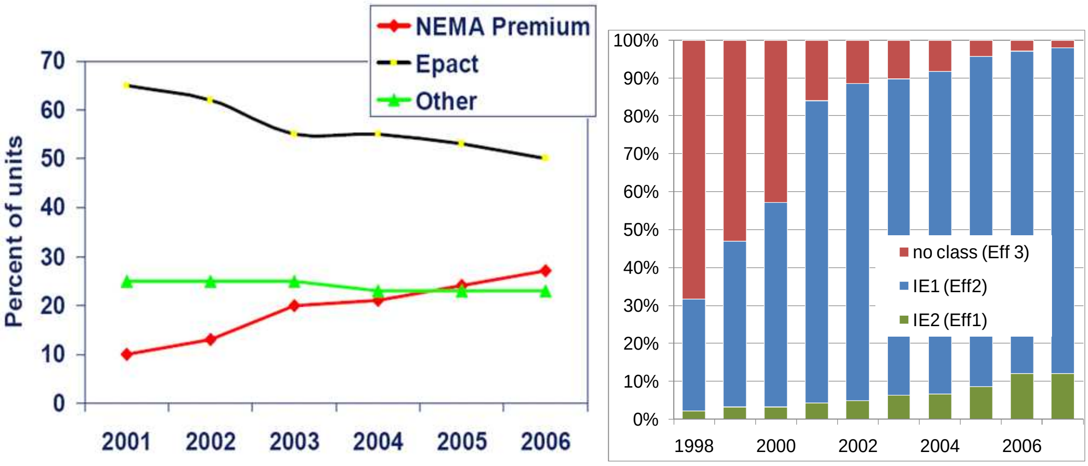
Source: compare data with (Almeida et al., 2008; Brunner et al., 2009).

A look at the historic motor market data reveals that market transformation towards more efficient motors has taken place in the past (see Figure 13). In Europe, the labelling has contributed to reducing the market share of the least efficient (Eff3) motors. Their market share has dropped from about 68 percent in 1998 to 16 percent in 2001, and only 2 percent in 2007. However, motor labelling could not significantly improve the diffusion of high efficient IE2 (former Eff1) motors. This was often explained by a higher price premium for IE2 motors.

In the USA, NEMA premium motors, which equal IE3 motors, have shown constant increases since 2001 and accounted for close to 30 percent in 2006. In 2006, motors with IE2 or better made up about 80 percent of the market share in comparison to only 12 percent in the EU.

In Canada, motors with IE3 or higher even accounted for 39 percent of the market in 2007. In Korea, IE1 motors had a market share of 10 percent in 2005, while 90 percent of the motors were less efficient.

Figure 13 Market share of motors by efficiency class in the USA (left) and the EU (right)



Source: (Boteler, 2009) CEMEP.

The introduction of MEPS for electric motors in Brazil prevented the construction of 350 MW hydro power plants (Garcia et al., 2007). Electricity was saved at a cost of around US$ 22/MWh, which is far below market prices.

According to Garcia (2007), Brazilian motor manufacturers were easily convinced by the first MEPS introduced in 2002, because they were already producing motors on a comparably high efficiency level and hoped to dispose of competing foreign motor manufacturers. For South Africa, which imports almost all electric motors, it is crucial to develop standards that are in line with the international development in order to not negatively affect local distributors (Mthombeni and Sebitosi, 2008). Yet at the same time, the scheme has to ensure that the local manufacturers will be able to achieve the standards. Besides electric motors, MEPS and labelling are applied for several energy using products, of which many contain electric motors. Examples include the MEPS introduced in China in 1990 (Zhou, 2008). Preparatory studies for the Ecodesign Directive of the EU also proposed future MEPS for fans and pumps (AEA Energy and Environment, 2008; Radgen et al., 2007).

Although MEPS and labelling are an effective means to accelerate the diffusion of energy efficient electric motors, they only allow addressing a smaller part of the saving potential of the entire motor system. The core motor system can also be addressed by product-specific MEPS, similar to motor MEPS. The core motor system can be a circulation pump, a refrigerator or a fan for ventilation with an integrated motor. Thus, the product MEPS also consider the motor’s efficiency. What is challenging for policymakers is the large variety of different products and types of products. Nonetheless, the large saving potential justifies MEPS for many products. However, the most significant savings can be gained by optimizing the entire motor system. From a policy point of view, this is more difficult to achieve since motor systems and their integration into the production process vary among processes as well as plants, and optimization requires substantial knowledge about the relevant processes. Consequently, the necessary policies are more diverse and experts need to be involved in the different systems. Some possible approaches are presented in the following chapters. They include policies like energy audits and energy management combined with information and capacity building programmes all aiming at system optimization.

7.2 Energy audits and capacity development programmes

As shown in Chapter 3, to address the huge saving potential by optimizing the entire motor system (in contrast to the use of single high efficient components), a plant by plant approach is inevitable. As industrial plants differ considerably from one another, so do compressed air, pump or fan systems and system optimization is not possible without assessing individual plants. Consequently, system optimization is closely related to a firm's capacity development and energy management practices. Different policy options were proposed and implemented to address the system perspective in motor system optimization. Among these are energy audit schemes. They have been implemented in many countries, but differentiate in terms of design aspects, the system they address and also in how they are integrated into the wider scope of energy efficiency policies in the given country. The audits are either mandatory (requiring a minimum interval for when the audits must take place) or voluntary (e.g. offering subsidies per audit), they can be so-called "walk through" audits or be very detailed (often, both types are combined). Audits are frequently combined with additional policies like training of qualified auditors, energy efficiency goals of companies or financial support for energy efficiency investments. The following interesting examples from China, Brazil, India and Germany give an idea of how such a scheme can be designed. The brief review does not intend to be complete; a lot more countries have different types of audit systems in place.

The success of auditing schemes is closely bound to the training of the energy experts conducting the audit. Therefore, particularly in developing countries, audit schemes should be accompanied by capacity development programmes. An illustrative example of such a combination is the **China Motor Systems Energy Conservation Program**, which was implemented by UNIDO between 2001 and 2004[6] (Williams et al., 2005). It was designed as a pilot programme and was implemented in two Chinese provinces (Jiangsu and Shainghai). The results provide a basis for a nationwide implementation at a later point. The main components of the programme are the training of experts for motor system optimization and the conducting of energy audits in industrial plants in which trainees and teachers jointly assess the pump, fan and compressed air systems of select companies. Two groups of experts were trained, the factory personnel and external experts. The external experts continued working in the two energy centres that were chosen for the pilot programme. The centres planned to offer motor system optimization audits and training programmes.

The programme trained 22 engineers as system optimization experts, and 38 plant assessments were conducted which revealed an annual saving potential of 40 GWh, which translates into about 23 percent of electricity consumption per system. Most of the proposed energy efficiency

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[6] The programme was implemented in cooperation with the Lawrence Berkeley National Laboratory (LBNL) and the American Council for an Energy Efficiency Economy (ACEEE).

investments showed very short payback times of one to two years. Moreover, more than 10 demonstration projects were implemented and close to 1,000 factory personnel were trained. Some of the case studies are described in Chapter 4. Thus, the programme not only trained many experts, but also achieved considerable energy efficiency improvements in several companies.

The **Brazilian** industrial energy efficiency programme entered into force in 2003. Its initial focus was industrial motor systems optimization. It has three objectives: optimizing already installed motor systems, accelerating market penetration of high efficiency induction motors and strengthening technical support. To increase the commitment from industry, the National Confederation of Industry was involved in programme design and implementation. The programme is strongly based on capacity development. In the first phase, multipliers like university teachers and consultants were trained during a 176-hour course in motor system optimization. Furthermore, motor system laboratories and education centres were installed in different universities. The next step was the training of industry staff by these multipliers so they acquire the capabilities to conduct energy audits within their own companies. The objective was to train representatives from 2,000 companies in motor system optimization. By 2005, 766 companies participated and 906 company representatives were trained, who planned to conduct 1,140 motor system audits in their companies (Perrone and Soares, 2005). Furthermore, a total of 123 multipliers from universities and consultancies were involved in the training. After four years, several lessons could be gleaned from the programme, including: the successful training of motor system experts and a reduction in the gap between university and industry by integrating university teachers as multipliers. After the first energy audits, the majority of optimization recommendations focused on motor replacement and less on system optimization aspects. As a result, many audits had to be repeated. Furthermore, the initial training of university and consultancy multipliers lacked practical aspects. Thus, the training was extended by practical in-company training which better prepared the multipliers to support companies with their motor system audits (Soares, 2008).

In **India**, the Energy Conservation Act (EC Act) of 2001 provided the legal basis for a broad variety of energy efficiency policies addressing different actors and economic sectors using a variety of policy approaches. Among others, the EC Act established the Bureau for Energy Efficiency (BEE), which replaced the former Centre for Energy Management and is responsible for introducing the proposed energy efficiency activities. The act also requires companies from a defined list of energy intensive branches to:

1. Set goals for energy consumption reduction,
2. Appoint internal energy managers, and
3. Carry out mandatory energy audits by external accredited auditors (Yang, 2006).

This combined scheme of energy efficiency targets, energy management and mandatory audits is supported by a capacity development programme. It is the task of the BEE to ensure that energy managers as well as accredited auditors are professionally qualified (Nandi and Basu, 2008). The BEE offers training modules and is responsible for the certification of energy managers and auditors. It has also prepared technical codes and guidelines for the audits of seven types of technical systems, including electric motors, ventilation and air-conditioning systems and fluid pumping systems. Thus, motor systems are explicitly addressed. From 2004 to 2006, 713 energy managers and 2013 energy auditors successfully passed the annual certification examinations. In these three years, about 3,000 energy audits were carried out (BEE, 2007).

The energy auditing and management scheme in India is a mixture of obligations, on the one hand, but also support measures like qualification training, on the other. It aims to involve both, external as well as internal energy efficiency experts. In many other countries, energy audits have long since been introduced to improve energy efficiency in industry.

In **Germany**, for example**,** an energy efficiency fund was introduced in 2008 which combines subsidized energy audits for small and medium-sized enterprises (SME) with low interest loans for investment in energy efficiency. This combination helps overcome barriers like lack of capital for project financing, as well as lack of internal knowledge and capacity to evaluate the systems. Although it does not focus on motor systems specifically, many of the proposed and realized improvement projects are found in this field.

These examples represent different successful approaches to address the tremendous energy efficiency potential motor system optimization offers. They also show the need to combine motor system optimization programmes with capacity development, because system optimization is a complex task and a plant by plant assessment is indispensable.

7.3 Energy management

Energy management schemes are very well suited to tackle efficiency improvements from system optimization. Mc Kane et al. (2007a) underline the significance of energy management standards to tackle the saving potentials hidden in motor system optimization.

These schemes help industrial facilities overcome some of the often observed organizational barriers that prevent energy efficiency projects from being realized. They aim to integrate energy efficiency into the firm’s management process. Most energy management schemes consist of five distinct steps that can be summarized as follows (McKane et al., 2007a):

1. Implementing an energy policy within the firm
2. Planning distinct projects and improvements
3. Implementing projects
4. Checking the results and adapting the plan
5. Reviewing the process.

Energy management systems require the appointment of an energy manager who coordinates the process, but also require the breoad involvement of staff at all levels of the firm.

Although several countries already have energy management standards in place (Ireland, India, Denmark, Korea, US, Netherlands, UK, Australia), they are not very widely used in developing countries. As mentioned above, India has a mandatory energy management scheme for energy intensive industrial sectors. In China, standards have been published as well, while in Brazil, standards are currently being developed. In China, energy management was introduced within the scope of the Top-1,000 Enterprises Programme, which requires the 1,000 most energy intensive enterprises to improve their energy efficiency. According to Price et al. (2008), about 95 percent of the enterprises had appointed energy managers (half- or full-time).

In Denmark, for example, the energy management standard DS 2403 was introduced in 2001. It is closely related to the ISO 14001. Still, a survey from 2006 revealed that only 3 to 14 percent of Danish companies practice energy management (Christoffersen et al., 2006).

As more and more countries began developing their national energy management standards, the ISO began elaborating a global energy management standard, the ISO 50001, in 2008. The final standard was published in late 2010. It ensures compatibility with the quality and environmental management standards ISO 9000 and 14000. Thev will also follow the “plan-do-check-act” approach as most national standards do.

8. Conclusions

Energy efficiency potentials in industrial motor systems are massive, in particular if a system optimization approach is pursued. Furthermore, many of the energy efficiency investments have payback times of a few years only.

Developing countries with high growth rates and a fast growing industry can benefit from policies for energy efficient motor systems. Using system optimization tools and high efficiency components for the construction of new production plants is the least costly and most efficient way to improve energy efficiency. Many of the components have lifetimes of up to 20 years and not choosing energy efficient components implies inefficient production for a long period of time and makes future optimization more costly. This is an advantage developing countries have in comparison to developed countries, where a – sometimes several decades old and less efficient – technological production structure has been established and energy efficiency improvements often are more expensive, because they require substantial system changes or are not even possible to realize because they would require an interruption of the production process.

Policies to improve motor system efficiency are in place in many countries worldwide and examples have been introduced here. The BRICs countries like China or Brazil have implemented policies like minimum energy performance standards for electric motors on the market, as well as audits and energy management standards. The latter are particularly useful for addressing the huge saving potential that lies in system optimization. The success of audits and energy management in industrial facilities is closely bound to the availability of skilled staff and experts. The needed experts are particularly scarce in developing countries and capacity development programmes related to motor system optimization are indispensable to further promote energy efficiency in these countries.

Still, in both developed and developing countries, the policies in place are insufficient to exploit the energy efficiency potentials of motor system optimization.

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