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Investigating the Use of Energy Performance Indicators in Korean Industry Sector

Hong-Souk Shim[1,2], Sung-Joo Lee[2,3*]
[1]Building Energy Management Division, Korea Energy Agency,
[2]Department of Industrial Engineering, Ajou University,
[3]Department of Artificial Intelligence, Ajou University

한국 산업부문의 에너지성과 지표 이용에 관한 연구

심홍석[1,2], 이성주[2,3*]
[1]한국에너지공단 건물에너지실, [2]아주대학교 산업공학과, [3]아주대학교 인공지능학과

Abstract Energy management systems (EnMS) contribute to sustainable energy saving and greenhouse gas reduction by emphasizing the role of energy management in production-oriented economies. Although understanding the methods used to measure energy performance is a key factor in constructing successful EnMS, few attempts have been made to examine these methods, their applicability, and their utility in practice. To fill this research gap, this study aimed to deepen the understanding of energy performance measures by focusing on four energy performance indicators (EnPIs) proposed by ISO 50006, namely the measured energy value, ratio between measured values, linear regression model, and nonlinear regression model. This paper presents policy and managerial implications to facilitate the effective use of these measures. An analytic hierarchy process (AHP) analysis was conducted with 41 experts to analyze the preference for EnPIs and their key selection criteria by the industry sector, and organization and user type. The findings suggest that the most preferred EnPI is the ratio between the measured values followed by the measured energy value. The ease of use was considered to be most important while choosing EnPIs.

요 약 에너지경영시스템은 생산 중심으로 발전하는 한국의 경제구조에서 에너지경영의 역할을 강조하여 지속 가능한 에너지 절약 및 온실가스 감축에 기여하고 있다. 에너지 성과에 대한 측정 방법론을 이해하는 것은 기업이 성공적인 에너지경영시스템을 구축하는 데 핵심 요소이지만, 적용 방법론, 적용 가능성 및 실제 활용도를 조사하려는 시도는 국내에서 찾아보기 어렵다. 본 연구는 에너지경영시스템에 관한 국제표준인 ISO 50006에서 제안한 4가지 에너지 성과 지표(EnPI)인 ①측정 된 에너지 값, ②측정 된 값 간의 비율, ③ 선형 회귀 모델, ④ 비선형 회귀 모델에 초점을 맞추어 에너지 성과 측정에 대한 이해를 심화시키고, 효과적으로 확산시키기 위한 정책과 적정 관리 지표를 제시하는 것을 목표로 한다. 41명의 전문가들의 설문조사를 통해 수집된 데이터를 활용하여, EnPI에 대한 선호도와 산업 분류별, 조직규모, 전문가 유형별로 EnPI의 주요 선책 기준을 분석하였다. 연구 결과에 따르면 가장 선호되는 EnPI는 측정 된 값과 측정 된 에너지 값 사이의 비율이며 EnPI를 선택하는 기준은 사용 편의성이 가장 중요하다고 분석되었다.

Keywords : Energy Management System, EnMS, Energy Performance Indicator, EnPI, Industrial Energy Use

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*Corresponding Author : Sungjoo Lee(Ajou Univ.)
email: sungjoo@ajou.ac.kr
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1. Introduction

1.1 Background of Research

In the 21st UN Framework Convention on Climate Change Conference of the Parties (UN- FCCC COP21) held in Paris, France, 197 parties submitted Intended Nationally Determined Contributions (INDCs) to achieve voluntary greenhouse gas (GHG) reduction targets [1]. Among various sectors, the International Energy Agency reported that energy saving in the industrial sector can contribute significantly to the national GHG reduction; the in- dustrial sector accounted for 37% of the world's final energy consumption, followed by the transportation sector (29%) and residential sector (22%) [2]. However, it may also cause a slowdown in economic growth for countries relying heavily on energy-intensive industries (e.g., manufacturing) such as Republic of Korea (Korea). The key here is to consume energy more efficiently in such a country while ensuring that production is not affected negatively.

Korea is ranked eighth (2%) in the world's final energy consumption rankings, and sub- mitted its INDC, which aims at reducing GHG emissions by 37% when compared to business as usual (BAU) by 2030 and emphasizes making improvements in the energy efficiency of the industrial sector to meet this target [3]. The final energy consumption as of 2017 for Korea was 233,901 ton of oil equivalent (toe) with the industrial sector representing 61.7% [4], indicating that the industrial sector represents over 50% of the national energy consumption. CDIAC & GCP [5],[6] data show annual emissions of carbon dioxide (CO_2) by fuel, measured in tonnes. Globally, the share of CO_2 emission by oil was the highest in the early 2000s, but the share of CO_2 emission by coal has overtaken it since the mid-2000s.

Recently, notable contributions from gas, but solid and liquid fuels dominate yet. Cements and flares are relatively small. Contribution by types of fuels varies greatly over time, and there are also significant differences by region. In Korea, the contribution of cement is relatively high compared to other countries, which is a common feature of Asian countries. In addition, while the global co2 emissions from oil are gradually increasing, in Korea, the oil emissions are decreasing from 2000 to 2014, and from 2014 it is showing a tendency to decrease again. The Korean government established a national energy master plan with a target of reducing the final energy consumption by 13% by 2035 and of improving the energy intensity as of 2011 by 30%, where the dissemination of energy management system (EnMS) is a key policy to improve energy efficiency in the industrial sector [7].

1.2 EnMS in Korea

An EnMS is defined as "a set of elements that establish and implement energy policies, energy targets, and processes and procedures to achieve such targets"[4]. It contributes to sustainable energy saving and GHG reduction by adding the role of energy management to the production-oriented management activities of industries and by promoting improvements in energy efficiency [8]. To support the use of EnMS, the International Organization for Standards (ISO) has developed several standards. ISO 50001 is the inter-national standard for EnMSs. It outlines the requirements for an organization to adhere to while establishing systems and processes in order to improve energy performance (i.e., en- ergy efficiency, energy use, and energy consumption). On the contrary, ISO 50004 provides guidelines for systematic approaches to continuously improve energy performance [9]. ISO 50006 contributes to the spread of energy management as a part of organizational culture while providing guidelines on the establishment and use of the energy baseline (EnB) and energy performance indices (EnPIs) to measure changes in energy performance [9].

The Republic of Korea first implemented the ISO 50001 certification system in December 2012. And in May 2013, KS A ISO 50001, the first certification institution in Korea, was designated [10]. In 2016, LG Chemical's Ochang Plant was awarded the ISO 50001 by the seventh Clean Energy Ministerial(CEM7). The plant has achieved ISO 50001 certification, reducing energy consumption by 10% and reducing costs by $9 million. It will also help you achieve your national and international energy and greenhouse gas targets, including the Korean government's goal to reduce national carbon emissions by 30% by 2020 [11]. In addition, Samsung electronics, companies with North American, facilities adopting ISO 50001 yields greater, more cost-effective, and more sustainable energy savings than traditional energy efficiency program [12].

1.3 Purpose of Research

Despite all these efforts, however, energy managers in industries have encountered difficulties in introducing EnMS, particularly in determining suitable EnPIs for their organizations [13]. As organizations may have different production processes and constraints in the investment of energy management, the EnPIs available to them may vary. For example, without specific energy measurement equipment, energy consumption data may not be collected and as a result, some EnPIs may not be available. On the one hand, thus, organizational differences can be a barrier to the adoption of suitable EnPIs. The lack of technical understanding of methods to measure energy performance can be another barrier to the effective use of EnPIs [14]; the understanding of available methods and their use in practice is a key factor in attempting to construct a successful EnMS. Nevertheless, most previous studies have focused on proposing a desirable direction for EnMS [15] or on making a case for the implementation of an EnMS [16], while little effort has been made to investigate the current use of energy performance measures, which is essential for the development of a successful EnMS.

To overcome such limitations, this study aims to examine how different types of EnPIs have been adopted by industries with different characteristics, namely industry classifications, enterprise sizes, and user types. A survey for analytic hierarchy process (AHP) analysis was carried out with two groups of professionals, energy managers in industries, and energy management consultants who had participated in government EnMS dissemination programs. The survey asked about the awareness, the current use, and will-to-use of four types of EnPI, and the selection criteria that affect the preference of EnPIs. The findings can serve as a useful guideline for organizations in choosing suitable EnPIs, and can ultimately help facilitate the use of EnPIs by identifying factors that are most likely to affect their adoption. They can be used by energy managers to improve energy efficiency in order to achieve a reduction in GHG. They can also be used by policy makers to establish effective policy programs for the dissemination of sustainable EnMS.

The rest of this paper comprises four sections. Section 2 presents the background information for this study and Section 3 presents the research framework. Section 4 summarizes the results, and Section 5 discusses the implications of these results. Section 6 addresses the contributions and limitations of this study and proposes directions for future research.

2. Preliminary Considerations

2.1 Measuring Energy Performance

The energy management program is one of the most effective policies for the achievement of national energy targets for energy efficiency improvement and GHG reduction [8]. Energy efficiency policies and regulations such as energy efficiency measurement and EnPI management have played important roles in reducing global GHG emissions and are known as the most cost-effective approaches [2]. An analysis of recent literature on energy shows that research has been conducted largely on management, performance, and sustainability [17]. These three areas are key items in the ISO 50001 standard for the implementation of EnMS. In ISO 50001, EnMS is based on the continuous improvement system of Plan- Do-Check-Act [4]. Monitoring, measurement, and analysis in the Check process are the key items of EnMS and they act on energy performance measurement in the same context. Energy management refers to maintaining sustainability based on the measurement of energy performance.

In the ISO 50001 standard, energy performance is described as “measurable result(s) related to energy efficiency, energy use, and energy consumption[4].” To measure energy performance, which is at the core of EnMS, the boundaries of the measurement targets must be set first.

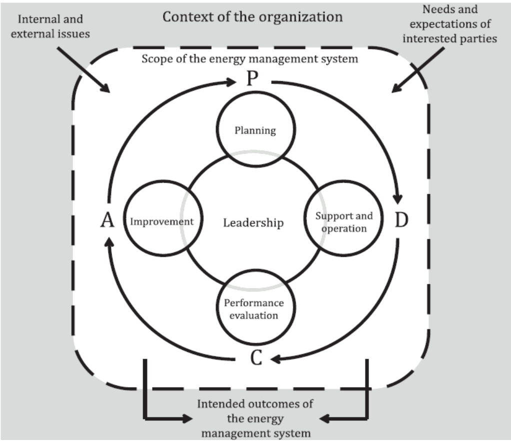

Fig. 1. EnMS Model(Source : ISO 50001)

A literature review indicates that the boundaries of the measurement targets have been classified into the macroscopic boundaries of country, region, and sector/industry, and the microscopic boundaries of enterprise, place of business, and process/system (see Table 1).

Table 1. Boundaries for energy performance measurement

Measurement target		Main approaches	References
Macroscopic boundary	Country	Energy intensity by national economic activity data	[18], [19]
	Region	Decomposition energy intensity by regional economic activity data	[19], [20]
	Sector/ industry	Decomposition energy intensity by sectoral economic activity data	[19], [21], [22], [23]
Microscopic boundary	Enterprise	Energy efficiency measurement by organizational economic and physical activity data	[24], [25], [26]
	Place of business	Energy efficiency measurement or absolute energy consumption by production volume data	[27], [28], [29]
	Process/ system	Energy efficiency measurement or specific energy consumption by thermodynamic and technology data	[24], [29], [30], [31], [32]

As seen in the Table 1, many studies have been conducted using the measurement indicators of the energy efficiency levels at various boundaries. The types of data to be collected as well as the approaches to analyze the data vary based on the level of the energy performance measurement boundary. At macroscopic boundaries, the measurement methodology is mainly referred to as energy intensity, and economic activity data by level are used. At microscopic boundaries, the measurement methodology is mainly referred to as energy efficiency, and measurement is carried out using physical/thermodynamic data.

2.2 Energy Performance Indicators

In ISO 50001, EnPI is defined as “measure of unit of energy performance, as defined by the organization” ([4] , page 5). EnPIs can be measured at the facility, system, process, or equipment level and must have an appropriate baseline at the same level for effective comparisons [9]. For the identification of EnPIs, an organization must understand its energy consumption characteristics such as variable loads caused by production, weather, or other factors and base loads (i.e., fixed energy consumption) [9]. Table 2 shows the types and characteristics of the EnPIs proposed by ISO 50006.

When the characteristics of each EnPI in Table 2 are linked with the approaches toward the measurement of energy performance in Table 1, the applicability of EnPIs for each approach can be summarized as seen in Table 3. The energy intensity in Table 1 can be replaced with the ratio of the measured energy value to the measured value in Table 2, and energy efficiency in Table 1 can be replaced with the ratio between measured values, statistical model, and engineering model in Table 2. In this study, EnPI types that were applicable to the enterprise/ place of business/process/system boundaries had to be selected by the energy managers. Among the four types of EnPIs, most previous studies have focused only on the three including the measured energy value, ratio between measured values, and statistical model, and they were applicable to most boundaries [27].

On the contrary, the engineering model is difficult to use in practice given that high costs and expertise are necessary for its application. Thus, it was excluded from our study. On the other hand, a statistical model was divided into two categories based on the degree of complexity - linear regression and nonlinear regression. As a result of this complexity in decision-making, there is a need for a systematic approach to select EnPIs that are suitable for organizational needs and constraints.

The use of AHP is one of the most frequently adopted approaches to support such decision-making. Originally developed by Professor Thomas L. Saaty, AHP is a multi-criteria decision-making tool [33]. It assigns priorities by comparing alternatives against several decision-making criteria and is considered a scientific and powerful decision-making tool [34]. Recognizing the value of AHP in organizing and analyzing complex decisions in the field of energy management, previous studies have also used the tool to introduce an energy indicator that is most

Table 2. Types and Characteristics of EnPIs (Source : ISO 50006)

EnPI type	Description	Case	Challenges
Measured energy value	Energy consumption of the entire place of business or one or more energy values measured by measuring instruments	Lighting energy consumption (kWh), Boiler fuel consumption (GJ), Peak period power consumption (kWh)	Wrong results can be provided because the influence of related variables is not considered.
Ratio between measured values	Expression of energy efficiency	kWh/production (ton), kWh/total floor area (m2),boilerefficiency(%),kWh/currencyaddedvalue,kWh/salesunit	Facilities with large base loads can be misunderstood because base loads and the effect of using nonlinear energy are not considered.
Statistical model	Relationships between the energy consumption that uses linear or nonlinear regression and related variables	Energy performance of a production facility with two or more production types, energy performance of a facility with base loads, energy performance of a hotel according to the variable room occupancy rate and outside temperature	Decision-making can be difficult for a model with multiple variable relationships and model production may take a long time.
Engineering model	Relationships between the energy consumption that uses engineering simulation and related variables	Industrial or power generation systems for which changes in related variables and their interactions can be explained through engineering calculation or simulation	The model requires continuous maintenance to ensure valid results.

appropriate for the organization. For example, [35] used AHP analysis to propose indicators for the evaluation of energy saving performance when a control system was operated to save the energy used in a building.

Table 3. Applicability of EnPIs by boundary

EnPI type	Measurement target boundary		
	Country, region, or sector	Enterprise or place of business	Process or system
Measured energy value	Applicable	Applicable	Applicable
Ratio between measured values	Applicable	Applicable	Applicable
Statistical model	Not applicable	Applicable	Applicable
Engineering model	Not applicable	Not applicable	Applicable

Sometimes, AHP was combined with decision-making tools. For example, [36] adopted Delphi-AHP (DHP) to create a qualitative and quantitative measurement system to select indicators to predict the energy efficiency of a building. Despite those efforts, most studies have focused on the EnPI of a single organization, while few have investigated the general preference of EnPIs across organizations in the industry. The purpose of this study is to examine the criteria considered in the selection of EnPIs as well as the most preferred EnPIs according to industry types, firm sizes, and users based on AHP analysis. Those involved in the survey for AHP analysis are experts with sufficient experience and knowledge in the field of EnMS to ensure the reliability of the analysis. The final goal is to propose guidelines for industries with different characteristics to choose the most suitable EnPIs, and to develop policies required for spreading sustainable EnMSs.

3. Research Framework

3.1 Overall Research Process

Figure 2 presents the overall research process. It consisted of three steps: identifying EnPI selection criteria, understanding the use of EnPI in practice, and analyzing EnPI preference based on the criteria identified. In the first step, a rich literature review focusing on the fields of the environment-, energy- and sustainability-related research was conducted to identify the factors that are likely to affect the selection of EnPIs (i.e., policy relevance, ease of use, measurability, and cost-effectiveness). In the second step, a survey was conducted to analyze the awareness,

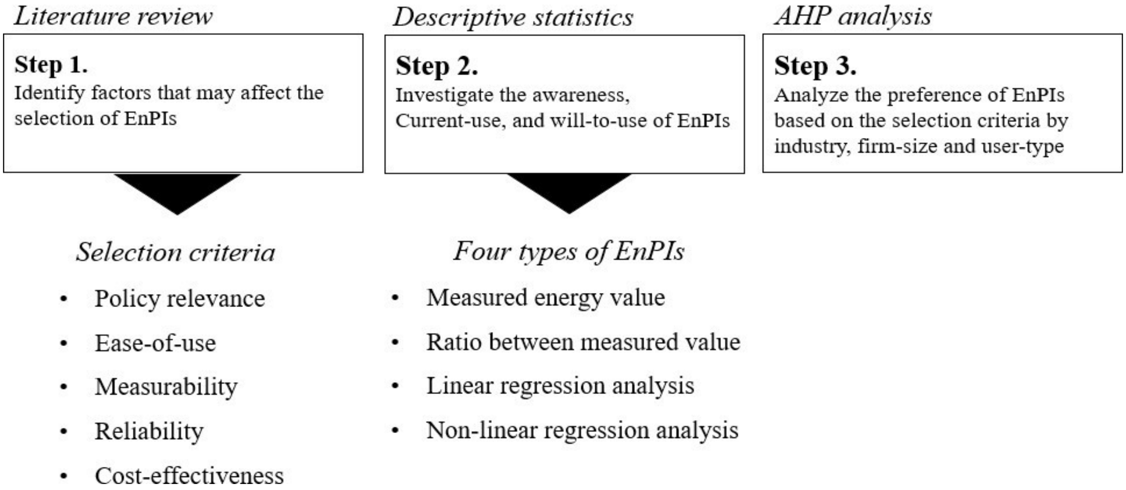

Fig. 2. Overall Reseach Process

current use, and will-to-use of four EnPIs (i.e., measured energy value, ratio between measured values, linear regression analysis, and nonlinear regression analysis) along with the reasons for the choices made. Finally, AHP analysis was performed to understand the preference for EnPIs and the factors that affect the preference.

3.2 Overall Research Process

The survey was designed to elicit sufficient information on the four types of EnPIs and the selection criteria. It was tested thoroughly with the support of an industry expert. Then, it was distributed to those who had been or were involved in the government policy program that facilitated the use of EnPIs. The data collection took approximately three months, from June to August 2018. A total of 44 responses were collected, of which 32 were from energy managers using EnMS and 12 were from energy consultants. The responses from three consultants were removed because of their limited experience in the field (less than 1 year). The survey was conducted by ECOSYAN, a professional service company for energy consulting.

The survey consisted of three sections. The first section asked for information to build the basic profiles of the respondents and their organizations. The second section collected information on the ranks of four EnPIs, namely the measured value, ratio between measured values, linear regression model, and non-regression model, with respect to the awareness, current use, and will-to-use. The respondents were also asked to provide a reason for their preferences pertaining to the current use by choosing one of the given criteria (policy relevance, ease of use, measurability, reliability, and cost-effectiveness). In the third section, pairwise comparisons were conducted to obtain the preference values of EnPIs and to deter- mine the weights of the criteria.

Given that the understanding of such EnPIs may vary by industry, firm, and individual characteristics, the relevant information was collected as well. First, one of the most commonly used sectors proposed Pavitt [37] was adopted to identify industry characteristics. We used the sectors defined by Kim [38] based on Pavitt [37] and customized them to suit Korea in this study. These sectors included supplier-dominated (SD), scale-intensive (SI), specialized-supplier (SS), and science-based (SB) sectors (see Appendix 1 for more details). Second, responding enterprises were classified into two types based on size: small and medium/large enterprises.

Table 4. Number of Respondents in each category

Industrial Classification		Enterprise Size		Respondent Type	
Suppler dominated	9 persons	Small enterprise	19 persons	Energy manager	32 persons
Scale-intensive	11 persons				
Specialized suppliers	12 persons	Medium/large enterprise	22 persons	Consultant	9 persons
Science-based	9 persons				

Finally, respondents were divided into two categories by user type: energy managers and energy consultants. The number of re- sponses in each category is presented in Table 4. Detailed information on the respondents is presented in Appendix 2.

3.3 Selection Criteria

The factors that may affect the selection of EnPIs were identified from the existing stud- ies. As EnPIs are a matter of interest in various research fields such as energy, environment, and sustainability, an extensive literature review was undertaken across the fields. Table 5 explains the results of the review.

Table 5. Factors that Affect the Selection of EnPIs and EnPI Selection Criteria's Definition

Research fields	Criteria	Reference
Environment	Policy relevance, informative, measurable, representative, practical	[39]
	Policy relevance, utility, soundness, interpretability, data availability and quality	[40]
	Robustness, relevance, effectiveness, clear and easy to measure, practicality	[41]
	Quantifiable, cost-effectiveness, calculable	[42]
	Policy relevance, utility for users, analytical soundness, measurability	[43]
Energy	Understanding, availability, relevance, measurability	[44]
	Purposeful/relevant, simple, normative, measurable, cost-effective, accurate	[45]
Sustainability	Relevance, practicality, reliability, independency, simplicity	[46]
	Link to planning goals, relevance, conceptual robustness, availability and quality of data, interpretative capacity, flexibility, costs	[47]

Criterion	Definition
Policy relevance	Ensure consistency with the targets of the energy/GHG-related regulations of the government.
Ease of use	Ensure user convenience, result analysis, and easy linkage with other indicators.
Measurability	Ensure transparency in the data collection process and periodic measurability.
Reliability	Ensure the accuracy of indicators and scientific verification.
Cost-effectiveness	Consider direct/indirect cost effects for indicator establishment, utilization, and improvement.

4. Results

4.1 Use of EnPI

The results indicated that the ratio between measured values was ranked highest by most respondents for all three perspectives, namely awareness, current use, and will-to-use in most cases (see Figure 3). The only exceptions included 1) the awareness, current use, and will-to-use for the specialized-supplier sector; and 2) the awareness and will-to-use for consultant user groups. For the former, the measured energy value was ranked as a top EnPI by most respondents (58%, 58% and 50% of the respondents for awareness, current use, and will-to-use, respectively). For the latter, a linear regression model was ranked highest by most respondents for consultant user groups in terms of awareness (44%) and will-to-use (98%). The consultants were more likely to apply a linear regression model than the ratio between measured values as shown by awareness and will-to-use.

When the survey results on the selection criteria for the highest ranked EnPI were examined, ease of use was found to be the most important in most cases particularly with respect to awareness and current use (see Figure 4). However, reliability seems to have a greater effect than the will-to-use as users are willing to adopt reliable EnPIs but are using those they are familiar with. Policy relevance seems to have a relatively weak impact on the selection of EnPIs. Specialized suppliers consider measurability as one of the most significant reasons for their current use and their will-to-use of EnPI. It seems that energy efficiency is difficult to measure and accordingly, measurability needs to be considered an essential condition in adopting the EnPIs. On the contrary, small enterprises tend to choose cost-effectiveness as the most important criterion in adopting their EnPIs.

Finally, reliability is the most important criterion in the selection of EnPIs followed by policy relevance for will-to-use and ease of use for current use. We contrast three perspectives that focus alternately on the EnPIs that are known to firms (awareness), the EnPIs that are actually used by firms (current use), and the EnPIs that are considered as desirable (will-to-use). We then argue that the differences in the key selection criteria from the three perspectives indicates a gap between the ideal and the reality. The greater the difference is, the larger is the gap.

Category			Measured energy value	Ratio between measured values	Linear regression model	Nonlinear regression model	Total
Awareness	Integrated		29.3%	58.5%	9.8%	2.4%	100.0%
	Industrial classification	SD	11.1%	66.7%	11.1%	11.1%	100.0%
		SI	27.3%	63.6%	9.1%	0.0%	100.0%
		SS	58.3%	41.7%	0.0%	0.0%	100.0%
		SB	11.1%	66.7%	22.2%	0.0%	100.0%
	Enterprise size	SE	42.1%	57.9%	0.0%	0.0%	100.0%
		M/LE	18.2%	59.1%	18.2%	4.5%	100.0%
	Respondent type	Energy manager	37.5%	62.5%	0.0%	0.0%	100.0%
		Consultant	0.0%	44.4%	44.4%	11.1%	100.0%
Current use	Integrated		26.8%	65.9%	7.3%	0.0%	100.0%
	Industrial classification	SD	11.1%	77.8%	11.1%	0.0%	100.0%
		SI	18.2%	81.8%	0.0%	0.0%	100.0%
		SS	58.3%	41.7%	0.0%	0.0%	100.0%
		SB	11.1%	66.7%	22.2%	0.0%	100.0%
	Enterprise size	SE	36.8%	63.2%	0.0%	0.0%	100.0%
		M/LE	18.2%	68.2%	13.6%	0.0%	100.0%
	Respondent type	Energy manager	34.4%	65.6%	0.0%	0.0%	100.0%
		Consultant	0.0%	66.7%	33.3%	0.0%	100.0%
Will-to-use	Integrated		17.1%	58.5%	22.0%	2.4%	100.0%
	Industrial classification	SD	11.1%	55.6%	33.3%	0.0%	100.0%
		SI	0.0%	72.7%	27.3%	0.0%	100.0%
		SS	50.0%	50.0%	0.0%	0.0%	100.0%
		SB	0.0%	55.6%	33.3%	11.1%	100.0%
	Enterprise size	SE	31.6%	68.4%	0.0%	0.0%	100.0%
		M/LE	4.5%	50.0%	40.9%	4.5%	100.0%
	Respondent type	Energy manager	21.9%	71.9%	3.1%	3.1%	100.0%
		Consultant	0.0%	11.1%	88.9%	0.0%	100.0%

Fig. 3. Top-ranked EnPIs by industrial classification, enterprise size, and respondent type

Category			Policy relevance	Ease of use	Measurability	Reliability	Cost-effectiveness	Total
Awareness	Industrial classification	SD	0%	44%	0%	22%	33%	100%
		SI	9%	45%	27%	18%	0%	100%
		SS	8%	33%	33%	17%	8%	100%
		SB	22%	44%	0%	22%	11%	100%
	Enterprise size	SE	5%	32%	26%	11%	26%	100%
		M/LE	14%	50%	9%	27%	0%	100%
	Respondent type	Energy manager	6%	44%	22%	13%	16%	100%
		Consultant	22%	33%	0%	44%	0%	100%
Current Use	Industrial classification	SD	0%	44%	11%	11%	33%	100%
		SI	0%	45%	27%	18%	9%	100%
		SS	8%	25%	42%	17%	8%	100%
		SB	22%	33%	11%	22%	11%	100%
	Enterprise size	SE	5%	26%	26%	11%	32%	100%
		M/LE	9%	45%	23%	23%	0%	100%
	Respondent type	Energy manager	6%	34%	28%	13%	19%	100%
		Consultant	11%	44%	11%	33%	0%	100%
Will-to-use	Industrial classification	SD	11%	22%	11%	11%	44%	100%
		SI	9%	27%	27%	27%	9%	100%
		SS	8%	25%	42%	17%	8%	100%
		SB	0%	33%	11%	44%	11%	100%
	Enterprise size	SE	5%	26%	21%	11%	37%	100%
		M/LE	9%	27%	27%	36%	0%	100%
	Respondent type	Energy manager	3%	31%	28%	16%	22%	100%
		Consultant	22%	11%	11%	56%	0%	100%

Fig. 4. Criteria considered for the selection of the top-ranked EnPI

4.2 Preference of EnPI

AHP analysis was performed to analyze the preference of EnPIs based on the five selection criteria (policy relevance, ease of use, measurability, reliability, and cost- effectiveness), assuming that the three perspectives will be used together to prioritize EnPIs. To ensure the reliability of the results by avoiding inconsistent responses, the consistency ratio value was calculated for each respondent where 10% of the cut-off value was applied to exclude inconsistent responses (see Appendix 3). Figure 5 summarizes the results. It shows that the ratio between measured values was the most preferred EnPI, followed by the measured energy value.

While focusing on the industry differences, the supplier-dominated sector was found to prefer the ratio between measured values the most with respect to all the selection criteria except measurability. The measured energy value seems capable of obtaining measurement values more easily than the ratio between measured value. Scale-intensive sector was found to prefer the ratio between measured values the most because of the advantages in policy relevance, ease of use, and reliability, whereas the measured energy value was preferred most for measurability and cost-effectiveness. Unlike the other three sectors, specialized suppliers were found to prefer the measured energy value as to the all selection criteria but reliability; they regarded the ratio between measured values more reliable than the others. It seems that this sector had to adopt a less reliable EnPI because of the constraints in its industry characteristics. Science-based was found to prefer the ratio between measured values in all the selection criteria.

Second, the firm size seems to affect the preference for EnPIs. Small enterprises preferred the ratio between measured values because of the advantages in policy relevance, ease of use, and reliability, and preferred measured energy value in terms of measurability and cost-effectiveness. The measured energy value is easy to measure and less expensive to apply. Larger firms were less affected by measurability and cost in their selection of EnPIs and accordingly, they were found to prefer the ratio between measured values most for all five selection criteria. Medium and larger enterprises gave more weight to regression models (both linear and nonlinear) than small enterprises in terms of policy relevance and reliability, which indicates that they can be more easily affected by policy programs and are ready to adopt more complicated but reliable approaches. The complexities in the production systems in larger enterprises encouraged them to adopt more sophisticated approaches to produce more reliability energy efficiency values.

Finally, in terms of user type, the differences in the users led to interesting results. Energy managers in practice were found to prefer the ratio between measured values in all selection criteria but measurability. The measured energy value is easy to obtain in practice. However, the lower preference for measured energy value was observed more among consultants than among energy managers. The weights given by consultants on regression models (both linear and nonlinear) were noticeable.

Although they preferred the ratio between measured values in most of the selection criteria, they claimed that the linear regression model is the most reliable EnPI, followed by the nonlinear regression model and the ratio between the measured values and measured energy value. Another finding worth discussing is that the preference of the ratio between the measured value and the linear regression model from the perspectives of cost-effectiveness showed only a small gap with 0.311 for the former and 0.295 for the latter. This shows the possibilities that once the approach is established well in the firm with the support of external experts, it may cost less than expected by energy managers.

Category				Measured energy value	Ratio between measured values	Linear regression model	Non-linear regression model
Integrated				0.326(2)	0.374(1)	0.153(3)	0.147(4)
Industrial classification	SD		1.000	0.282	0.366	0.182	0.171
		Policy relevance	0.092	0.241	0.391	0.203	0.165
		Ease-of-use	0.188	0.281	0.426	0.167	0.126
		Measurability	0.254	0.370	0.345	0.131	0.154
		Reliability	0.271	0.242	0.282	0.253	0.223
		Cost-effectiveness	0.195	0.229	0.370	0.211	0.190
	SI		1.000	0.307	0.366	0.166	0.161
		Policy relevance	0.145	0.280	0.377	0.194	0.149
		Ease-of-use	0.237	0.327	0.390	0.164	0.119
		Measurability	0.229	0.381	0.330	0.162	0.127
		Reliability	0.240	0.245	0.363	0.224	0.167
		Cost-effectiveness	0.149	0.355	0.328	0.178	0.140
	SS		1.000	0.382	0.356	0.131	0.13
		Policy relevance	0.106	0.363	0.354	0.155	0.128
		Ease-of-use	0.256	0.397	0.344	0.142	0.117
		Measurability	0.214	0.405	0.336	0.131	0.128
		Reliability	0.219	0.342	0.344	0.163	0.151
		Cost-effectiveness	0.205	0.367	0.354	0.150	0.129
	SB		1.000	0.314	0.426	0.133	0.128
		Policy relevance	0.053	0.208	0.383	0.242	0.167
		Ease-of-use	0.224	0.315	0.418	0.178	0.088
		Measurability	0.194	0.301	0.368	0.204	0.127
		Reliability	0.294	0.207	0.316	0.281	0.196
		Cost-effectiveness	0.234	0.234	0.385	0.228	0.157
Enterprise size	SE		1.000	0.363	0.369	0.135	0.133
		Policy relevance	0.105	0.353	0.403	0.125	0.119
		Ease-of-use	0.205	0.380	0.402	0.115	0.103
		Measurability	0.234	0.415	0.340	0.123	0.122
		Reliability	0.236	0.331	0.354	0.174	0.141
		Cost-effectiveness	0.221	0.373	0.366	0.135	0.126
	M/LE		1.000	0.291	0.378	0.170	0.161
		Policy relevance	0.099	0.226	0.360	0.245	0.169
		Ease-of-use	0.244	0.308	0.382	0.194	0.116
		Measurability	0.213	0.333	0.349	0.180	0.138
		Reliability	0.275	0.210	0.311	0.267	0.212
		Cost-effectiveness	0.169	0.245	0.361	0.224	0.170
Respondent type	Energy manager		1.000	0.348	0.386	0.134	0.133
		Policy relevance	0.104	0.325	0.390	0.158	0.127
		Ease-of-use	0.237	0.362	0.394	0.138	0.106
		Measurability	0.221	0.388	0.353	0.138	0.121
		Reliability	0.243	0.299	0.354	0.203	0.153
		Cost-effectiveness	0.194	0.345	0.377	0.154	0.124
	Consultant		1.000	0.233	0.326	0.232	0.209
		Policy relevance	0.086	0.112	0.351	0.318	0.219
		Ease-of-use	0.189	0.242	0.383	0.244	0.131
		Measurability	0.222	0.315	0.318	0.206	0.160
		Reliability	0.297	0.170	0.246	0.314	0.270
		Cost-effectiveness	0.206	0.149	0.311	0.295	0.245

Fig. 5. EnPI preferences

5. Discussion

The energy management policies of Korea and developed countries with advanced industrial sectors have mandatory management systems and voluntary participation programs, and the target achievement of each place of business is evaluated using EnPIs. In Korea, energy management is induced for industries using measured energy value, the ratio between measured values, and linear regression analysis, and more diversified EnPIs are being applied to policies in Germany, the United States, and Japan (see Table 6).

The results for the manufacturing sector in Korea, where various EnPIs are applied to energy management policies, are presented in Table 7. For most sectors, the ratio be- tween measured values was the most important, followed by the measured energy value, and linear regression model. The AHP analysis results also showed the same order of prefer- ences. The linear regression model was ranked second in the will-to-use survey results. The AHP analysis results of specialized suppliers in the industrial classification showed that the measured energy value was preferred most. In terms of respondent type, energy managers exhibited similar preferences for the ratio between measured values and the measured energy value while

Table 6. Applicability of EnPIs by boundary

Country	Policy program	Participation	Management	EnPI
Korea	Emissions trading	Mandatory	GHG emissions allocation	Measured energy value
	Energy champion certification	Voluntary	Energy intensity	Ratio between measured values
Germany	Emissions trading	Mandatory	Linear regression model	Linear regression model
	Voluntary agreement	Voluntary	GHG emissions allocation	Measured energy value
USA	Better Plant	Voluntary	Energy intensity	Ratio between measured values
	Superior Energy Performance	Voluntary	Energy intensity	Ratio between measured values
Japan	Energy rating system	Mandatory	Linear regression model	Linear regression model

Table 7. Applicability of EnPIs by Boundary

Category		Measured Energy value	Ratio Between Measured Values	Linear Regression Model	Nonlinear Regression Model
Top ranking	Awareness	29%	59%	10%	2%
	Current use	27%	66%	7%	0%
	Will-to-use	17%	59%	22%	2%
AHP analysis	Integrated	0.326	0.374	0.153	0.147
Industrial classification	SD	0.282	0.365	0.182	0.171
	SI	0.307	0.366	0.166	0.161
	SS	0.382	0.357	0.131	0.130
	SB	0.314	0.425	0.133	0.128
Enterprise size	Small Enterprise	0.363	0.369	0.135	0.133

consultants showed similar preferences for the measured energy value, which was ranked second, and the linear regression model. The nonlinear regression model also showed a relatively high preference value for consultants.

It was found that industries generally consider ease of use in the highest propor- tion when they select EnPIs, and that specialized suppliers, small enterprises, and energy managers also consider measurability in high proportions. Supplier-dominated and small enterprises consider cost-effectiveness. The ratio between measured values and the mea- sured energy value are the easiest to use and some classifications judge that they are highly measurable and cost-effective. The ratio of measured values to the measured energy value is relatively easy to use because it can be evaluated using only the data by year during the energy performance evaluation and its measurability and cost-effectiveness are also excellent because the currently measured and retained data are utilized. The ratio between measured values is preferred over the measured energy value because changes in production by year can be reflected and energy performance can be evaluated in a more reliable manner.

From the characteristics of each EnPI type in ISO 50006 (see Table 2), it is clear that the most suitable EnPI for manufacturing is the linear regression model. This is because manufacturing is affected by various related variables such as raw materials for production, weather, and facility efficiency, and it consumes energy while producing products. Manu- facturing has base loads that consume a certain amount of energy because it also consumes energy in utility facilities, offices, laboratories, and dormitories other than product production and even in the production activity preparation course after holidays or interrupted production for maintenance.

6. Conclusion and Policy Implications

In this study, the selection criteria for EnPIs were derived by investigating studies on the environment, energy, and sustainability. The preferences for EnPIs in each classification were derived through AHP analysis after conducting a survey on EnPI awareness, current use, and will-to-use as well as pairwise comparisons of EnPI types with EnMS experts. The results of this study can be summarized as follows.

EnMS experts selected the ratio between measured values as the first ranking with the highest proportions in all areas 59% for awareness, 66% for current use, and 59% for will-to-use. In the detailed classifications, the survey on current use showed that the proportion of the measured energy value (58%) was higher than that of the ratio between measured values (42%) for specialized suppliers in the industrial classification, and the survey on the will-to-use showed that the consultants chose the will-to-use for the linear regression model at an 89% proportion in the respondent type classification.

The results on the selection criteria showed that ease of use was chosen as the most important criterion in most of the classifications when the top-ranked EnPI was selected for awareness and current use. When the top-ranked EnPI was selected for will-to-use, however, specialized suppliers in the industrial classification chose measurability while science-based suppliers chose reliability as the most important criterion. Small enterprises chose cost- effectiveness while medium and large enterprises chose reliability as the most important criterion. Consultants (under the respondent type classification) chose reliability as the most important criterion.

The AHP analysis results through pairwise comparisons revealed that the ratio between measured values (0.374) was the most preferred, followed by the measured energy value (0.326), linear regression model (0.153), and nonlinear regression model (0.147). When each classification was analyzed, there were some singularities. The measured energy value (0.382) was higher than the ratio between measured values (0.357) for specialized suppliers. Small enterprises showed similar preferences for the ratio between measured values (0.369) and the measured energy value (0.363). Consultants exhibited similar preferences for the measured energy value (0.233) and the linear regression model (0.232) while selecting the second EnPI.

The findings indicate that the government and enterprises play a role in disseminating EnMS that utilize EnPIs that are most suitable for industries. The government needs to support the installation of digital measuring instruments so that more variables can be measured and utilized in the field. It will also be necessary for the government to develop tools that are capable of conducting linear regression analysis more easily and to distribute these tools at no cost. The results of the survey with consultants in Figure 3 show that the will-to-use for the linear regression model is very high (89%), but the actual current use is low (33%). This is because the cost of consulting that utilizes the linear regression model is high and industries choose the ratio between the measured values that is relatively easy. Enterprises need to use EnPIs as department evaluation indicators by actively introducing EnMS that utilize EnPIs, and should participate in the projects supported by the government in a positive manner.

Finally, consulting companies need to improve the capabilities of their consultants through periodic training and create business models in which proper EnPIs can be applied to manufacturing. They also need to maintain consulting costs that do not act as a burden on industries by actively relying on the support of the governmen. The suggestion of this study to help understand how the roles required to supplement the shortcomings between government manufacturing enterprises and consulting companies is Table 8.

Table 8. Roles of the government, enterprises, consulting companies

Government	Manufacturing enterprises	Consulting companies
Support instruments for digital measurement, develop linear regression model analysis tools and distribute them at no cost, and support consulting	Use EnPIs as department evaluation indicators, receive EnMS certification, and actively utilize projects supported by the government	Reinforce the capabilities of consultants, discover business models that use EnPIs, and actively utilize projects supported by the government

Research that identifies the EnPI types and characteristics suggested by ISO 50006 and compares results using the data of actual manufacturing enterprises is necessary in order to explain EnPIs that are suitable for manufacturing in practice. Future research can aim to derive the energy performance results for each EnPI type and analyze the differences using data from industries that engage with the energy management policies of the government.

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심 홍 석(Hong-Souk Shim) [정회원]

- 2008년 2월 : 아주대학교 생명분자공학부 응용화학전공 (공학사)
- 2010년 2월 : 아주대학교 일반대학원 에너지학과 (경제학석사)
- 2017년 2월 : 아주대학교 일반대학원 산업공학과 (박사수료)
- 2010년 3월 ~ 현재 : 한국에너지공단 과장

〈관심분야〉
에너지 수요관리, 4차산업, 스마트시티

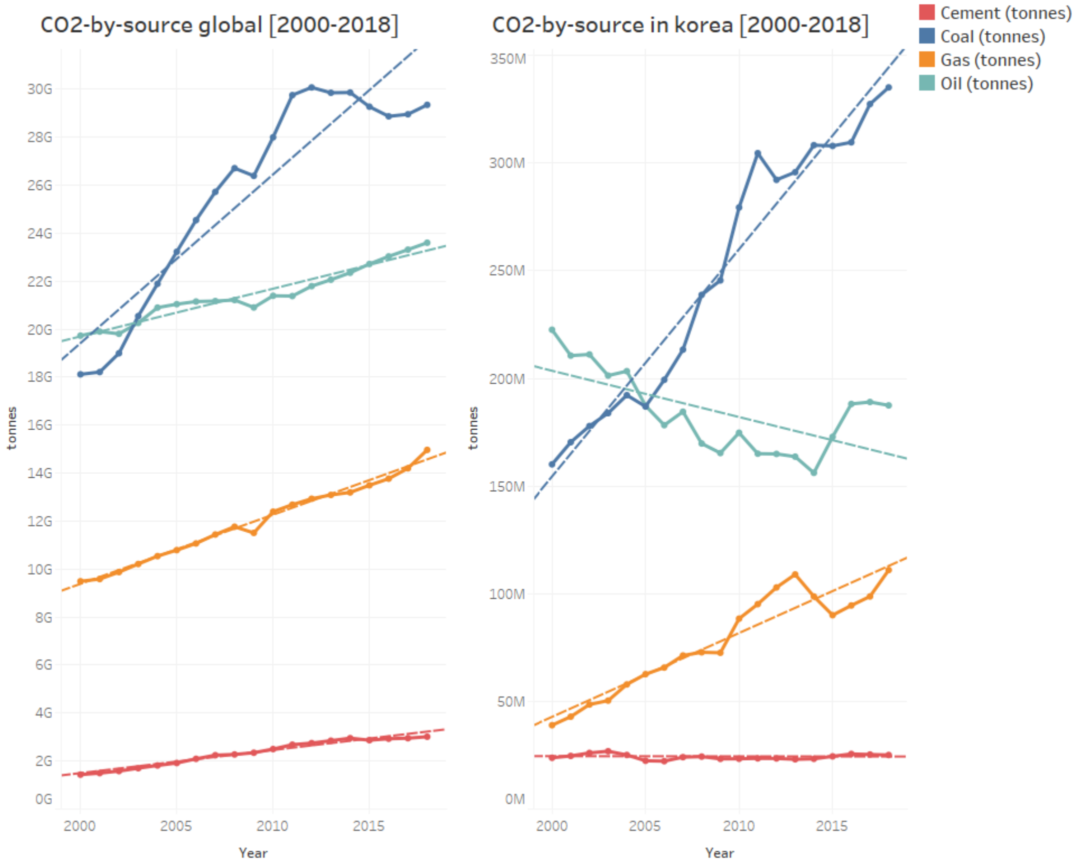
이 성 주(Sungjoo Lee) [정회원]

- 2002년 2월 : 서울대학교 산업공학과 (공학사)
- 2007년 8월 : 서울대학교 일반대학원 산업공학과 (공학박사)
- 2008년 1월 ~ 2008년 12월 : 영국 캠브리지대 방문연구원
- 2009년 3월 ~ 현재 : 아주대학교 산업공과 교수

〈관심분야〉
기술로드맵, 전략기획, 에너지기술정책

APPENDIX 1

〈 Annual Emissions of Carbon Dioxide (CO_2) by Fuel, Measured in tonnes 〉



APPENDIX 2

Supplier-dominated industries were classified into food and beverage (D15), textile (D17), clothing and fur (D18), leather shoes (D19), paper (D21), refined petroleum (D23), furniture (D36), and processed raw materials (D37).

Scale-intensive industries were classified into wood (D20), printing (D22), rubber and plastic products (D25), nonmetallic minerals (D26), primary metals (D27), automobiles and trailers (D34), and other transport equipment (D35).

Specialized-supplier industries were classified into mechanical equipment (D29), other electricity (D31), and assembled metal products (D28).

Finally, science-based industries were classified into chemistry (D24), machinery for office calculating and accounting (D30), visual and acoustic communication (D32), and medical precision optics (D33).

APPENDIX 3

〈 Information of Respondents 〉

Respondent	Industrial classification	Enterprise size	Respondent type	Gender	Career year in Energy Field
1	SS	Small	Energy Manager	Male	10
2	SS	Medium	Energy Manager	Male	17
3	SS	Medium	Energy Manager	Male	13
4	SS	Medium	Energy Manager	Male	11
5	SS	Small	Energy Manager	Male	12
6	SS	Small	Energy Manager	Male	18
7	SS	Small	Energy Manager	Male	18
8	SS	Medium	Energy Manager	Male	7
9	SS	Small	Energy Manager	Male	5
10	SS	Small	Energy Manager	Male	20
11	SS	Small	Energy Manager	Male	5
12	SS	Small	Energy Manager	Male	5
13	SD	Small	Energy Manager	Male	7
14	SD	Small	Energy Manager	Male	22
15	SD	Small	Energy Manager	Male	5
16	SD	Small	Energy Manager	Male	25
17	SD	Small	Energy Manager	Male	20
18	SD	Medium	Consultant	Male	9
19	SD	Medium	Consultant	Male	3
20	SD	Medium	Consultant	Male	8
21	SD	Small	Energy Manager	Male	3
22	SI	Small	Energy Manager	Male	3
23	SI	Medium	Energy Manager	Male	3
24	SI	Medium	Energy Manager	Male	25
25	SI	Medium	Energy Manager	Male	11
26	SI	Small	Energy Manager	Male	11
27	SI	Medium	Energy Manager	Male	7
28	SI	Small	Energy Manager	Male	10
29	SI	Small	Energy Manager	Male	20
30	SI	Medium	Energy Manager	Male	6
31	SI	Medium	Consultant	Male	5
32	SI	Medium	Consultant	Male	5
33	SB	Small	Energy Manager	Male	10
34	SB	Medium	Energy Manager	Male	7
35	SB	Medium	Energy Manager	Male	3
36	SB	Large	Energy Manager	Male	5
37	SB	Large	Energy Manager	Male	6
38	SB	Medium	Consultant	Female	5
39	SB	Medium	Consultant	Male	9
40	SB	Medium	Consultant	Male	8
41	SB	Medium	Consultant	Male	8

APPENDIX 4

〈 Consistency Ratio by Respondents 〉

Respondent	Policy relevance	Ease of use	Measurability	Reliability	Cost-effectiveness
1	0.76%	2.24%	16.61%	11.93%	5.71%
2	5.72%	11.52%	9.20%	13.36%	4.41%
3	2.25%	2.25%	8.72%	10.57%	5.71%
4	5.73%	11.95%	16.61%	11.93%	2.25%
5	30.70%	30.70%	30.70%	30.70%	30.70%
6	1.70%	2.25%	2.25%	2.25%	2.25%
7	2.25%	10.57%	2.25%	0.76%	2.25%
8	5.72%	11.52%	9.20%	13.36%	4.41%
9	9.29%	5.72%	5.71%	5.71%	9.29%
10	5.71%	5.75%	5.71%	2.25%	5.71%
11	0.76%	4.39%	2.25%	0.76%	2.25%
12	9.29%	9.29%	5.71%	5.71%	9.27%
13	9.29%	9.29%	5.71%	5.71%	9.27%
14	5.75%	0.76%	8.72%	10.57%	5.71%
15	5.71%	5.71%	5.71%	5.71%	5.71%
16	5.71%	5.71%	5.71%	5.71%	2.24%
17	12.82%	12.82%	12.82%	12.82%	12.82%
18	30.70%	5.71%	2.24%	5.71%	18.30%
19	2.24%	2.24%	2.24%	2.24%	2.24%
20	22.61%	18.47%	24.34%	12.39%	5.78%
21	5.72%	5.72%	0.00%	5.71%	0.00%
22	2.25%	2.25%	2.26%	2.25%	2.25%
23	4.64%	2.24%	4.39%	16.66%	1.70%
24	11.11%	12.82%	0.00%	3.97%	9.27%
25	5.75%	5.75%	5.75%	5.75%	5.75%
26	0.00%	2.25%	3.08%	9.29%	2.25%
27	9.29%	9.29%	9.29%	5.72%	4.37%
28	5.71%	5.71%	5.71%	5.71%	5.71%
29	5.75%	5.75%	5.75%	3.10%	5.75%
30	11.20%	11.20%	9.37%	11.23%	11.23%
31	39.86%	6.47%	3.66%	48.53%	34.66%
32	16.54%	0.00%	2.24%	7.89%	5.73%
33	6.97%	0.76%	0.00%	2.26%	0.00%
34	4.68%	2.24%	2.47%	7.15%	0.38%
35	5.80%	9.27%	12.06%	2.26%	11.95%
36	11.11%	7.66%	8.70%	4.40%	20.14%
37	2.25%	3.26%	11.23%	6.95%	1.70%
38	27.78%	37.23%	44.30%	14.07%	28.51%
39	10.83%	8.97%	18.06%	4.42%	5.86%
40	27.79%	41.06%	14.60%	14.60%	25.65%
41	2.24%	2.24%	2.24%	2.24%	2.24%