ORIGINAL ARTICLE

An analysis of the electricity consumption reduction potential of electric motors in the South Korean manufacturing sector

Joon Han · Sun-Jin Yun

Abstract Electric motors account for 42.9 % (as of 2010) of electricity consumption in the Korean manufacturing sector, which represents 20.9 % of total electric power demand in Korea. Efficient use of motors in the manufacturing sector is therefore essential in controlling electric power demand in Korea. This study analyzes the potential and economic feasibility of reducing electric motor electricity consumption in the Korean manufacturing sector. Presently, Korea only enforces minimum energy performance standards (MEPS) for three-phase induction electric motors rated 200 kW or less, and the industrial electricity price is much lower than the Organization for Economic Co-operation and Development (OECD) average. In addition, load factors of electric motors are generally far below optimal efficiency, and variable-speed drive (VSD) installation rates are lower than in other advanced countries. This study analyzes the amount and cost of reducing electricity consumption under each of the following scenarios, modeled as additional strategies to the current MEPS, for reducing energy consumption: (1) expansion of MEPS enforcement, (2) increasing the industrial electricity price, (3) enhancement of motor load factors, and (4) installation of VSDs. This study found that

increasing the industrial electricity price has the largest electricity reduction potential and is economically most beneficial to the society.

Introduction

While South Korea (hereafter Korea) was ranked 15th in the world in terms of gross domestic product (GDP) in 2011, it was ranked eighth in terms of total electricity consumption, at 455 TWh in the same year. Its electricity intensity was 0.489 kWh/US$2005, ranking the country fifth in the world in 2011. The annual growth rate in electricity demand level during the period of 1973–2010 was 10.1 %, the highest among the Organization for Economic Co-operation and Development (OECD) member countries (IEA 2012a). The annual growth rate in electricity demand during the recent decade, 2002–2011, was 6.0 %, which was much higher than the annual growth rate of final energy demand over the same period, 2.7 % (MKE and KEEI 2012). Thus, Korea's electricity consumption has been rapidly increasing on an absolute scale and in terms of growth rates.

Thus far, Korea has used supply-side management-oriented energy strategies to meet the rapidly increasing electricity demand. Currently, there are 23 nuclear reactors under operation and five more under construction. Six more reactors will be added by 2024. Coal-fired and

J. Han
Green Technology Center Korea, Seoul, Republic of Korea
e-mail: jooniehan@gmail.com

S.-J. Yun (✉)
Graduate School of Environmental Studies, Seoul National University, Seoul, Republic of Korea
e-mail: ecodemo@snu.ac.kr

LNG-fired power plants with a total capacity of 15.3 GW will also be added by 2027 (MKE 2013). A supply-oriented energy policy was also adopted in the case of renewable energy. The Korean government switched its renewable energy distribution policy instrument from a feed-in-tariff (FIT) to a renewable portfolio standard (RPS) in 2012 in order to supply energy from renewables within a short time period.

Nevertheless, the electricity supply has become more unstable in Korea. Korean society experienced large-scale rolling blackouts in 2011, and its electric power reserve rate nosedived to 3.8 % in 2012 from 17.1 % in 2003. Although the government has updated its projections of future electricity demands every 2 years and has increased its power capacity, actual electricity consumption has frequently exceeded estimates by 10 %. Meeting exponentially increasing electricity demand will be extremely challenging even with continued increases in the electricity supply.

Considering this aspect, supply-side management alone is not enough. Demand-side management is also important to cope with the rapidly increasing electricity demand. In other words, it is necessary to offset electricity demand increases by means of improved load management and/or through improvements in energy efficiency. Specifically, energy efficiency improvements are important because they can reduce energy use without compromising energy services. They are also beneficial because they contribute to job creation, reductions in energy-related public expenditures, increased energy security, reductions in greenhouse gas (GHG) emissions, energy price moderation, and better natural resource management at the international level (IEA 2012b). In addition, they can be implemented quickly compared to other measures such as regulations and are generally more cost-effective. The International Energy Agency (IEA) (2012c) forecasts that the ratio of fuel cost savings to the energy efficiency investment cost will be about 1.9 in OECD and 1.3 in non-OECD countries between 2012 and 2035.

Meanwhile, electric motors are electricity-intensive and consume about one fifth of all electricity in Korea (MKE 2012a). The efficient use of electric motors is critical. As a result, the Korean government introduced the minimum energy performance standard (MEPS) for electric motors in 2008, and existing low-efficiency motors have gradually been replaced with high-efficiency motors which meet these criteria. However, as electric motors consume a large amount of electricity, it is necessary to review additional options to reduce

electricity consumption and analyze their potential. For example, raising the current low electricity tariffs could reduce the high growth in electricity demand. In addition, increasing load factors and installing variable-speed drives (VSD) can enhance the efficiency of electric motors and generate savings.

Thus, this study develops five alternative scenarios that explore different means of reducing electricity consumption in addition to MEPS and analyzes the electricity reduction potential and economic feasibility of each scenario. As various technologies compete with each other in the electric motor market for cost-effectiveness, this study uses the Model for Energy Supply System Alternatives and their General Environmental Impact (MESSAGE), which is an optimization model that determines the most cost-effective technology mix (IAEA 2007).

This paper is organized as follows. In "Electric motors and strategies to reduce the electricity consumption of motors in Korea," we describe MEPS and the major issues related to electricity consumption by electric motors. In "Methodology," we describe the methodology. The scenarios are described in the "Results" and the results are explained in section "Conclusions." Finally, we discuss policy implications in section "Conclusions."

Electric motors and strategies to reduce the electricity consumption of motors in Korea

Electric motor electricity consumption in Korea

As shown in Fig. 1, manufacturing accounted for 48.7 % of electricity sales in Korea (MKE and KEEI 2012), the fifth largest proportion among OECD countries (IEA 2012a). Electric motors accounted for 42.9 % of the total electricity demand in the manufacturing sector (MKE 2012a). Therefore, the electricity used in electric motors involving in the manufacturing sector represents as much as 20.9 % of total electricity use in Korea. Considering this, electricity demand-side management strategies pertaining to the efficient use of electric motors in the Korean manufacturing industry are extremely important.

MEPS for electric motors in Korea

The USA, EU, Canada, Australia, Mexico, China, Brazil, Taiwan, and New Zealand have already adopted MEPS. The Korean government started to introduce MEPS in 2008 for three-phase induction motors of
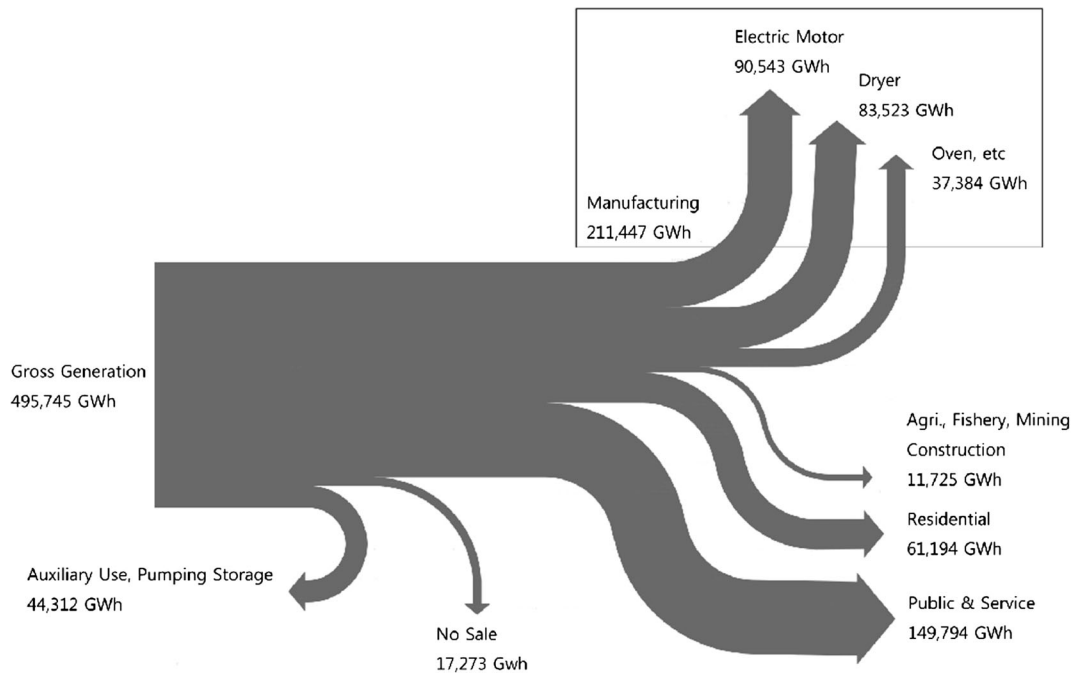
Fig. 1 The amount of electricity in power generation and consumption

200 kW or less, a standard which is now mandatory. If electric motors do not comply, their production, import, and sale are prohibited. The efficiency criteria set for three-phase induction motors under MEPS, which is same as IE2 level, are given in Table 1.

Although not currently a compulsory regulation like MEPS, there is also a premium performance standard for three-phase induction motors, which is the same as the IE3 level, as shown in Table 2. This was introduced in April 2012 and will make the production, import, and sale of premium motors (IE3) mandatory from 2015.

Figure 2 shows the IE2 and IE3 level used in Korea, EU, and USA. IE2 means high-efficiency motor and IE3 means premium motor.

Strategies to reduce the electricity consumption of motors

Strategies to reduce the electricity consumption of motors include the application scope of MEPS, the industrial electricity price, and the load factor and installation rate of VSDs.

Application scope of MEPS

Unlike Korea, the USA and the EU apply MEPS to high-capacity electric motors rated 200 kW or more.

The Korean government announced that it will expand MEPS to cover motors up to 385 kW in 2012, but this is yet to be implemented. If this were to be applied and enforced, it would be possible to save more electricity since the electricity consumed at over 200 kW is estimated to be 9.7–13.4 % of the total consumption of electric motors in Korea.

The industrial electricity price

The industrial electricity price in Korea is very low compared to those of other advanced countries. When not considering purchasing power parity (PPP), it was the lowest among OECD nations in 2009 (IEA 2013). In addition, the ratio of the electricity price compared to the fossil fuel price is the smallest among OECD countries. Table 3 shows the relative ratio of industrial electricity prices to industrial light oil and natural gas prices in the USA, Japan, Germany, France, Canada, Korea, and the OECD average. Korea has the smallest ratios in the OECD. Also, the ratio of the industrial electricity price compared to the industrial light oil rate in Korea is less than 1. This is known as the "price reversal phenomenon," which intensifies the energy electrification rate, deepens the instability of the electricity supply system, reduces energy efficiency, and increases social conflicts (Seok 2012; Jo 2012). As a result, controlling

Table 1 MEPS for three-phase induction motors (IE2 level) in Korea (unit: %)

KW	Open type				Totally enclosed type			
	2 poles	4 poles	6 poles	8 poles	2 poles	4 poles	6 poles	8 poles
0.75	75.5	82.5	80.0	74.0	75.5	82.5	80.0	74.0
1.5	84.0	84.0	85.5	85.5	84.0	84.0	86.5	82.5
2.2	84.0	86.5	86.5	86.5	85.5	87.5	87.5	84.0
3.7	85.5	87.5	87.5	87.5	87.5	87.5	87.5	85.5
5.5	87.5	88.5	88.5	88.5	88.5	89.5	89.5	85.5
7.5	88.5	89.5	90.2	89.5	89.5	89.5	89.5	88.5
11	89.5	91.0	90.2	89.5	90.2	91.0	90.2	88.5
15	90.2	91.0	91.0	90.2	90.2	91.0	90.2	89.5
18.5	91.0	91.7	91.7	90.2	91.0	92.4	91.7	89.5
22	91.0	92.4	92.4	91.0	91.0	92.4	91.7	91.0
30	91.7	93.0	93.0	91.0	91.7	93.0	93.0	91.0
37	92.4	93.0	93.0	91.7	92.4	93.0	93.0	91.7
45	93.0	93.6	93.6	92.4	93.0	93.6	93.6	91.7
55	93.0	94.1	93.6	93.6	93.0	94.1	93.6	93.0
75	93.0	94.1	94.1	93.6	93.6	94.5	94.1	93.0
90	93.6	94.5	94.1	93.6	94.5	94.5	94.1	93.6
110	93.6	95.0	94.5	93.6	94.5	95.0	95.0	93.6
132	93.6	95.0	94.5	94.1	94.5	95.0	95.0	94.1
160	94.5	95.0	94.5	94.1	95.0	95.0	95.0	94.1
200	94.5	95.0	94.5	94.1	95.0	95.0	95.0	94.1

These values mean full load nominal efficiency

electricity consumption of electric motors is very difficult with the low electricity price in the manufacturing sector.

Load factor

The motor load factor refers to the average load compared to the rated capacity of a motor for a given period of time (CEE 2011). The load factor is important with regard to the electricity consumption of a motor as a low load factor can reduce the efficiency of the motor.[1] Efficiency levels do not differ much at load factors of 75 to 100 %, and the efficiency is highest at load factors of 75 to 80 % (CEE 2011). However, the efficiency decreases remarkably at a load factor of 50 % or less

(Beggs 2009), and as the capacity increases, the level for the load factor at which the efficiency decreases rapidly also decreases (Natural Resources Canada 2003).

According to several previous studies and related data, the load factor decreases when the motor capacity is unnecessarily large (Beggs 2009; Bortoni 2009; DOE 2008; Saidur 2010). In the USA, more than 40 % of industrial motors in use were operating at less than a partial load of 40 % (DOE 2002). This resulted from motor oversizing and it showed that matching the size of motor to the load was very important for electricity saving. Therefore, maintaining a high load factor in a motor is necessary to obtain the highest efficiency.

Variable-speed drives

A VSD is a device that regulates the speed and rotational force or the output torque of mechanical equipment (Saidur et al. 2010). It is an important device when attempting to reduce the electricity consumption of a

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[1] In fact, it is whether the average load factor is low or not or whether the load factor varies substantially or not during the course of the motor duty cycle that affects the efficiency of the motor system. However, this paper focuses on the former because oversizing is usually serious and it reduces efficiency.

Table 2 Premium performance standard for three-phase motors (IE3 level) in Korea (unit: %)

KW	Open type				Totally enclosed type			
	2 poles	4 poles	6 poles	8 poles	2 poles	4 poles	6 poles	8 poles
0.75	77.0	85.5	82.5		77.0	85.5	82.5	75.5
1.5	85.5	86.5	87.5		85.5	86.5	88.5	84.0
2.2	85.5	89.5	88.5		86.5	89.5	89.5	85.5
3.7	86.5	89.5	89.5		88.5	89.5	89.5	86.5
5.5	88.5	91.0	90.2		89.5	91.7	91.0	86.5
7.5	89.5	91.7	91.7		90.2	91.7	91.0	89.5
11	90.2	93.0	91.7		91.0	92.4	91.7	89.5
15	91.0	93.0	92.4		91.0	93.0	91.7	90.2
18.5	91.7	93.6	93.0		91.7	93.6	93.0	90.2
22	91.7	94.1	93.6		91.7	93.6	93.0	91.7
30	92.4	94.1	94.1		92.4	94.1	94.1	91.7
37	93.0	94.5	94.1		93.0	94.5	94.1	92.4
45	93.6	95.0	94.5		93.6	95.0	94.5	92.4
55	93.6	95.0	94.5		93.6	95.4	94.5	93.6
75	93.6	95.4	95.0		94.1	95.4	95.0	93.6
90	94.1	95.4	95.0		95.0	95.4	95.0	94.1
110	94.1	95.8	95.4		95.0	95.8	95.8	94.1
132	94.5	95.8	95.4		95.4	95.8	95.8	94.5
160	95.0	95.8	95.4		95.4	96.2	95.8	94.5
200	95.0	95.8	95.4		95.8	96.2	95.8	94.5

motor, as it enables the motor to better match the requirements of the process it is driving. The use of VSDs can reduce the electrical energy required by a motor system by from 5 to 35 % (UNIDO 2010).

Despite the fact that the VSD has a considerable effect on reducing electricity consumption, the percentage of motors installed with VSDs is very low in Korea (1~7 %) (Yun 2009). In fact, the Korean government

Fig. 2 IE2 and IE3 level in Korea, EU, and USA. Note: The values are for totally enclosed type, four-pole motors
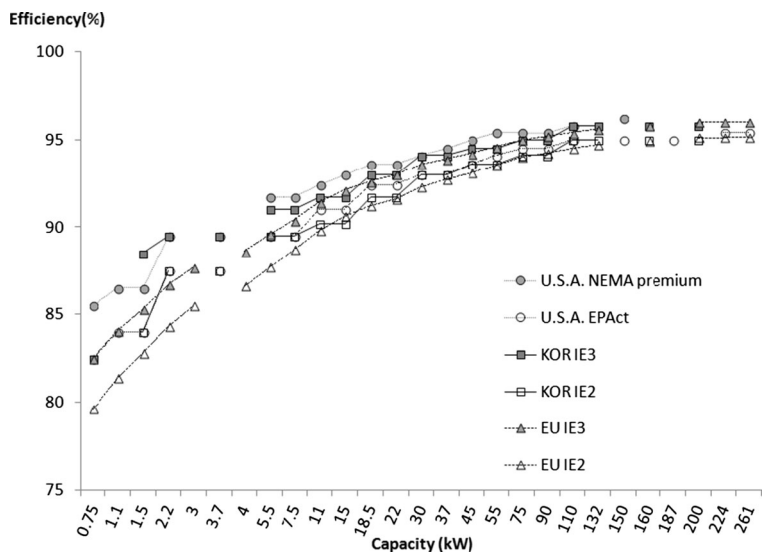
Table 3 The ratio of the industrial electricity price compared to the industrial light oil and natural gas price in major countries

	Ratio of industrial electricity price to industrial diesel price	Ratio of industrial electricity price to industrial natural gas price
Japan	2.50	2.92
Germany	2.35	2.63
OECD average	1.96	3.50
France	1.74	2.54
USA	1.62	3.48
Canada	1.10	3.57
South Korea	0.63	1.26

Ratios are calculated from 2008 data of IEA (2013)

started subsidizing high-efficiency VSDs in 2001, but the level of subsidies has differed greatly each year, most recently experiencing a rapid decrease, as shown in Fig. 3.

Methodology

The MESSAGE model

In order to analyze the electricity consumption and cost of motors in the manufacturing industry, this study used the MESSAGE model. MESSAGE is a bottom-up model based on detailed data pertaining to technologies as well as an optimization model which determines the most optimal technology mix depending on demand. In the motor market, motors generally compete in terms of cost-effectiveness. MESSAGE can determine an optimal motor technology mix with the lowest cost to meet the electricity demand level. In addition, it can account for various policies and technical situations, such as enforcement of MEPS, load factor improvements, efficiency improvements via VSD installations, and electricity price increases.

The optimization process in the MESSAGE model is based on levelized cost, which is used to compare the unit costs of different technologies over their economic lifetimes. Levelized cost can be calculated by the technology's lifetime, the initial investment cost, operation and maintenance (O&M) costs, the load factor, and the level of efficiency (Messner and Strubegger 1995).

Major premise and input data

Major preconditions

The reference year of the analysis is 2010, and the analysis period is from 2010 to 2030. This study uses a 2005 currency value and a discount rate of 5.0 %

Industrial electricity price projection

The business-as-usual (BAU) scenario reflects the industrial electricity price projection used to forecast the reference electricity demand in the "Sixth Basic Plan for Electricity Demand and Supply" formulated by the Korean government.[2] It is assumed that the ratio between the OECD average price and the Korean price would remain the same until 2030 in the BAU scenario.

However, the sixth plan was based on the premise that increases in the nominal electricity price would not exceed consumer price index (CPI) inflation (Hur 2013), suggesting future declines in the real rate of electricity. However, this is very unlikely, because the ever increasing growth in electricity demand and ineffective demand-side management is mainly due to the low electricity price in Korea (Jeong 2011; Park 2011; Yun 2013). Accordingly, this study added an electricity price increase scenario, which assumes that the industrial electricity price in Korea would increase by as much as the OECD average until 2030 through a high-price policy. In 2010, the OECD average industrial electricity price (US$110.8/MWh) was 1.67 times the Korean price (US$66.3/MWh) (IEA 2013). Therefore, the 2030 OECD average price was assumed to become 159.5 KRW/kWh, 1.67 times the 2030 Korean price (108.0 KRW/kWh). This is illustrated in Fig. 4.

Electricity service projection

The electricity service demanded by electric motors in the manufacturing sector was estimated based on total industrial electricity demand, the manufacturing sector's proportion of total industrial electricity consumption, and the average efficiency of motors, which is effective

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[2] It is a plan to present directions for demand-side management targets, an adequate reserve margin, the generation mix, renewables percentage, power plant construction plans, and other related issues based on the electricity demand forecast.
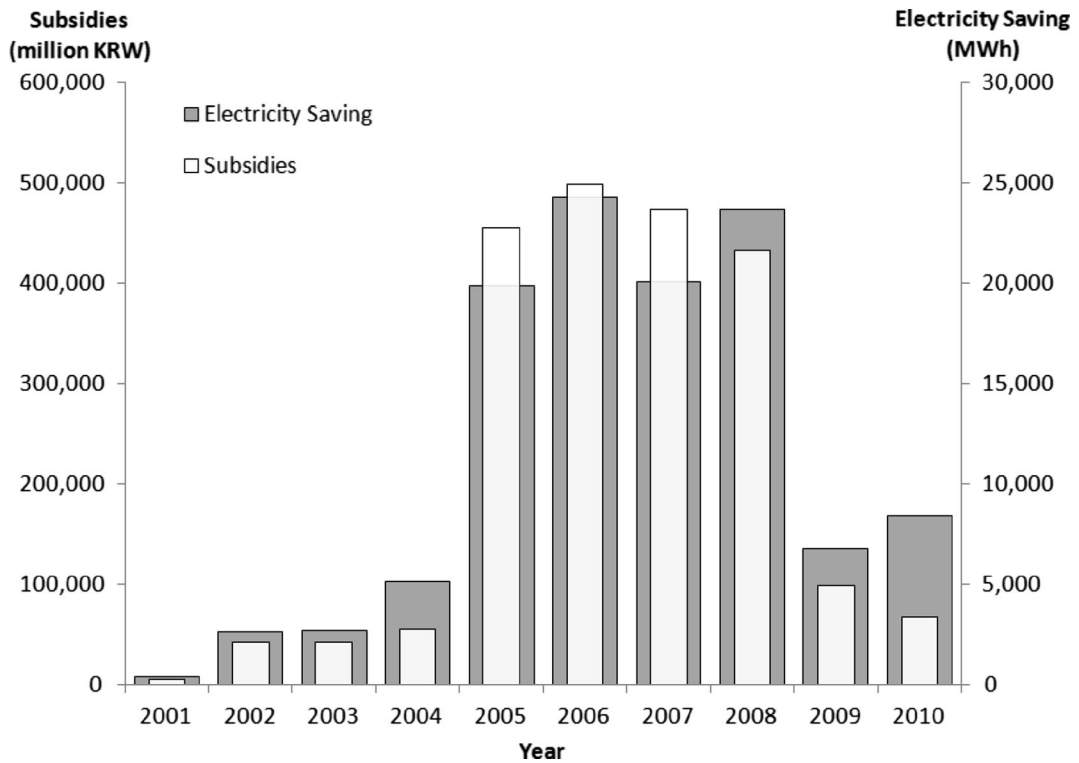
Fig. 3 Trends in subsidies for and electricity savings from high-efficiency VSDs in Korea (2001–2010). Sources: MKE (2012b)
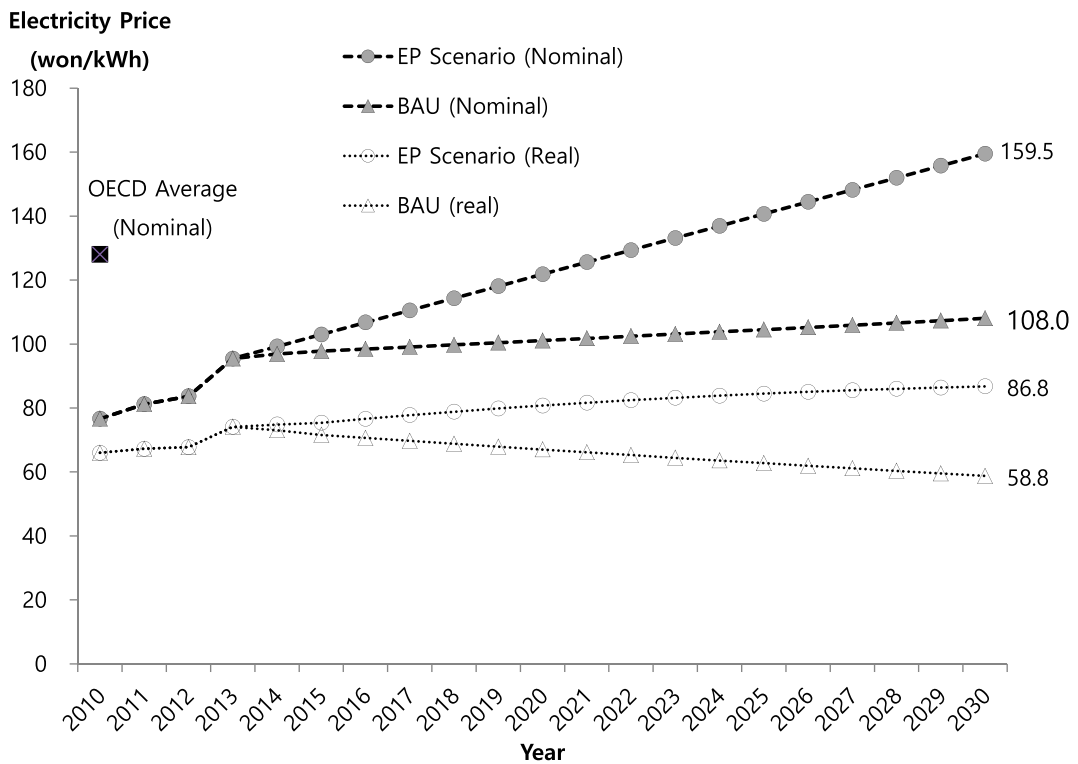

Fig. 4 Industrial electricity price increase scenario

energy, a proxy variable for energy service (Pachauri and Spreng 2004; Reister and Warren 1981).

The total industrial electricity demand was estimated using Cha et al. (2008)'s industrial electricity demand function, as shown in the equation below. Cha et al.

(2008) derived an electricity demand function through simultaneous equations reflecting the feedback between energy demand and supply and macroeconomic variables. They showed that it is very suitable and stable through a simulation.

$$\ln(\text{IEle}_t) = -4.152 + 0.374\ln(\text{IEle}_{t-1}) - 0.045\ln\left(\text{PRIEle}_t\middle/\text{CPI}_t\right) + 0.757\ln\text{GDP}_t$$
$$\quad\quad\quad (0.681)\ \ (0.066)\quad\quad\quad (0.040)\quad\quad\quad\quad (0.092)$$
$$\overline{\sigma^2} = 0.019\,,\ \overline{R^2} = 0.999\,,\ \text{D.W.} = 1.41$$

Values in brackets are the standard errors of estimates.

IEle   Industrial electricity (1000 toe)
PRIEle   Industrial electricity price (1000 KRW/toe)
CPI   Consumer price index (2005=100)
GDP   Real GDP (billion KRW, 2000 constant prices)

Because the price elasticity[3] of electricity demand varies according to many studies, this study uses data from Kim (2009) and Jeong and Park (2010) in addition to that from Cha et al. (2008). These studies provide the maximum, median, and minimum values for the price elasticity of the electricity demand levels estimated in Korea, respectively. These values are 0.66, 0.460, and 0.045, respectively.

Historical capacity of motors

We estimated electric motor supply data for Korean manufacturing by extrapolating raw data from the Korea Energy Management Corporation (KEMCO) (2004) and the Ministry of Knowledge Economy (MKE) (2008). The annual motor supply capacity is shown in Fig. 5.

Electric motor properties

We used the information from reference KEMCO (2009) for the efficiency, cost (initial investment cost, operation, and maintenance cost), and the new technology introduction time for electric motors. With regard to high-efficiency motors, the average efficiency of three-phase induction motors registered as IE2 and IE3 in the

efficiency grading system of KEMCO[4] and the average distribution price of high-efficiency motors were used. In addition, the annual motor maintenance cost was assumed to be 10 % of the initial investment cost.

Load factor

Because the efficiency of an electric motor differs depending on its load factor, it is necessary to adjust the efficiency as input data in the model while considering load factors. Table 4 shows how much different load factors reduce efficiency for motors of different capacities. The values were calculated from the International Motor Selection and Saving Analysis (IMSSA) data[5] and corroborates Beggs (2009), CEE (2011) or Natural Resources Canada (2003)'s findings that efficiency decreases as the load factor decreases. As the average load factor of Korean industrial electric motors appears to be about 65 % (MKE 2008), the percentage decreases in efficiency for each load factor were also estimated, as shown in Table 4.

VSD

As shown in Table 5, the United Nations Industrial Development Organization (UNIDO) (2010) data were used to determine the cost of a VSD and its efficiency improvements. The average values were used for the pumping system and the fan, which were the most widely used

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[3] Price elasticity of demand is the percentage change in quantity demanded in response to a 1 % change in price.
[4] KEMCO Energy Efficiency Management System homepage http://bpms.kemco.or.kr/efficiency_system/

[5] The IMSSA software tool is a program that presents detailed information about motors released onto the market, including information on capacity, enclosure type, number of pole, voltage, efficiency, cost, power factor, torque, and amperage. It is mainly intended for motor suppliers, energy consultants, and motor consumers.
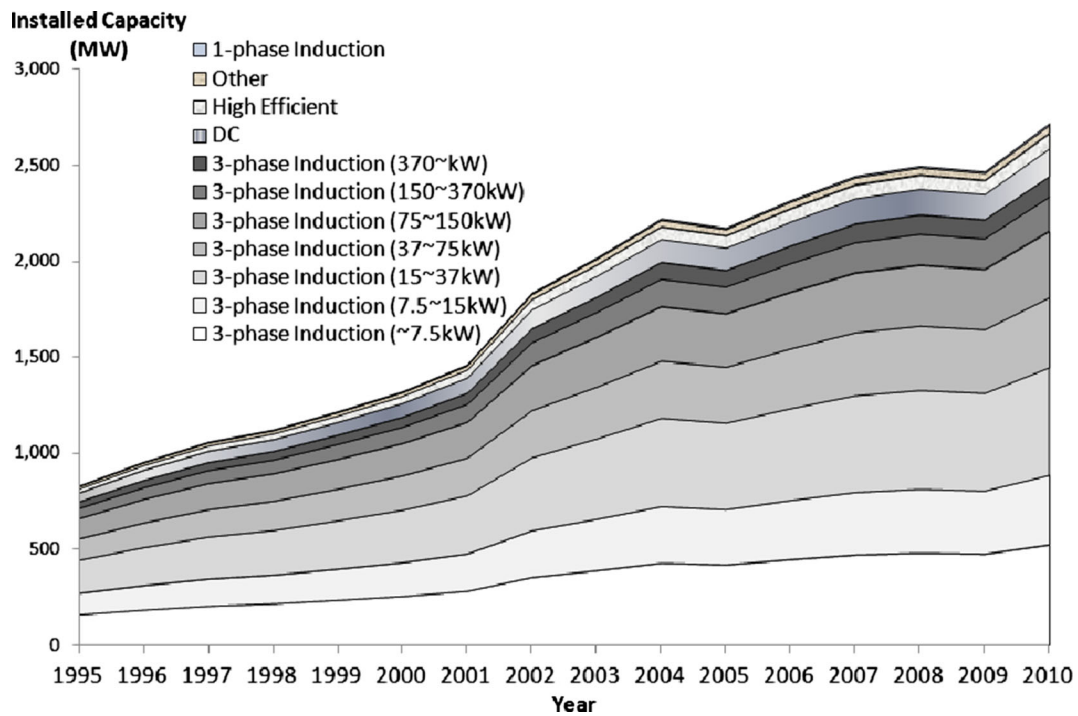
Fig. 5 Estimates of motor supply capacity in Korean manufacturing by year (1995–2010)

types. It was also assumed that an efficiency improvement means a decrease in the input electricity.

Scenarios

The scenarios for electricity consumption by electric motors in the Korean manufacturing sector are as follows: the BAU scenario represents the current situation, in which MEPS are in effect, and the alternative scenarios represent

Table 4 % Efficiency decreases from maximum efficiency, by capacity and load factor

Capacity (kW)	Load factor 25 %	Load factor 50 %	Load factor 100 %	Load factor 65 % (estimates)
~7.5	14.08	2.93	−0.08	2.59
7.5~15	7.33	1.05	0.64	1.45
15~37	5.48	0.81	0.56	1.12
37~75	4.72	0.78	0.35	0.93
75~150	4.17	0.77	0.22	0.81
150~370	3.17	0.79	0.09	0.64
370~	2.43	0.59	0.12	0.50

The 65 % data are estimated by the trend of data at 25, 50, and 100 %

situations in which additional electricity demand reduction strategies, such as an increase in the industrial electricity price (EP),[6] an expansion of MEPS (ME), an enhancement of motor load factors (LF), and increased VSD installation (VD) are put into effect. To be more specific, the EP scenario increases the Korean industrial electricity price to the OECD level until 2030. The ME scenario applies MEPS to three-phase induction motors of 200 kW or more, for which the standard was assumed to be similar to that of the EU (95.1 %—the efficiency threshold for IE2 four-pole motors).[7] The LF scenario improves the motor load factor by as much as 75 %, which maximizes motor efficiencies.[8] The VD scenario installs VSDs on electric motors, and the MX scenario runs all of these options simultaneously. Each scenario is summarized in Table 6.

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[6] An increase in electricity price may be passed on to consumers by an increase in product prices or absorbed by industry in other ways in the short run. However, in the long run, demand on electricity will decrease due to such increase.
[7] Minimum efficiency standards for motors over 200 kW in the USA and the EU are 95.4~95.8 and 95.1 %, respectively.
[8] It is not desirable to increase load factor all the time as different load factors can be selected based on the purpose of using motors. However, this study analyzes the possible maximum electricity reduction capacity of motors when properly chosen motors reach the maximum load factor as it focuses on the issue of using oversized motors.

Table 5 Efficiency improvement and cost

		Pumping system	Fan
% Improvement in energy efficiency	Over low efficiency base case	25	35
	Over middle efficiency base case	15	20
	Over high efficiency base case	10	8
Cost ($)	~37 kW	4000	8000
	37~75 kW	9000	15,000
	75~150 kW	18,000	30,000
	150~370 kW	30,000	80,000
	370 kW~	65,000	150,000

Source: UNIDO (2010)

Results

The model's projections of electricity consumption in each scenario for 2010–2030 (price elasticity=0.460) are shown in Fig. 6. Electricity consumption can be reduced from the BAU scenario each year through the EP, LF, or VD scenarios. The EP scenario reduces electricity consumption the most. On the other hand, the ME scenario has a relatively small electricity-saving effect.

Table 7 shows cumulative electricity consumption and cost by scenario. The costs include the initial investment cost, the annual O&M cost, and the electricity cost.[9] The lattermost accounts for 94~97 % of the total cost, as electric motors are energy-intensive and have long lifetimes. Therefore, it is important to reduce electricity consumption more than anything else. Electricity consumption and cost decrease remarkably with an increase in the electricity price (EP, MX), although the extent depends on the price elasticity of demand for electricity. In the case of the EP scenario, the investment cost and annual O&M cost is relatively small because the demand for motors lowers in the long run as the electricity price goes up. In the case of the VD scenario, the cost is relatively high due to the cost to install VSDs.

Table 8 shows electricity consumption change, cost change, and the unit reduction cost compared to BAU by scenarios, that were calculated on the basis of Table 7.

Assuming a price elasticity of 0.460, the EP scenario can reduce electricity usage by 130 TWh (7.5 % of BAU electricity consumption) by 2030, which is the largest reduction as a single reduction plan. It also offers the

largest cost reduction among the scenarios. However, the ME scenario has the lowest electricity reduction, as high-efficiency technologies for large-capacity motors are not developed enough and because the electricity reduction potential is not large. The MX scenario can reduce electricity consumption by as much as 170 TWh (9.8 % of BAU electricity consumption) by 2030.

In terms of unit reduction cost, the LF scenario emerged as the alternative plan with the greatest benefit (−108.7 KRW/kWh), because improvements in load factors improve motor efficiency without any additional costs. Apart from the ME scenario, the remaining scenarios also showed negative values for their unit reduction costs. This shows that an efficiency improvement can result in a greater benefit than a cost improvement, as the electricity cost accounts for most of the total cost (94~97 %) and because reduced electricity consumption translates into cost savings. This finding reflects discussions in previous studies (e.g., McKinsey and Company 2009) of how industrial efficiency improvements can result in negative costs.

Meanwhile, the ME scenario emerged as the alternative that resulted in the lowest electricity reduction

Table 6 Scenarios

Scenario	Content
BAU	MEPS
EP	Increase of industrial electricity price (same as OECD average in 2030)
ME	Expansion of MEPS (including three-phase induction motors of 200 kW or more)
LF	Enhancement of motor load factor (75 %)
VD	Installation of VSD
MX	Includes all options

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[9] In this paper, electricity cost is calculated by the electricity price which is expected as the average industrial electricity price of OECD countries in 2030. We apply the price at EC scenario.

Fig. 6 Projections of motor electricity consumption in manufacturing (price elasticity= 0.460). Note: The ref scenario is the result of the assumption that MEPS is not applied
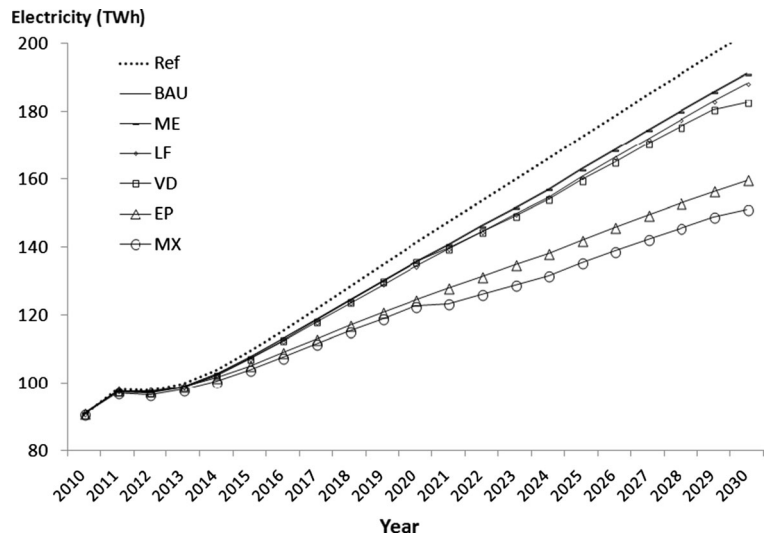
amount and had the most expensive unit reduction cost (32.7 KRW/kWh). This result was observed because the development of high-efficiency technology is not sufficiently realized and does not have a large electricity reduction potential. However, the unit reduction cost of the ME scenario is lower than the lowest real industrial electricity price for 2010–2030 (66.0 KRW/kWh); hence, the expansion plan of MEPS also appears to have major benefits. If the technical development of large-capacity motors is realized under MEPS in the future, the potential reductions in electricity consumption will be even greater.

Even if other price elasticity values (0.66 or 0.045) are used, as a stand-alone plan, the increase in the electricity price showed the greatest effect on energy

reduction. Using the other price elasticities did not substantially alter unit reduction costs.

Conclusions

This study analyzed the economic feasibility and electricity savings potential of different strategies to reduce the energy use of electric motors in Korea. And because electric motors in manufacturing represent one fifth of all electricity consumption in Korea, they are very important in electricity-demand-control efforts, as are the reduction scenarios dealt within this study. Our findings present a number of important policy implications.

Table 7 2010–2030 cumulative electricity consumption and cost of motors in the Korean manufacturing, by scenario

Electricity and cost are discounted to 2010 values

[a]Price elasticity=0.66

[b]Price elasticity=0.460

[c]Price elasticity=0.045

Scenario		Cumulative electricity (TWh)	Cumulative cost (billion KRW)		
			Electricity cost	Investment cost and annual O&M cost	Sum
BAU		1724	135,963	5448	141,411
EP	EP[a]	1544	120,937	4576	125,513
	EP[b]	1594	125,156	4850	130,007
	EP[c]	1702	134,144	5443	139,587
ME		1722	135,800	5676	141,475
LF		1708	134,651	5031	139,682
VD		1704	134,287	6118	140,405
MX	MX[a]	1506	117,816	4732	122,547
	MX[b]	1554	121,867	5014	126,881
	MX[c]	1658	130,490	5623	136,113

Table 8 Electricity consumption change, cost change, and unit reduction cost compared to BAU by scenarios

Scenario		Electricity consumption change (GWh)	Cost change (billion KRW)	Unit reduction cost (KRW/kWh)
EP	EP[a]	180 (10.5 %)	−15,899	−88.3
	EP[b]	130 (7.5 %)	−11,405	−88.0
	EP[c]	22 (1.3 %)	−1824	−83.7
ME		2 (0.1 %)	64	32.7
LF		16 (0.9 %)	−1729	−108.7
VD		20 (1.2 %)	−1006	−50.1
MX	MX[a]	218 (12.6 %)	−18,864	−86.5
	MX[b]	170 (9.8 %)	−14,530	−85.8
	MX[c]	66 (3.8 %)	−5298	−80.3

Electricity and cost are discounted to 2010 value. Values in brackets mean ratios of electricity consumption change compared with BAU

[a] Price elasticity=0.66

[b] Price elasticity=0.460

[c] Price elasticity=0.045

First, investments in electricity consumption reductions are connected to remarkable cost savings. More active publicity and investments in motor energy savings should be realized. Active incentives and support for the development of high-efficiency motors and the installation of VSDs are necessary. Specifically, the government's existing high-efficiency VSD support policy should be continued consistently. In addition, the government should enact various consulting and education programs that help motor users overcome the energy efficiency paradox, the phenomenon in which individuals and firms hesitate to invest in profitable energy-saving businesses.

Second, an increase in the electricity price is more necessary than any other method to control electricity demand. Korea has implemented various electricity-demand-control policies while maintaining a low electricity price thus far. However, these measures have been ineffective, showing that it is necessary to increase the electricity price. However, increasing the electricity price is politically challenging because the Korean government has kept the industrial electricity price low and the electricity-intensive industrial structure has been maintained thus far. Regardless, an increase in the electricity price is overdue and sorely needed. Improved communications by the government with industry and society about the necessity of increasing electricity prices in relation to the issues of energy security and climate change may help smooth over the inevitable resistance to rate increases.

Third, if properly enforced, a form of MEPS for motors is desirable in that it can reduce electricity consumption remarkably through improvements in the efficiency of electric motors. Although an expansion of MEPS has less potential to reduce electricity use and is relatively expensive compared to other plans, it appears to be feasible because the unit reduction cost is lower than the industrial electricity price. Moreover, the enforcement of MEPS can result in technical developments and efficiency improvements which can reduce electricity consumption even more.

Fourth, it is important for users to select motors of the proper capacity so that their load factors will not be too low. The government should provide information and guides for users to calculate and improve their load factors.

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