Energy End-Use Analysis and DSM Potential Estimation of Industrial Sector

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ABSTRACT

The object of this study is to analyze electric energy use by end-use and to estimate the DSM potential (energy and peak demand) in the industrial sector for the period from 1997 to 2010 in Korea. The modeling system used in this study is a combination of top-down analysis using system-level consumption data for the sector and bottom-up analysis using specific information of DSM technologies. Energy consumption in industrial sector is segmented by SIC 3 digit industries and disaggregated by end-use. A library of energy conservation measures applicable to each end-use or apparatus is developed, and energy savings and other factors are applied to the baseline demand estimation of consumption to produce potential savings estimation. This system is structured in a modular fashion so that more refined information will be available and modification may be effectively made to the model.

1. Introduction

After the oil crisis in the 1970's, energy conservation has been considered an important issue in Korea, a country that depends 97.5% of its energy on overseas import. For the purpose of overcoming overconsumption of energy, the Korean government has implemented various kinds of regulations and campaigns, Especially 29.5% of the total primary energy is consumed by electricity sector. The concept of DSM (Demand Side Management) was introduced in the beginning of the 1980's. In the beginning, most DSM programs were tariff systems or other kinds of regulations but DSM technologies such as high efficient lighting system and motors were later introduced in the 1990's.

The systematic evaluation process of energy savings and peak reduction is very important in order to determine the optimum investment of DSM activities in the future. Therefore, the detailed data on energy consumption and its behavior are necessary for the systematic development, promotion, and evaluation of DSM programs.

In this study, energy and coincident load by end-use in the industrial sector were first analyzed, and then DSM potential (technical and economic) for the 14 year period (1997 – 2010) was estimated. The modeling system that will be described is the hybrid top-down/bottom-up approach.

In the case study, the energy and load by end-use of the industrial sector were analyzed. Based on this analysis, the potential evaluation model was established. Technical potential and economic potential for DSM technologies and measures were also estimated by industrial types.

Table 1. DSM Program in Korea

Type		Program	Year
Load Management	Rate System	- Customer rate cutting	1991
		- Seasonal rate in commercial sector	1990
		- Discount rate for summer	1985
		- T-O-U rate in industrial sector	1977
		- Off-peak discount rate	1988
		- Cool storage facility subsidy	1991
		- Overnight rate	1985
	DSM Technology	- Cooling storage system	1991
		- High efficiency vending machine	1998
Energy Conservation	Rate System	- Increasing rate system in residential sector	1974
		- Discount rate system for customer	1978
	DSM Technology	- Compact fluorescent lighting - Lamps with electronic ballasts	1993

2. DSM Potential Evaluation Procedure

DSM potential means the energy and load that can be saved through special technologies, machinery, or measures for energy conservation and load management. Generally, the electric rate system and DLC (Direct Load Control) also include DSM potential. But in this study, only DSM measures such as energy efficiency technologies were considered

DSM potential evaluation is largely determined by base demand forecast and estimation of the portion of the load that could be saved in various industries and industrial end-use. The DSM potential evaluation procedure employed in this study includes the survey by DSM technologies, the technical potential estimation by identification of DSM technologies, the economic potential estimation by economic screening and achievable potential estimation by DSM technology diffusion. Figure 1 shows the DSM potential evaluation procedure.

2.1 Base Demand Forecast

Base demand forecast is the forecast of the energy and the coincident demand of end-use and equipment by industrial sector. There are three methods in developing the DSM base demand forecast namely: bottom-up, top-down, and prototype approach. However, in this study, a hybrid top-down/bottom-up approach is used. Figure 2 shows top-down approach of industrial sector.

Generally, three methods are available for base demand forecast of the industrial sector. The first method is to survey the intensity of the energy used in the factory. The second method is to use unit energy consumption by unit of value added. The third method is to use utility aggregate data. In Korea, the applicable method is to use utility data and unit energy consumption. The actual data about energy consumption in the industrial sector are used to calculate the component ratio of energy and demand in the industrial sector. The actual utility load data are used for industrial energy consumption and the survey data are used for end-uses and technologies. To calculate demand component ratio, the available total system value and load characteristics by customer are considered, and the weighted value of load characteristics is calculated seasonally, monthly, daily, and hourly. Figure 3 shows base demand forecast procedures.

Figure 1. Industrial "Top-Down" Approach

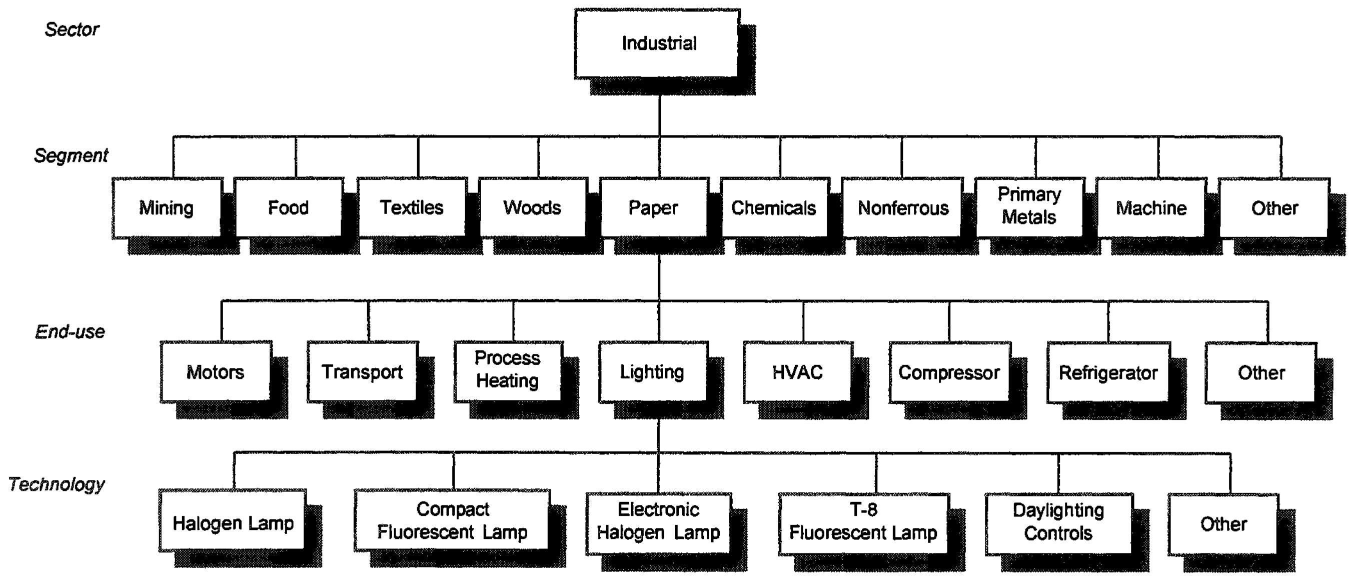
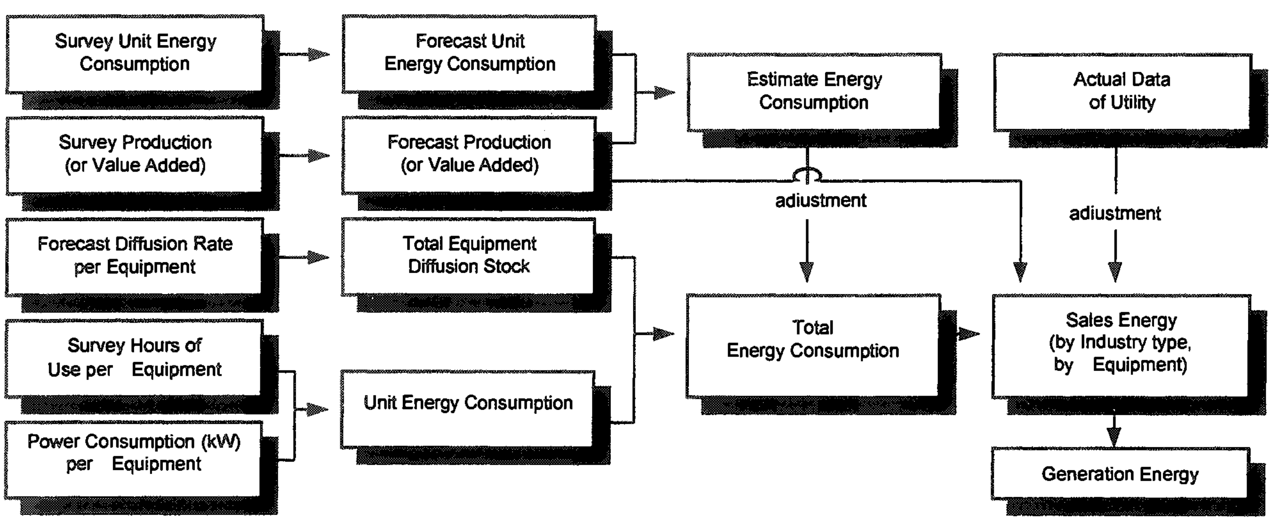


Figure 2. Industrial Base Demand Forecast Procedure



To estimate energy demand and peak load by end-use in the industrial sector for the 14 year period, equipment stock and its unit consumption are estimated. First, equipment stock is attained by equipment diffusion rate (SATR) and unit production (UNP) as shown below:

$$TVIN_{i,t}(t) = SATR_{i,j}(t) \times UNP(t) \tag{1}$$

where, TVIN = equipment diffusion stock
UNP = unit production
i = end use, j = equipment, t = year

Unit energy consumption (UEC) and unit coincident demand (UCD) are calculated as follows:

$$UEC_{i,j}(t) = NOM_{i,j}(t) \bullet HOUR_{i,j}(t) \tag{2}$$

$$UCD_{i,j}(t) = MOM_{i,j}(t) \bullet UCF_{i,j}(t) \tag{3}$$

where, NOM = Nominal Capacity of Apparatus (kW)
UCF = Coincident Factor of Apparatus (%)

Based on the above calculation, the total energy consumption (PEM) and the total peak demand (LEM) by equipment are as follows:

$$PEM_{i,j}(t) = TVIN_{i,j} \bullet UEC_{i,j}(t) \tag{4}$$

$$LEM_{i,j}(t) = TVIN_{i,j} \bullet UCD_{i,j}(t) \tag{5}$$

At the same time, the energy use that is affected by unit energy production can be used. The industrial energy consumption (UPJ) is the sum of utility sales and self-generation. It is the product of production (HHP) and unit energy consumption (PF) as shown in equation 6.

$$UPJ_k(t) = HHP_k(t) \bullet PF_k(t) \tag{6}$$

Here, k indicates the industry type. The value-added forecast (HHP) is the product of value added increase rate (VAL) and production of the base year (HHST). The unit energy production (PF) is the product of unit energy production of the base year (PFST) and estimation coefficient of unit energy production (PFCF). The estimation coefficient of unit energy production is estimated by unit energy production of the target year and specific function.

$$HHP_k(t) = VAL_k(t) \bullet HHST_k(t) \tag{7}$$

$$PF_k(t) = PFST_k(t) \bullet PFCF_k(t) \tag{8}$$

2.2 Potential Estimation

2.2.1 Technical Potential

Instantaneous technical potential (ITP) for energy is the base demand (DEM) multiplied by savings ratio (EFFR). For peak demand, ITP is an average nominal capacity (NOM) per equipment multiplied by stocks of use in system peak.

$$ITP_{i,j}^{E}(t) = \sum_{i}\sum_{j}(DEM_{i,j}(t) \bullet EFFR_{i,j}(t)) \tag{9}$$

$$ITP_{i,j}^{k}(t) = \sum_{i}\sum_{j}(NOM_{i,j}(t) \bullet PVIN_{i,j}(t)) \tag{10}$$

Phase-in technical potential (PTP) for energy and demand, assuming equipment replacement and retrofit, is the product of ITP and replacement rate per equipment (VINR) as shown in 11 and 12.

$$PTP_{i,j}^{E}(t) = \sum_{i}\sum_{j}(ITP_{i,j}^{E}(t) \bullet VINF_{i,j}(t)) \tag{11}$$

$$PTP_{i,j}^{k}(t) = \sum_{i}\sum_{j}(ITP_{i,j}^{K}(t) \bullet VINF_{i,j}(t)) \tag{12}$$

2.2.2 Economic Potential

Economic potential is a measure of the energy and peak demand savings that are economically feasible for each market sector over the years considered in the DSM analysis. The economic potential is a subset of the technical potential estimated only over those DSM measures that are economically attractive. For the economic screening, TRC (Total Resource Cost) test is preferred because its estimation is based on the social point of view.

DSM technology benefit is the avoided cost of energy and capacity of utility during the program's lifetime. On the other hand, DSM cost is the incremental cost of the existing technology.

In this study, utility avoided cost was estimated in order to quantify the benefit of DSM. The avoided cost includes avoided capacity cost, avoided energy cost, and avoided environmental cost. The LNG combined cycle generation, one of the peak capacities in KEPCO (Korea Electric Power Corporation), was applied to the avoided capacity and the survey data was applied to avoided environmental cost calculation.

① Utility Avoided Cost Calculation

The avoided cost includes avoided capacity cost (AVCF), avoided energy cost (AVCV), and avoided environmental cost (AVCE). The avoided capacity cost is a component of generation (AVCG), and transmission and distribution (AVCTD), as shown below:

$$AVC = AVC_F + AVC_V + AVC_E \tag{13}$$

$$AVC_F = AVC_G + AVC_{TD} \tag{14}$$

Equations 15 to 18 show avoided generation capacity cost (AVCG), avoided transmission capacity cost (AVCTD), avoided energy cost (AVCV), and avoided environmental cost (AVCE).

$$AVC_G = \frac{\left(\sum_{t=1}^{n} PVFC^t\right)}{\sum_{t=1}^{n} PVI^t} \bullet \frac{1}{(1-R_C)\bullet(1-R_{TD})} \tag{15}$$

$$AVC_{TD} = \left[\frac{\sum_{t=1}^{n} PTDC_t}{\sum_{t=1}^{n} PDLD_t}\right] \bullet CRF \bullet (1+R_{OM}) \bullet \frac{1}{(1-R_c)\bullet(1-R_{TD})} \tag{16}$$

$$AVC_V = \frac{C_F}{(1-R_c)\bullet(1-R_{TD})} \tag{17}$$

$$AVC_E = \frac{P_{COX} + P_{NOX} + P_{SOX} + P_{ASH} + P_{RAD}}{(1-R_c)\bullet(1-R_{TD})} \tag{18}$$

where, PVFC = Total Fixed Cost (present value)
GC = Unit Capacity
PVI = Present Value Coefficient
RC = Inner Consumption Rate
RTD = Transmission Loss
PTDC = Transmission Plan Present Value
PDLD = Load Incremental Present Value
FUC = Fuel Price
PCOX = CO_2 Cost
PNOX = NOx Cost
PSOX = SOx Cost
PASH = Ash Cost
PRAD = Radiation Waste Cost

② DSM Technology Cost Calculation

Incremental cost for DSM technology (DMC) is as follows:

$$\triangle C_{DSM} = (C_{DSM} \bullet CRF_i - C_{EXI} \bullet CRF_j) \tag{19}$$

where, i= DSM Technology Life Span;
j = Existing Life Span

$$B/C = \frac{AVC}{C_{DSM}} \tag{20}$$

Equations 21 and 22 show EP for energy and demand. Addition of all savings of technologies that exceed 1 in benefit-cost ratio (B/C) of TRC among PTP is EP.

$$EP_{i,j}^{E}(t) = \sum_i \sum_j PTP_{i,j}^{E}(t)(단, TRCi, j(t) \geq 1) \tag{21}$$

$$EP_{i,j}^{K}(t) = \sum_i \sum_j PTP_{i,j}^{K}(t)(단, TRCi, j(t) \geq 1) \tag{22}$$

2.2.3 Achievable Potential

Achievable potential is a measure of energy and peak demand savings that are economically feasible, taking into account realistic customer participation rates. The achievable potential establishes a realistic target for the DSM savings that a utility can hope to achieve through DSM. Achievable potential estimates can be used to identify clusters of DSM measures that may be worth packaging into one or more DSM programs.

$$AP_{i,j}^{E}(t)=\sum_{i}\sum_{j}(EP_{i,j}^{E}(t)\bullet SATR_{i,j}(t)) \tag{23}$$

$$AP_{i,j}^{K}(t)=\sum_{i}\sum_{j}(EP_{i,j}^{K}(t)\bullet SATR_{i,j}(t)) \tag{24}$$

$$SATR=\int_{t_k}^{t_{k+1}} m\bullet\frac{p(p+q)^2 e^{-(p+q)s}}{(p+q\bullet e^{-(p+q)s})^2}dt \tag{25}$$

3. Case Study

3.1 Baseline Forecast

End-use component ratio analysis by industry type in fixed period is essential for base demand forecasting. Table 2 shows energy component ratio by end-use industry type taken from a study entitled "Korea Report on Mining and Manufacturing Survey". In this table, the share of motors and conveyors are 31.6% and 26.4% respectively, and the share of heating is 19.6 %. However, the end-use component ratio can be varied due to manufacturing process. As for the wood industry, the share of motors is about 88% because motors are mostly used in this process. While in the primary metal industry, the share of heating is 61 %, and the share of motors is 6%.

Table 2. Component Ratio of Energy by End-Use and Industry Type (1997)

Industry Type	Lighting	Motors	Process Heating	Transport	HVAC	Compressor	Refrigerator	Other	Total
Mining	2.10	15.30	0.10	1.20	1.60	79.30	0.10	0.30	100.00
Food	1.00	15.60	5.00	1.00	11.70	32.20	28.70	4.80	100.00
Textiles	3.60	73.80	0.40	2.10	11.50	8.10	0.20	0.30	100.00
Woods	1.70	87.70	0.20	1.60	0.20	7.40	1.00	0.20	100.00
Paper	1.90	57.10	0.10	1.00	10.20	29.00	0.10	0.60	100.00
Chemicals	3.80	42.00	0.10	0.90	8.00	41.20	2.60	1.40	100.00
Nonferrous	4.80	32.80	4.30	1.00	22.60	31.40	3.00	0.10	100.00
Primary Metals	1.50	5.90	61.20	2.20	4.10	20.50	0.60	4.00	100.00
Machine	5.10	21.60	19.80	1.80	25.30	22.40	1.20	2.80	100.00
Other	9.10	14.50	0.80	4.10	14.30	51.40	3.80	2.00	100.00
Total	3.34	31.60	19.62	1.59	12.67	26.41	2.58	2.19	100.00

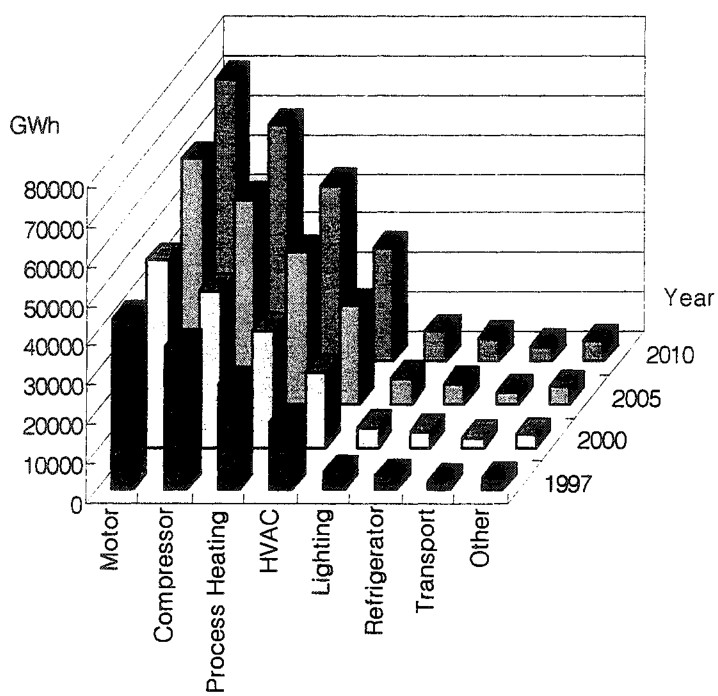
Table 3 shows base demand forecast by end use.

Table 3. Base Demand Forecast by End-Use.

End-Use	1997		2000		2005		2010	
	GWh	MW	GWh	MW	GWh	MW	GWh	MW
Lighting	4607	668	5021	733	6580	944	7575	1136
Motors	43556	6822	47470	7481	62208	9640	71621	11606
Process Heating	27038	4028	29468	4417	38617	5692	44460	6853
Transport	2188	342	2385	375	3125	483	3598	581
HVAC	17467	2658	19037	2915	24947	3756	28722	4522
Compressor	36402	4707	39674	5162	51991	6652	59858	8009
Refrigerator	3560	425	3880	466	5084	601	5854	724
Other	3012	394	3283	432	4302	557	4953	670
Total	137830	20043	150216	21981	196853	28323	226640	34102

Figure 4 shows base demand forecast by end-use for industrial energy.

Figure 4. Baseline Forecast by End-Use (Energy).



3.2 Potential Estimation

Table 4 shows the output of instantaneous technical potential. The result of the case study shows that ITP of energy is 12,054 GWh in 1997 and 19,821 GWh in 2010. Thus ITP increases by 1.6 times from 1997 to 2010. Therefore, the share of ITP in 2010 is 8.8% of the total industry energy. In 2010, the high component ratio in potential is expected to be in the order of HVAC, motors, and heating.

In case of demand, the industrial ITP is 1,936 MW in 1997 and 3,293 MW in 2010, thus ITP increases by 1.7 times from 1997 to 2010. Therefore, the share of ITP in 2010 is 5.3% of the industrial peak demand. . In 2010, the high component ratio in potential for energy and demand is in the same order.

Table 5 shows the output of phase-in technical potential. The result of the case study shows that the industrial PTP of energy is 1,920 GWh in 1997 and 18,831 GWh in 2010, thus PTP increases over the 14 year period, thus making the share of PTP 8.3% of total industrial energy in 2010. High component ratio in potential is expected to be in the order of motors, HVAC, and refrigerator in 1997. In 2010, high potential is expected to be in the order of HVAC, motors, and compressor.

Table 4. Instantaneous Technical Potential by End-Use

End-Use	1997		2000		2005		2010	
	GWh	MW	GWh	MW	GWh	MW	GWh	MW
Lighting	1151.7	167.0	1255.2	183.1	1644.9	236.0	1893.8	284.1
Motors	2177.8	341.1	2373.5	374.1	3110.4	482.0	3581.1	580.3
Process Heating	1351.9	201.4	1473.4	220.9	1930.8	284.6	2223.0	342.7
Transport	109.4	17.1	119.2	18.7	156.3	24.1	179.9	29.1
HVAC	4366.8	664.4	4759.2	728.7	6236.7	938.9	7180.4	1130.5
Compressor	1820.1	235.4	1983.7	258.1	2599.6	332.6	2992.9	400.5
Refrigerator	925.6	110.6	1008.8	121.3	1322.0	156.3	1522.0	188.2
Other	150.6	19.7	164.2	21.6	215.1	27.8	247.7	33.5
Total	12053.9	1756.6	13137.2	1926.4	17215.8	2482.3	19820.8	2988.8
Industry	137830	35851	150216	39498	196853	52479	226640	62191

In case of demand, the industrial PTP is 103 MW in 1997 and 2,536 MW in 2010, so that the share of PTP in 2010 is 4.5% of industrial peak demand. In 2010, the high component ratio in potential is expected to be in the order of HVAC, motors, lighting, and compressor.

Table 5. Phase-In Technical Potential by End-Use

End-Use	1997		2000		2005		2010	
	GWh	MW	GWh	MW	GWh	MW	GWh	MW
Lighting	115.2	16.7	614.4	82.3	1546.3	219.4	1893.8	284.1
Motors	1088.9	17.1	2373.5	99.5	3110.4	296.4	3581.1	474.4
Process Heating	135.2	10.1	721.2	58.7	1815.0	175.0	2223.0	280.1
Transport	10.9	0.9	58.4	5.0	146.9	14.8	179.9	23.8
HVAC	218.3	33.2	1519.7	193.8	4179.3	577.4	6190.3	924.3
Compressor	151.7	11.8	858.5	68.7	2209.8	204.5	2992.9	327.4
Refrigerator	185.1	11.1	826.6	54.5	1322.0	145.3	1522.0	188.2
Other	15.1	2.0	80.4	9.7	202.2	25.9	247.7	33.5
Total	1920.4	102.7	7052.7	572.2	14531.9	1658.7	18830.7	2535.8
Industry	137830	35851	150216	39498	196853	52479	226640	62191

4. Results and Conclusions

The results of the analysis in this study indicated that the instantaneous technical potential for DSM in the industrial sector in 2010, relative to a base demand plan (226,642 GWh and 34,102 MW), is 19,821 GWh (8.7%) and 2,989 MW (8.8%). And phase-in technical potential is 18,831 GWh (8.3%) and 2,536 MW (7.4%) in the industrial sector.

In this study, the industrial DSM potential by end-use was estimated in accordance with the DSM potential evaluation procedure. Korea had partly conducted DSM potential estimation for some customers but never had done for all national customers. This study found and suggested a consistent model to apply for DSM potential evaluation in Korea and evaluated its efficiency through case studies.

In the future, data on the technology and economic index should be collected in order to estimate economic potential and research on analysis of reliable data must be continuously performed to update this estimation.

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