The Mutual Effect of Carbon Pricing and KOC Potential using Multi Criteria Decision Making Model

Insik Yu

February 2017

Cooperative Course for Climate Change
The Graduate School
Sejong University

The Mutual Effect of Carbon Pricing and KOC Potential using Multi Criteria Decision Making Model

Insik Yu

A dissertation submitted to the Faculty of the Sejong University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering

February 2017

Approved by Euichan Jeon, Advisor

The Mutual Effect of Carbon Pricing and KOC Potential using Multi Criteria Decision Making Model

by

Insik Yu

Approved --
Wisup Bae, Chair of the committee

Approved --
Jungin Kim, Member of dissertation committee

Approved --
Sungwook Lee, Member of dissertation committee

Approved --
Sungwoo Kim, Member of dissertation committee

Approved --
Euichan Jeon, Advisor

Abstract

Korea Emission Trading Scheme (K-ETS) is important for the government to gain policy legitimacy in the international community through achievement of Intended Nationally Determined Contribution (INDC). In addition, the success of K-ETS is also significant in achieving actual target of GreenHouse Gas (GHG) emission reduction in Korea. However, K-ETS has not been properly operating since the start of the scheme. The domestic Korea Offset Credit (KOC) supply is the solution of short statement at the K-ETS.

The purpose of study is to estimate KOC supply potential and analysis of mutual effect of carbon pricing and KOC potential using Multi Criteria Decision Making (MCDM) and LEAP Modelling.

The amount of GHG emission reduction potential through high efficient lighting equipments replacement is 2,548.7KtCO_2eq at 2017, 7,168.9KtCO_2eq at 2020 and 27,911.4KtCO_2eq at 2030. But, the KOC potential compared to the amount of total GHG emission reduction is 6.7% at the carbon price of 5,000 won, 12.7% at 10,000 won, 19.2% at 30,000 won and 26.2% at 100,000 won.

Net ratio (+0.79) of Korea Allowance Unit (KAU) with Market Stability Reserve (MSR) and Early Action Credits (EAC) is higher than +0.6 include the evidence of over-allocation in much stronger like EU-ETS.

The amount of domestic KOC potential is small but it would have significant impact on the carbon market in terms of providing carbon credits continuously in the market. Policy support needs for increasing the potential KOC which will have significant affect the soft landing of K-ETS. Business support on project must be done through financial support programs designed to invest on GHG reduction projects. And additional measures regarding administration support are required to increase of KOC potential.

Keywords: Emission Trading, MCDM, LEAP, KOC, KAU

국문초록

다기준의사결정모형을 통한 상쇄배출권 공급잠재량과 탄소배출권 가격의 상호영향 연구

세종대학교 대학원
기후변화협동과정 기후변화공학 전공
유 인 식

배출권거래제도는 국가감축기여방안(INDC; Intended Nationally Determined Contributions) 달성을 위한 온실가스 감축의 중요 정책수단 중 하나이다. 그러나 배출권거래제 시행 이후 다수의 할당기업이 이의신청과 행정소송을 제기하고, 매수가능 배출권의 부족과 배출권거래제 운영부처의 변경 등으로 현재까지 제대로 정착되지 못하고 있다. 시장전문가들은 매수가능 배출권의 부족문제를 현 배출권거래제의 가장 큰 문제점으로 지적하고 있다. 배출권 매도물량을 확대하는 방안 중 하나가 상쇄배출권의 공급이다. 상쇄배출권을 효율적으로 공급하기 위한 제도 설계 및 운영에 있어서 탄소배출권 가격에 따른 상쇄배출권 공급량을 파악하고, 상쇄배출권 공급량이 탄소시장에 미치는 영향을 파악하는 것이 제도 설계 및 운영에 있어 중요하다. 그러나 현재까지 국내에는 이와 관련된 연구가 거의 없어 정부의 정책수립과 기업의 대응에 어려움이 있다.

본 연구에서는 상쇄배출권 공급잠재량의 추정방법론을 개발하고, 이를 이용하여 온실가스감축사업의 상쇄배출권 공급잠재량을 도출한 후, 상쇄배출권 공급잠재량이 탄소시장에 미치는 영향을 분석하였다. 분석 결과를 바탕으로, 배출권거래제도 발전을 위한 정책제언을 하고자 하였다. 본 연구에서는 산업 및 상업부문 고효율조명 교체를 통한 온실가스 감축사업을 대상으로 하였다. 온실가스 배출량 및 감축잠재량, KOC(Korea Offset Credit) 공급잠재량은 상향식 분석 모델인 LEAP(Long Range

Energy Alternative Planning)을 이용하여 추정하였다. 대안시나리오 분석에는 다기준의사결정모형(MCDM; Multi Criteria Decision Making) 중 계층화분석법(AHP; Analytic Hierarchy Process)을 사용하였다. AHP분석을 위해 중소기업 대상 설문조사를 수행하였다. 배출권거래시장에서 배출권 매매 가격 변화에 따른 KOC 공급잠재량 변화를 추정하기 위해서 배출권 가격이 5,000원, 10,000원, 30,000원, 100,000원으로 가정하고, 전문 컨설팅사와 검증기관의 계약담당자를 대상으로 인터뷰를 진행하여 컨설팅과 검증비용을 파악하였다.

MCDM 모델링 결과, 기존 메탈할라이드 조명을 LED · 고효율메탈할라이드 · 무전극램프로 교체할 경우의 교체율은 각각 51% · 24.4% · 24.4%였다. LEAP 모델링을 통한 조명부문 온실가스 예상배출량은 2017년 32,127.3KtCO_2eq, 2020년 34,359.6KtCO_2eq, 2030년 41,777.1KtCO_2eq 였고, 고효율조명 교체를 통한 온실가스 감축잠재량은 2017년 2,548.7KtCO_2eq, 2020년 7,168.9KtCO_2eq, 2030년 27,911.4KtCO_2eq로 추정되었다.

전기요금 인상이 고효율조명 교체에 미치는 영향과 온실가스 배출량의 변화특성을 분석하였는데, 전기요금을 10%, 50%, 100% 인상할 경우. 온실가스 배출량은 2020년 기준 각각 4.6%, 20%, 35% 감소할 것으로 나타났다. 배출권 가격이 5,000원, 10,000원, 30,000원, 100,000원일 경우의 KOC 공급잠재량은 2030년 기준으로 각각 1,909.1KtCO_2eq, 3,591.7KtCO_2eq, 5,437.2KtCO_2eq, 7,427.3KtCO_2eq으로 추정되었는데, 이것은 온실가스 감축잠재량 대비 각각 6.7%, 12.7%, 19.2%, 26.2%에 해당하는 량이다. 배출권 가격이 오를수록 KOC 공급잠재량은 증가하지만 상승률은 점차 하락한다. 고효율조명 기술의 향상과 단가 하락으로 고효율조명 교체속도가 10년 단축된다고 가정하면, 배출권 가격이 각각 5,000원, 10,000원, 30,000원, 100,000원일 경우, KOC 공급잠재량은 2020년 기준으로 각각 1,909.1KtCO_2eq, 3,591.7KtCO_2eq, 5,437.2KtCO_2eq, 7,427.3KtCO_2eq으로 급증하였다.

모델링에 의한 KOC 공급잠재량과 탄소배출권 가격의 상호영향을 분석한 결과, KOC 공급이 배출권거래시장 가격에 즉각적인 변화와 거래참여자 매매심리에 영향을 주며, 배출권 가격 변동은 KOC 공급잠재량에 변화를 주는 유의미한 영향관계임을 알 수 있었다. 배출권거래제를 제일 먼저

도입하고 운영 중인 유럽연합 배출권거래제에서는 순공급과잉비중(Net long ratio)을 활용하여 시장의 수요공급 환경을 판단하고 있는데, 그 값이 0.6 이상일 경우 과대할당 상황으로 평가하고 있다. 현재 한국 배출권거래시장의 순공급과잉비중은 0.67~0.83으로 '공급과잉'으로 평가되었다.

배출권 할당기업, 컨설팅사, 그리고 브로커 등과의 인터뷰 결과와 배출권 거래 현황을 분석한 결과, 국내 배출권거래시장이 '공급과잉'으로 평가됨에도 불구하고, KOC 공급잠재량은 배출권거래시장에 미치는 영향이 큰 것으로 분석되었다. 할당배출권(KAU; Korea Allowance Unit)은 보유・이월 성향이 강하고, KOC는 매도성향이 강하므로, 배출권거래시장에서 배출권 부족상황이 발생할 수 있으며, 따라서 KOC 공급잠재량이 배출권거래시장에 큰 영향을 미치게 된다.

고효율조명 교체를 통한 KOC 공급잠재량은 전체 배출권 거래규모 대비 매우 적은 규모이지만 KAU가 과대할당되고, KOC가 공급부족인 현재의 배출권거래제 상황에서는 시장거래 및 가격 견인의 역할을 할 것이다.

연구결과, 고효율조명 교체를 통한 KOC 공급잠재량 확대는 배출권거래시장에 유동성을 공급하고, 온실가스 감축에 기여한다는 점에서 활성화할 필요가 있는 것으로 나타났다. KOC 공급을 활성화하는 방법은 온실가스 감축사업 지원, KOC사업 지원으로 나누어 볼 수 있다. 온실가스 감축사업을 활성화하는 방안에는 전기요금 인상, 배출권 가격 상승 및 고효율조명 기술개발 지원에 따른 단가 하락 등이 있다. KOC사업 지원 방안에는 KOC사업 활성화의 장애요인인 KOC 행정절차를 간소화하고 행정비용 지원 등을 들 수 있다.

한국의 배출권거래제도(K-ETS)는 정부의 과도한 시장개입, 참여기업의 거래역량 부족, 그리고 배출권 유동성의 부족과 금융기관의 참여 제한으로 유럽연합 배출권거래제(EU-ETS)와 다른 특성을 보이고 있다. 본 연구는 이와 같은 한국 배출권거래시장을 대상으로 상쇄배출권 공급확대를 통한 배출권거래시장 활성화 방안과 관련된 연구로서, 향후 지속적인 추적 연구가 필요하다.

주요어: 배출권거래시장, 탄소배출권가격, 상쇄배출권, 다기준의사결정모형, LEAP, KOC, KAU

Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1 Background and needs

International concern on Korea Emission Trading Scheme (K-ETS) which started from 2015 has been rising. However, 40% of 522 allocated companies have raised formal objection to the allocation results. As a result, 40 companies received additional allocation of Korea Allowance Unit (KAU) by 67 million tons. But 84% of companies' formal objection have been rejected, thereby raising conflict between the government.

In addition, 10% of 522 allocated companies have raised a suit against the government. The first outcome of this lawsuit was the case of Hyundai Steel. The court concluded that the allocation of carbon credits from the government was legal. This decision is expected to affect the other lawsuit cases (nonferrous metal, petroleum-chemical, waste industry). The conflict between the allocated companies and the government is still ongoing.

The main reason of allocated companies opposed to the government is high compliance costs derived from under allocation.

In case of European Emission Trading Scheme (EU-ETS), the carbon price have constantly risen because of short statement. The same signal have also been observed in Korea.

Therefore, interest on potential supply of carbon credits through emission reduction projects have risen. Because the only supply source of carbon credits into the K-ETS until the 2020 is Korea Offset Credit (KOC).

However, supply and demand projection of carbon credits in Korea cannot be made because of no such studies or relevant information. The existing studies on K-ETS after 2015 seem to focus on how to allocate allowances and effect for industries, rather than stabilization of carbon market.

Potential distortions in the K-ETS detected from the transaction cost, market power, regulations and uncertainty (Sunghee Shim et al., 2015). As indicated by the initial performance of the K-ETS, the system lacks liquidity (Jaehyung Lee et al., 2015).

The supply of allowances may be enlarged by banking and borrowing, offsets, and reserve. Carbon market price may be contained by price ceiling, price floor and a combined system of price ceiling and floor (Hyunjin Cho et al., 2016). A study on the VAT taxation after adaption of ETS is started (Jikyung Jang et al., 2016).

In oder to secure more legal certainty as to emission trading, it needs to adopt the provisions of presumption of possession and bona fide acquisition under the Act (Soonsuk Kim, 2016)

By estimating the dynamic pass-through of carbon price into electricity price for different periods of our sample, observe the weakening of the link between carbon and electricity prices as a result from the collapse on CO_2 prices (Freitas et al., 2017).

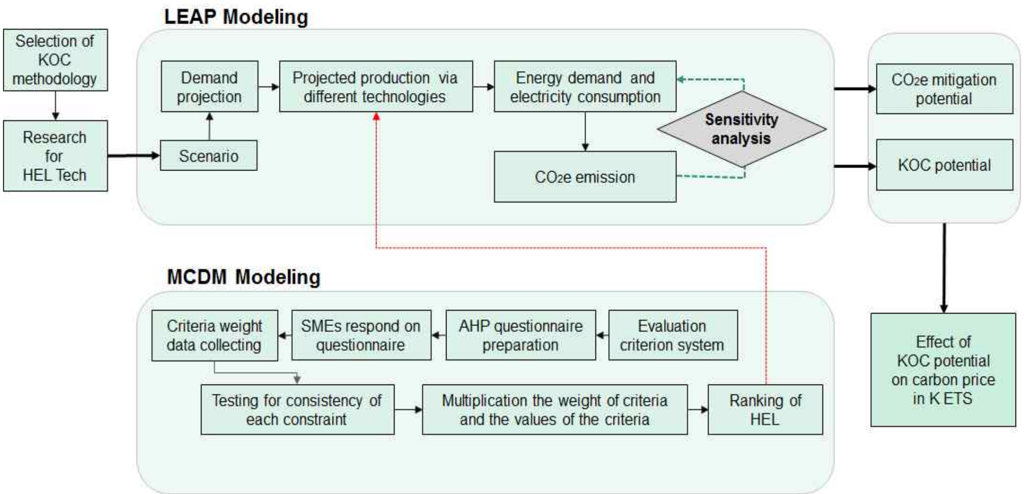
Such failure on carbon credit supply and demand outlook would eventually lead to problems in predicting carbon credit price and further disrupt working of market mechanism.

1.2 Purpose and procedure

There is a question of which path K-ETS is to take for the overall success of the scheme.

Carbon credit supply is the most important factor for soft landing of K-ETS. There is a need to motivate companies with surplus KAU to sell their carbon credits in the market but it cannot be forced by policy measures and also there are no drivers in terms of company management to encourage companies sell their surplus amount.

Currently, supplying KOC to the market through transforming of CER from CDM projects is on the limits. The only method in order to increase the supply in the K-ETS is by generation of KOC through implementation of domestic offset projects. In this study, high efficient lighting equipments replacement project methodology among 22 existing methodologies has been selected as the one with the largest range of applicability and influence in Korea. Through this methodology, the potential of KOC supply until 2030 has been calculated (<Figure 1.1>).



<Figure 1.1> Procedure of this study

First, study and analysis on high efficient lighting equipments technology has been performed. Then lighting equipments technologies with high applicability are selected. It is assumed that general lighting equipments replacement is done by using LED and replacement of metal halide lighting equipments is done by using one of either LED, HEM or IL. The range of application is intended for the entire industrial and commercial facilities. For the estimation of energy consumption and energy savings, modelling is done by using MCDM and LEAP model. In addition, sensitivity analysis for the calculation of potential KOC amount is performed according to four carbon price scenarios of 5,000 won, 10,000 won, 30,000 won and 100,000 won. Potential KOC amount is calculated through the analysis and additional analysis on implications of the result and mutual influence between the K-ETS are performed.

In this study, the potential supply of KOC until 2030 has been predicted. The results of this prediction would be used in the influence analysis by Long range Energy Alternatives Planning (LEAP) modelling regarding examining the affect of potential supply of KOC on K-ETS carbon price.

The results of the analysis would hopefully be used in the market design process and making of policy directions regarding government support on emission reduction technologies.

Chapter 2. Theoretical Background

2.1 Emission trading scheme and carbon price

2.1.1 International emission trading scheme

About 40 nations and over 20 local governments are putting a price on carbon (World bank, 2015).

These carbon pricing instruments can be diverse, incorporating carbon taxes, emission trading schemes and offsets. <Table 2.1> provides a count of the nations and local governments engaging with ETS which is most prominent carbon pricing policy.

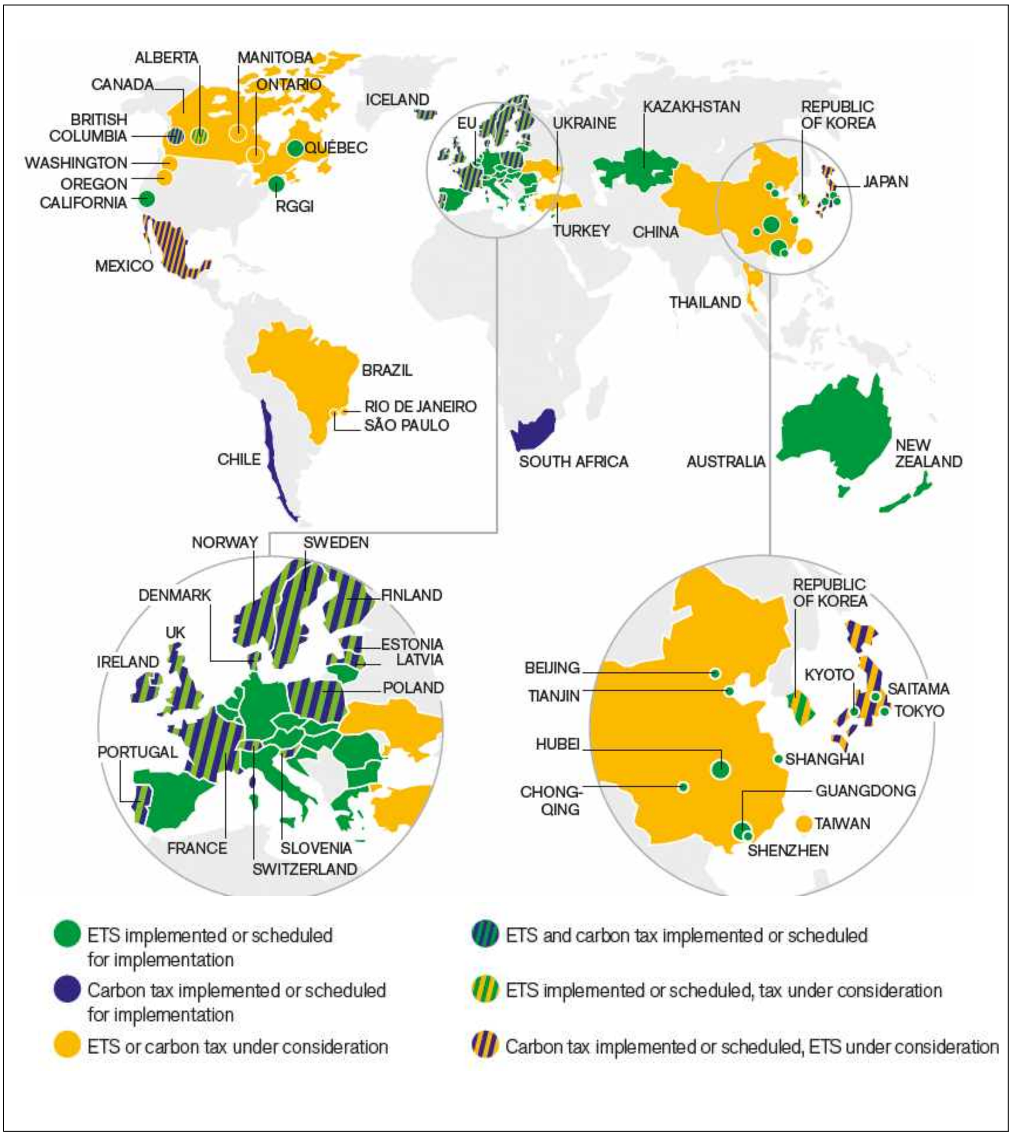
<Table 2.1> Status of international emission trading schemes

Status	Region	Nation	Local government	Total
Implemented[1)]	1	5	13	19
Implementation scheduled[2)]		0	1	1
Under consideration[3)]		8	3	11

1) Region: EU-ETS (31 countries)
Nation: Republic of Korea, Australia, Kazakhstan, New Zealand, Switzerland
Local government: RGGI, Chinese pilots, Alberta, California, Japanese schemes, Quebec
2) Local government: Chongqing
3) Nation: Brazil, Chile, China (at 2017), Japan, Mexico, Thailand, Turkey, Ukraine
Local government: Riode Janeiro, Sao Paulo, Washington State
* Reference: World bank, State and Trends of Carbon Pricing, 2016

The trend towards increasing nation or region level ETS continued at a steady pace in 2016. Trading volumes of international ETS are 30 billion US$. China ETS is the second largest scheme in the world. That scheme covers 1,115 MtCO_2eq volume of GHG emission compared with EU-ETS coverage (2,084 MtCO_2eq).

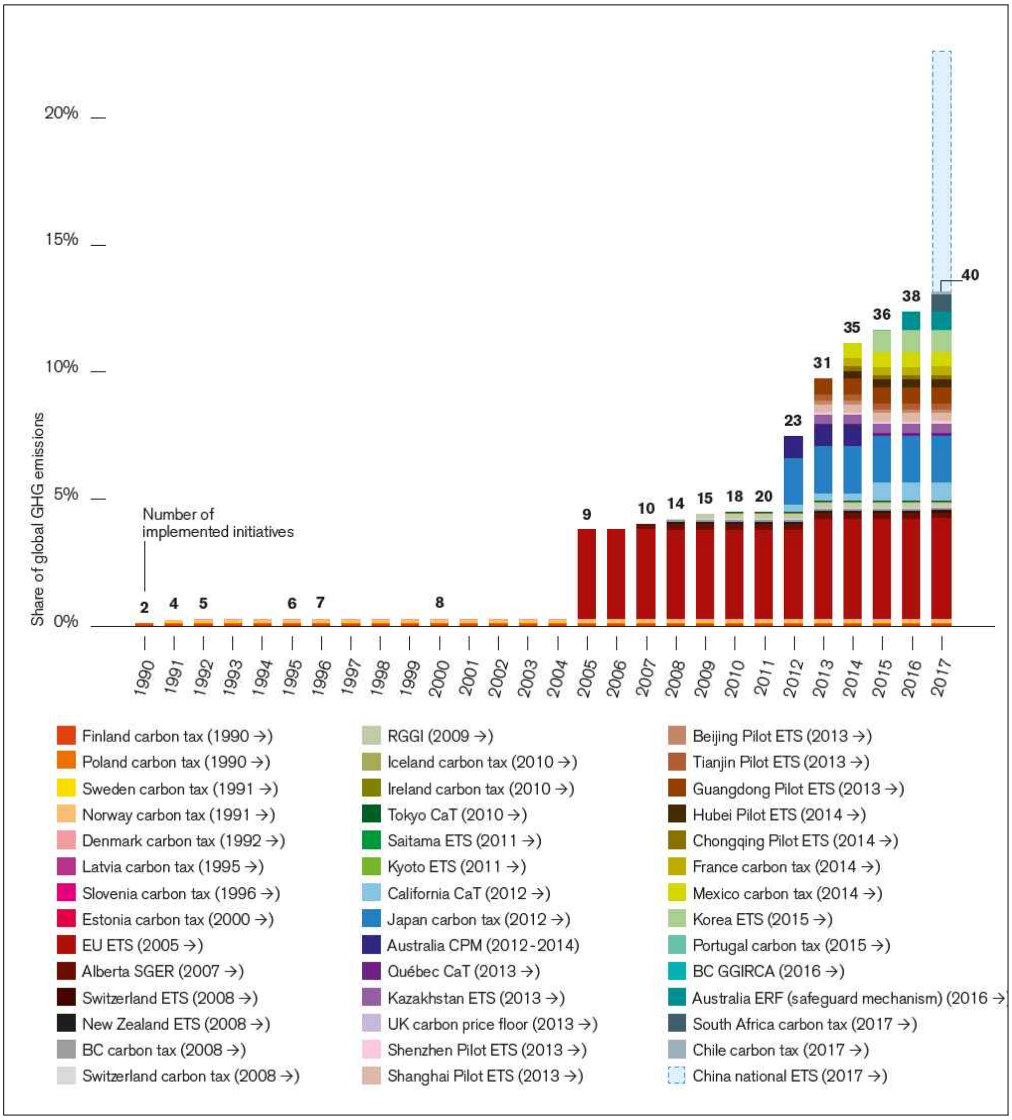
<Figure 2.1> shows that existing, emerging and potential ETS. Countries and regions who already had plans have been elaborating their individual policies further this year such as Brazil, Chile, Thailand, Indonesia and South Africa.



Reference: World bank, State and Trends of Carbon Pricing, 2016

<Figure 2.1> Status of international emission trading schemes

In <Figure 2.2>, the ETS in California, Quebec, Kazakhstan and local government of China started operation in 2013 and 2014. The Tokyo ETS is notable, with higher price policy signal than most emissions trading schemes at US $95/t$CO_2$eq.



Reference: World bank, State and Trends of Carbon Pricing, 2016

<Figure 2.2> Timetable of carbon tax and ETS

The European Emissions Trading Scheme (EU-ETS) which is the largest and oldest emission trading scheme playes a important role in the EU's policy to reduce GHG emissions. In 2014, EU adopted GHG emission reduction target of 30% from 2005 levels from EU-ETS until 2030 and agreed to stabilize the EU-ETS in line with the European Commission (EC) proposal to develop Market Stability Reserve (MSR) process.

The Swiss started domestic ETS at 2008 during five year with voluntary phase. Alternative option to CO_2 levy for the fossil fuels. Final regulations forced on 2013. The system subsequently became mandatory for large, energy intensive industries. It now cover about 10% of the country' total GHG emissions. During 2013-2020, participants of ETS are exempt form the CO_2 levy.

Switzerland is currently negotiating with the EU on linking the Swiss ETS with the EU-ETS. Many parts of the Swiss ETS designed to match provisions in the EU-ETS, current negotiations may have further impact on the Swiss ETS.

Kazakhstan launched an ETS in January 2013. After a one-year pilot phase, the program entered its second two-year phase in January 2014. The framework of a ETS program was laid out in 2011 through amendments and additions to Kazakhstan's environmental legislation. Kazakhstan is currently working on improving these underlying laws. Amendments to the environmental code and additional supporting regulations are expected to enter into force near future.

Russia is currently exploring policy options to meet its GHG emission reduction target of at least 25% below 1990 levels by 2020. In 2014, the Russian government adopted a plan for the development and implementation of a number of emissions reduction activities. The plan includes such important steps as the development and introduction of an MRV system at the company level, assessment of emissions reduction potential, and the development of a concept and an action plan to reach the 2020 emissions reductions target, which could potentially include emissions trading. The measures will be developed and implemented by the ministry for Economic Development and other relevant ministries and stakeholder.

National Climate change action plan (2011) of Turkey called for researched to be worked to establish a carbon market until 2015. In 2012, Turkey adopted a new regulatory about mandatory MRV (Measurable, Reportable , Verifiable) process. Monitoring is expected to start in 2015, and reporting (for 2015 emissions) in 2016. Turkey received funding in 2013 to develop MRV process by introducing a pilot MRV system for energy sector, and exploring options for market based process. This report considered emissions trading for the electricity sector, Turkey' largest emitting sector. Turkey is also a candidate to EU accession and thereby aims to complete the environmental obligations of the EU accession.

In 2014, Ukraine and the EU signed and ratified the association agreement, which requires Ukraine to establish an ETS within two years of the agreement's entry into force. Initially, the system would be district from the EU-ETS. The Ukrainian government must adopt the necessary legislation, and establish MRV and enforcement systems. Additionally, it must also develop a national allocation plan to distribute allowances to covered entities.

WCI is an scheme of American state and Canadian provincial governments to develop reducing GHG emission via a regional ETS program. The first compliance periods started on 2013.

Initiated in 2012, the California ETS began its compliance obligation on 2013 with the first compliance period. California has been part of the WCI since 2007 and formally linked its system with Quebec's on 1st January 2014. The Cap-and-Trade program covers sources responsible for approximately 85% of California's GHG emissions. A key policy pillar in California's climate law, the program will help to meet its mandate of reducing GHG emissions to 1990 levels by 2020 and achieving an 80% reduction from 1990 levels by 2050.

Quebec ETS for GHG emissions was started in 2012 with a transition period in which participants could prepare and familiarize themselves with the program without mandatory compliance. The program's enforceable compliance obligation began on 1st January 2013.

Brazil is currently assessing different carbon pricing instruments including an ETS and carbon tax. Over the next two and a half years, the Ministry of Finance will work on design options and conduct comprehensive economic and regulatory impact assessments for both instruments. In 2014, 21 companies organized a voluntary ETS simulation. The allocation process and trading is managed by the Rio de Janeiro Green Stock Exchange, and the ETS design was coordinated by the GCCes/GFV.

Tokyo ETS is Japan's first mandatory ETS, launched in April 2010. Under the ETS, large offices and factories are required reducing emissions by 6 to 8% in the first phase, while in the second phase the reduction target will be increased to 15～17%.

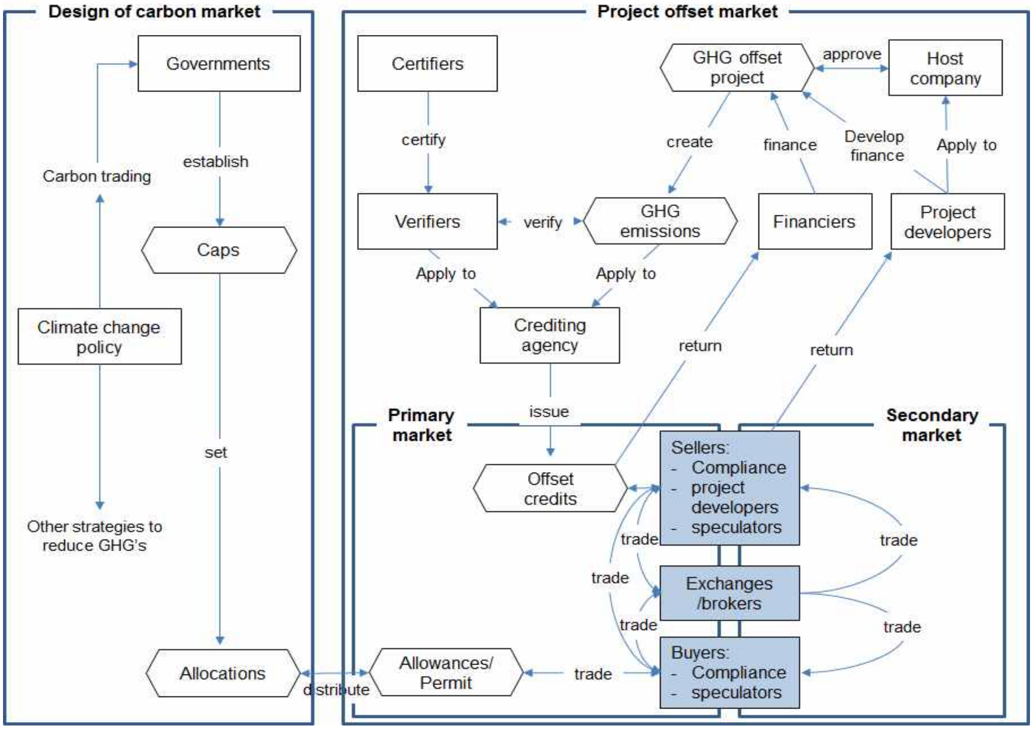
According to 12th Five Year Plan, China setup commitment to develop carbon market. The National Development Reform Commission (NDRC[1]) thereby designated seven provinces and cities as regional mandatory pilot ETS in October 2011. The pilots started operation in 2013 and 2015, and shall be incorporated in a national system during the 13th Five Year Plan (2016～2020). The basic rules for a national ETS were published in December 2014, which focused on core principles and the part of responsibilities between national and regional authorities. However, no specific details on the system's design have been published yet. In preparation for the national ETS, the NDRC has notified large emitters outside the pilots to report on their emissions.

---

1) Formerly State Planning Commission and State Development Planning Commission, is a macroeconomic management agency under the Chinese State Council, which has broad administrative and planning control over the Chinese economy. The candidate for the chairperson of the NDRC is nominated by the Premier of the People's Republic of China and approved by the National People's Congress. Since March 2013 the Commission has been headed by Xu Shaoshi.(http://en.ndrc.gov.cn)

2.1.2 Korea Emission Trading Scheme (K-ETS)

K-ETS market structure consisted with allocation and project offset market (<Figure 2.3>).



<Figure 2.3> Market structure of K-ETS

On 1st January 2015, the Government launched national ETS, the first nationwide cap and trade scheme in operation in Asia. With a cap of 573 $MtCO_2eq$ in 2015, K-ETS is the second largest ETS in the world after EU-ETS. It covers about 23% of the total national emissions.

The almost unanimous adoption of the framework for Korean ETS on 2012 was a important step. The economy has grown fast over the past two decades and became the fastest-growing GHG emitter in OECD. As a non-Annex 1 country in Kyoto Protocol, Korea has no legal binding emission reduction targets. It aims to reduce GHG emissions 30% against BAU by 2020. <Table 2.2>, <Table 2.3> introduce KAU and KCU trading volume and price in KRX platform

<Table 2.2> KAU trading volume and price (2015.1.～2016.6.)

Date	Unit price (won)	Trading volume (tCO_2eq)	Total price (won)	Bulletin Board[2] trading amount (tCO_2eq)	Bulletin Board trading total price (won)
2015/01/12	8,640	1,190	9,740,400	-	-
2015/01/13	9,500	50	475,000	-	-
2015/01/14	9,510	100	951,000	-	-
2015/01/16	9,610	40	384,400	-	-
2015/10/07	11,300	12,000	135,600,000	-	-
2015/10/08	11,300	168,000	2,024,400,000	168,000	2,024,400,000
2015/12/09	11,600	100,000	1,210,000,000	100,000	1,210,000,000
2015/12/10	11,600	40,000	484,000,000	40,000	484,000,000
2016/01/15	12,600	100	1,260,000	-	-
2016/02/22	14,400	1	14,400	-	-
2016/02/23	15,800	1	15,800	-	-
2016/03/15	18,450	7,000	122,975,000	6,500	113,750,000
2016/03/18	18,450	15,500	267,375,000	15,500	267,375,000
2016/04/11	18,450	10,000	185,000,000	10,000	185,000,000
2016/04/15	18,450	25,500	470,475,000	-	-
2016/04/18	18,450	52,300	964,935,000	-	-
2016/05/19	21,000	2,000	42,000,000	-	-
2016/05/20	21,000	600	12,600,000	-	-
2016/05/23	21,000	5,000	105,000,000	-	-
2016/05/27	18,950	15,838	300,747,000	-	-
2016/05/30	18,500	15,000	282,500,000	8,000	152,000,000
2016/06/01	18,500	137,155	2,221,911,000	137,155	2,221,911,000
2016/06/02	18,400	121,382	1,995,253,800	108,453	1,756,938,600
2016/06/03	18,400	65,221	1,138,772,700	43,510	737,860,000
2016/06/07	17,900	318,663	5,742,199,200	300,000	5,400,000,000
2016/06/08	17,600	81,586	1,449,318,500	34,105	610,479,500
2016/06/09	16,700	258,741	4,454,727,600	208,149	3,600,977,700
2016/06/10	16,600	131,000	2,187,242,700	100,000	1,670,000,000

Reference: KRX, 2016.10

2) Companies can trade using Bulletin Board in KRX

<Table 2.3> KCU trading volume and price (2015.1.～2016.6.)

Date	Unit price (won)	Trading volume (tCO_2eq)	Total price (won)	Bulletin Board trading amount (tCO_2eq)	Bulletin Board trading total price (won)
2015/12/21	12,200	10,059	122,719,800	-	
2015/12/22	13,400	23,000	306,650,000	-	
2015/12/23	13,700	78,000	1,138,800,000	78,000	1,138,800,000
2015/12/28	13,700	15,000	219,000,000	15,000	219,000,000
2015/12/29	13,700	15,000	219,000,000	15,000	219,000,000
2016/02/17	15,000	20,000	300,000,000	-	-
2016/02/18	16,000	233,000	3,843,000,000	230,000	3,795,000,000
2016/02/22	16,000	60,000	1,020,000,000	60,000	1,020,000,000
2016/03/08	17,600	8,300	145,750,000	-	-
2016/03/10	18,000	2,500	45,000,000	-	-
2016/03/15	18,500	2,529	46,786,500	-	-
2016/03/16	18,500	500	9,250,000	-	-
2016/04/11	18,500	10,000	185,000,000	-	-
2016/04/12	18,500	10,000	185,000,000	-	-
2016/04/14	18,500	10,000	185,000,000	-	-
2016/04/18	18,500	10,000	185,000,000	-	-
2016/04/20	18,500	10,000	185,000,000	-	-
2016/04/22	18,500	260,000	4,810,000,000	250,000	4,625,000,000
2016/04/25	18,500	10,000	185,000,000	-	-
2016/04/27	18,500	10,000	185,000,000	-	-
2016/04/28	18,500	10,000	185,000,000	-	-
2016/05/09	18,500	250,000	4,625,000,000	250,000	4,625,000,000
2016/05/10	18,500	1,400	25,900,000	1,400	25,900,000
2016/05/12	18,500	10,000	185,000,000	-	-
2016/05/13	18,500	10,000	185,000,000	-	-
2016/05/16	18,500	10,000	185,000,000	-	-
2016/05/17	18,500	10,000	185,000,000	-	-
2016/05/18	18,500	10,000	185,000,000	-	-
2016/05/20	18,500	250,000	4,625,000,000	250,000	4,625,000,000
2016/05/23	20,300	2,000	40,600,000	-	-
2016/05/26	20,300	3,000	60,900,000	-	-
2016/05/30	18,500	10,000	185,000,000	-	-
2016/05/31	18,450	15,000	276,750,000	-	-
2016/06/01	18,400	15,000	276,000,000	-	-
2016/06/02	18,400	26,000	478,400,000	-	-
2016/06/03	18,500	435,906	8,028,161,000	360,000	6,624,000,000

Reference: KRX, 2016.10

Number of Liable entities are 525 (at 2016, entities changes to 522) including Three public financial institutes. Allocation at phase1 (2015～2017) is 100% free, no auctioning. Participants received free allowances based on the GF (Grand Fathering) methodology of the base year.

Three sectors (grey clinker, oil refinery, aviation) allocated free allowance following benchmark based on previous data from the base year.

During phase1, about 5% of allowances retain for the market stabilization measures, early action, and other purposes. At Phase2 (2018～2020), 97% free allowances, three percent auctioning will be doing.

Domestic CDM credits (CER) is possible to use in the scheme. However, project which is implemented after 14 April 2010 are only eligible. Over the 10% of participant's compliance obligation and at phase3, up to 50% of the total offset allowed into scheme covered with international offset.

Almost every stakeholder had believed that the price threshold will be 10,000 won in 2015 and 2016. The stabilization measures may include:

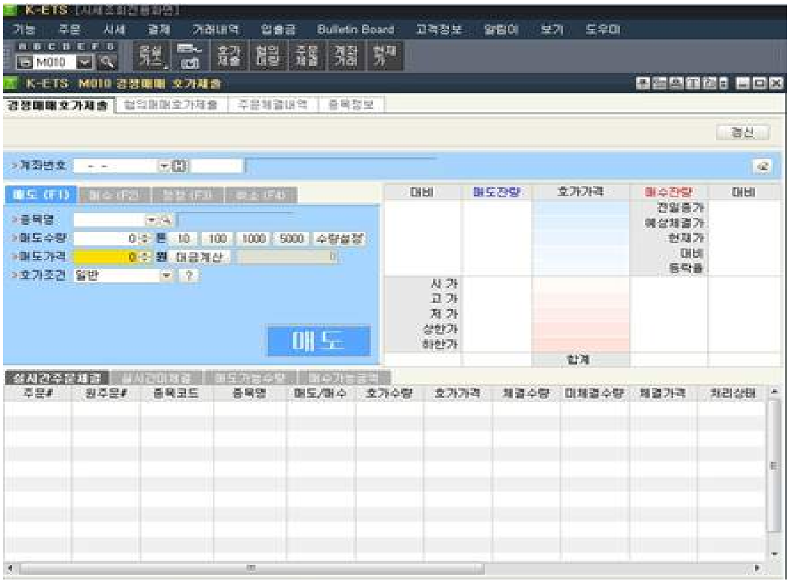
(1) Additional allocation from the reserve (up to 20%) (2) Setup of the limitation of an allowance retention: 70% or 150% of the allowance (3) An change of the borrowing's limit (up to 10%) (4) An change of the offsets limit (up to 10%) (5) Temporary set-up a price ceiling or price floor.

During 1st year, 12,900 $KtCO_2eq$ of credits are traded (207,670 10^6 won) and the carbon price (in case of KAU) is rise to 21,000 won at May 2016 and stabilization measures are started (<Table 2.4>).

<Table 2.4> Trading status in KRX and Over The Counter (OTC) market (2015.1.～2016.6.)

Credit type	Amount (10 $KtCO_{2eq}$)			Unit price (min-max)		Total price (10^8 won)		
	Platform	OTC	Total	Min	Max	Platform	OTC	Total
KAU	162	28.2	204	7,860	21,000	285.1	45.7	330.8
KCU	265	28.6	293	7,860	20,600	427.7	46.3	464
KOC	n.a	793.1	793	9,000	20,000	-	1,281.9	1,281.9
Total	427	850	1,290	-	-	712.8	1,363.9	2076.7

<Figure 2.4>, <Figure 2.5> shows that spot and Bulletin Board trading platform of K-ETS.



<Figure 2.4> Spot trading platform of K-ETS

<Figure 2.5> Bulletin Board trading platform of K-ETS

Since 1990, Korea emissions have doubled and making the world's seventh largest GHG emitter, which is the fastest growing emissions source among the OECD.

According to Copenhagen Accord, Korea pledged to reduce GHG emissions by 30% until 2020. A important step towards goal came on 2009, when government passed the "Low Carbon Green Growth Framework Act". This legislation builds on government's Green New Deal package from 2009 and National Strategy for Green Growth that was announced in 2008. The Five-Year Plan was released in 2009.

On April 2010, the government developed the Framework Act on Low Carbon. and In April 2011, released its final draft for an ETS, benchmarted with EU-ETS. Emission trading in Korea begin on 2015. The system designed to cater towards the opinion of stakeholder and industry, as Ill as accounting for Korea's international competitiveness.

To meet national cap goal, emission reduction from voluntary project is included, Offsets limits to a maximum of 10% of an participants surrender obligations and the amount must not exceed domestic offsets used for each compliance year.

1) Offset scheme in K-ETS

The KOC project has taken time to develop. Project which is developed domestically still represent a low fraction of the total KOC (KOC and CER). The first project appeared at the end of first year (when other 2million CER in existence).

This compares to below 0.0001% share in Korea GHG emissions in 2015. Transacted CER volumes in market amounted so far to 12MtCO_2eq, of which 90% contracted during the first year (2015.1.～2016.6.)

Carbon transactions are defined as purchased contracts or Emission Reduction Purchase Agreement (ERPA) whereby one party pays another party in return greenhouse gas (GHG) emission reductions, that the buyer use credit for their compliance.

Payment is using following forms which are equity, debt, cash or in-kind contributions. Transactions group into two categories:

- Allowance based transactions, which is the buyer purchases allowances created by government, Korea Allowance Units (KAU) under the K-ETS.
- Project based transaction, which is the buyer purchases credits from the project that it reduces GHG emissions compared with what would have happened otherwise. General activities are CER under the CDM of the Kyoto Protocol and Credits under the domestic offset scheme of the K-ETS, generating KOC and KCU respectively.

ETS regimes currently in place allow import of credits from project-based transaction for compliance purposes.

Once CER are issued and delivered. And they are fundamentally the same as allowances. Unlike allowances however, KOC credits are compliance assets that has various risks inherent with it and involve significantly big transaction costs.

2) Who is buyer in K-ETS?

The potential demand for KOC and KCU comes from players involved in GHG emission reduction systems on regional scale (K-ETS).

Through the investigation on carbon credit transactions during January of 2015 through the first half of the 2016, the major utility and some large companies have been identified as major carbon credit buyers. There were some SMEs and medium-sized companies which actively took actions by purchasing carbon credits, but the carbon credit trading volume of these companies were relatively small by about several thousand to tens of thousands tons.

Apart from utility and large companies, most of SME companies which purchased carbon credits were each lacking more than 10% of its 2015 emissions.

Therefore, these SME companies are confronted with difficulties in reaching its emission targets though borrowing of carbon credits alone.

The reason why most of carbon credit transaction have been carried out mostly though utility and large companies during first phase of emission trading scheme is that these companies were had the quick access to the appropriate market information such as carbon credit seller information and such quick access enabled them to make appropriate decisions on carbon credit transactions.

Most company' CEOs are currently focusing on observing the carbon market rather than actively participating in carbon credit transactions because of an possibility of appeasement policy by the government, lack of market experience and etc. In addition, these companies are projected to choose ‘burrowing’ rather than purchasing carbon credits.

3) Who is seller in K-ETS

All of KOC credits sold during first phase originated from CER which was a resale of CDM credits from enterprises which was a CDM project participant or companies which purchased domestic or foreign carbon credits.

Among these, Hu-Chems, Korea District Heating Corporation (KDHC), K-Water, Sudokwon Landfill Site Management Corporation (SLC) are good examples of companies which possessed CER based on CDM and also are classified as allocation companies in the emission trading scheme of Korea.

In turn, Korea Carbon Management, Ecoeye, Climate change Research Institute of Korea (CRIK), Industrial Bank of Korea (IBK) are major carbon credit seller and broker which are not included in 522 allocation companies as well as holders of CER.

In other words, carbon credits traded in the first year originated not from the domestic offset scheme but from carbon credits from prior CDM projects.

This is an indication that the domestic offset scheme in K-ETS has not yet been successfully settled.

SME companies leads other participants in the supply of KOC (except CER) credits with 90% of market volumes so far.

4) Insights on the price of KOC assets

The KAU and KCU price decrease when government supply Market Stability Reserve (MSR) (<Figure 2.6>, <Figure 2.7>).

<Figure 2.6> KAU15 trading pattern (2015.6.~2016.6.)

<Figure 2.7> KCU15 trading pattern (2015.6.~2016.6.)

Prices are up across the board in every segment of the project based carbon market, with average prices for primary CER at about 20,300 won (up from 9,000 in 2015) at May 2016, representing an almost 100% rise in year to year average prices. Primary KOC transacted at a price of 20,300 won in the first quarter of the year, and remained cheaper than KAU on average.

The prices at which KAU transaction at May 2016 increased to 21,000 won, representing a 130% year on year increase.

Prices of project based credits tended to be more stable than KAU at K-ETS. KOC prices were also influenced by power companies who tended to focus on longer term compliance needs than the predominantly financial buyers of KOC and secondary CER.

K-ETS have also appeared in stories by the foreign press (<Figure 2.8>).


http://carbon-pulse.com/22019/

DIALOGUE: What now for South Korea's emissions trading scheme?

Published 10:55 on July 5, 2016 / Last updated at 12:55 on July 5, 2016 / Asia Pacific, Conversations, Dialogue, South Korea / No Comments

Carbon Pulse Dialogues are discussions about carbon markets and climate policy by a selection of leading experts.

Irrespective of what will be the exact bala very limited liquidity. There are some 550 c cover emissions. Some need more than trading platform (the KRX exchange). Logically this should have been sufficient, no? Well, it clearly isn't.

The strategy can be said to have worked in the sense that we have not seen rapid ups and downs. Instead prices have increased steadily from 7,860 KRW per KAU in January 2015 to the current bid price of around 17,000. And yet offered volumes are very limited. We believe that if the Korean government really wants to boost liquidity it needs to 1) allow forward contracts, and 2) allow middlemen, even at the risk of more speculation.

Thomson Reuters Point Carbon has estimated that throughout 2015 the traded volume of Korean carbon allowances (KAUs) was limited to some 300,000 units. Against an annual budget (allocation) of 543 m KAUs, this gives a turnover rate of less than 0.1. In comparison, the turnover rate in Europe is 2.75.

<Figure 2.8> The foreign press for K-ETS

2.1.3 Outlook of future carbon market

As the emission trading itself is an international mechanism, careful and consistent observation on relevant national policy of other countries and fluctuation of international carbon market is crucial. In addition, the ideal road map of Korea’s emission trading scheme can be derived from relevant future policy of other countries.

China, the largest carbon polluter in the world, is now preparing to establish what will correspondingly become the world’s largest national carbon emissions trading market after 2017.

China's ambitious national emissions trading scheme is a "game changer" in the long term. Experimental programmes have been introduced to seven provinces since 2012. As part of a bilateral effort with the United States that aims to establish leadership against climate change, China’s incoming carbon market stands as a force of global beneficence with opportunities for the taking though risks still extant within imply not everyone will be a winner.

It is unclear how other major developing countries such as India and Brazil will be impacted. Both countries may benefit relative to China in terms of growth, as Indian and Brazilian industry will continue on unhindered in contrast to their “capped” counterparts in China.

On the other hand, China’s plunge into emissions restrictions might lead to international pressure forcing New Delhi and Brazil into national carbon markets earlier than originally anticipated.

The likelihood and magnitude of these developments is reliant on the substantive details of China’s cap-and-trade commitment. In spite of these uncertainties, it is nonetheless clear that the incoming Chinese carbon market evokes optimism in the long-term global outlook while concurrently creating numerous short-term winners and losers along the way.

Although the date of entry into force in 2020 may suggest delayed action, the Agreement will also have a mitigation effect before 2020. The agreement marks the first time that countries formally propose national pledges that cover a time-frame beyond 2020, but the implications of these targets for policy making and investments are immediate.

Countries will not wait until 2020 to begin to deviate from their current trajectories in order to meet their goals for 2025 and 2030, just as the private sector will not wait until 2020 to invest in the development and installation of low carbon technologies upon which the national pledges are based.

According to recent research, 71% of 52 surveyed developing countries have indicated that the process of preparing for the 2015 climate change agreement has substantially increased their capacity for enhanced pre-2020 mitigation action.

This not only results from long-term policy and market signals, but also the reported elevated status of climate change on domestic political agendas. Also, a wider understanding across line ministries of how climate change relates to their sectors may accelerate mainstream of climate change and sustainable considerations in sector planning.

The significance of the process surrounding the 2015 agreement goes far beyond the implications of Paris Agreement text itself. Probably equally important as the text of the Paris Agreement, is the indirect effect the Paris process has had on national governments and businesses.

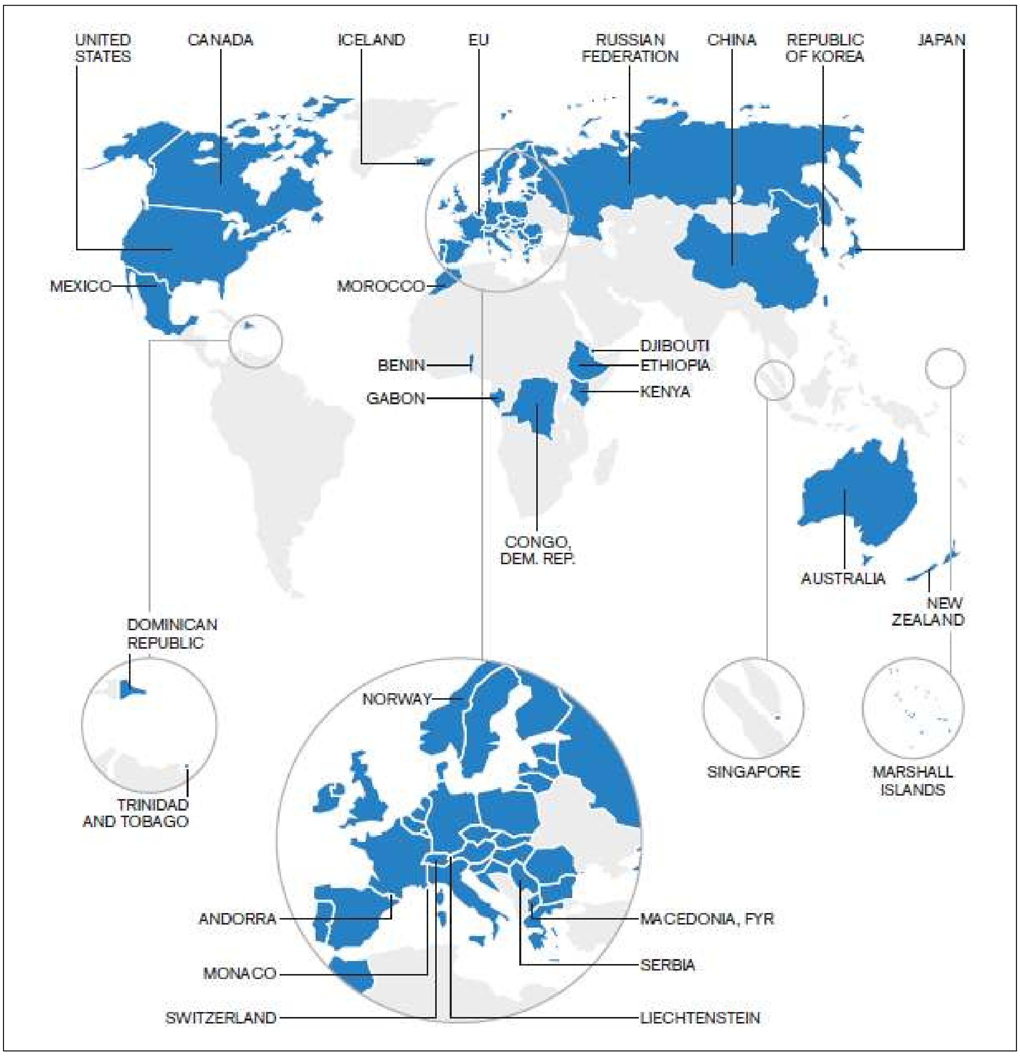
As mentioned, the process of preparing nationally determined contributions in the last 12 months has advanced national climate policy making even before the agreement was adopted.

INDC[3] have kick-started climate planning and strategy development processes and consolidated and built upon existing climate strategy and planning processes, as confirmed by over 70% of the consulted developing countries. Climate change mitigation is now a high political priority for the vast majority of consulted developing countries (84% compared to 67% before). The number

---

3) Term used under the United Nations Framework Convention on Climate Change (UNFCCC) for reductions in GHG emissions that all countries that signed the UNFCCC were asked to publish in the lead up to the 2015 United Nations Climate Change Conference held in Paris, France in December 2015 (http://www.wri.org/indc-definition).

of countries stating that climate change is understood well by all ministries nearly doubled through this process (<Figure 2.9>).



Reference: World bank, State and Trends of Carbon Pricing, 2016

<Figure 2.9> The countries of INDCs submitted

The Paris process also catalysed business and sub national actors to formulate their ambitions, which in some cases can increase the confidence of national governments to enhance their own ambition.

They are encouraged in the preamble of the Paris Agreement to continue doing so. Despite the major step forwards that the agreement represents, it is only one of many steps on a long road. The Agreement provides the mandate and framework for concerted action, the challenge now is to implement the agreed deep transition towards a low carbon and climate resilient future at all levels. First, the national contributions need to be implemented.

For many developing countries this requires continued support to enhance national capacity. In particular, the prevailing low level of the technical understanding of mitigation options and associated finance needs in some countries needs to be improved. Ambition needs to be ramped up.

National governments need to review their actions and squeeze out more ambition where they can. Front runner countries like the EU could take a first step in making their INDC more ambitious at the time of ratification of the new agreement, now being confident that the whole world is on board. Other countries could follow. The framing of mitigation in the context of wider development benefits may also increase the likelihood of national stakeholder, in particular key sectors, to get behind more ambitious GHG reductions.

The momentum of business and non-state actors has to be harvested and turned into more ambitious national actions. The participation of the "non-state actors" has been remarkable and is significant in size. These activities have to be taken into account, when countries make plans for the future.

It is up to all actors, governments, companies and individuals, at the international, national and local levels to use the encouraging outcome of Paris as inspiration for concerted action. The dynamic and momentum created by the process in the run up to COP21 and the conference itself needs to be maintained. Positive energy, continuous encouragement and strong cooperation will be needed for the challenges ahead of all of us.

2.2 Modelling methodologies for decision making

Multi Criteria Decision Making (MCDM) Model is using to solve decision and planning problems relating multiple criteria. The MCDM is used in many area as performance evaluation, supplier selection, assessment of health care, waste treatment, supply chain management, banking performance, e banking and in various multi choice selection process. Table describes about various applications of MCDM techniques. According to <Table 2.5>, Specially MCDM has been widely used to optimize sustainable energy solutions in many areas (Martin Aruldoss et al., 2013).

<Table 2.5> MCDM Applications

Banking performance	Performance management	Selection process
Business performance	Partner selection	Risk management
Automotive industry	Environmental assessment	Mold and Die industry
Education	Health care	Marine
Financial investment decisions	Financial ratios and business performance	Manufacturing systems
Demand forecasting	Material selection	Bioinformatics

Reference: Martin Aruldoss et al., A Survey on Multi Criteria Decision Making Methods and Its Applications, American Journal of Information Systems, 2013

MCDM effectively review the problem with the significance of different criteria and the preferences of the decision-maker (Martin Aruldoss et al., 2013). The Figure depicts the hierarchical view of MCDM methods and its types. The widely used MCDM methods have been described in following headings (Martin Aruldoss et al., 2013).

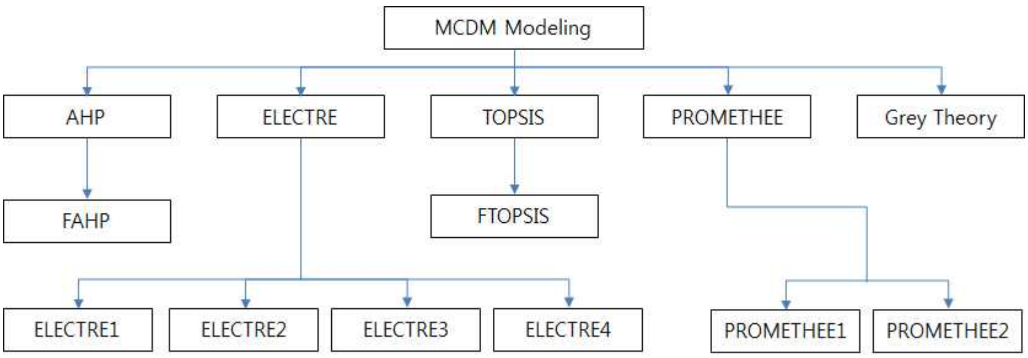
<Table 2.6> shows advantage and disadvantage of each MCDM modelling Methods.

<Table 2.6> Characteristics of MCDM modelling Methods

Method	Advantages	Disadvantages
AHP (Analytic hierarchy process)	1. Flexible, intuitive and checks inconsistencies 2. Since problem is constructed into a hierarchical structure, the importance of each element becomes clear 3. No bias in decision making	1. Irregularities in ranking 2. Additive aggregation is used, So important information may be lost 3. More number of pair wise comparisons are needed
ANP (Analytic Network Process)	1. Independence among elements is not required 2. Prediction is accurate because priorities are improved by feedback	1. Time consuming 2. Uncertainty 3. Hard to convince decision making
DAE (Data envelopment analysis)	1. Multiple inputs and outputs can be handled. 2. Relations between inputs and outputs are not necessary 3. Comparisons are directly against peers 4. Inputs and outputs can have very different units	1. Measurement error can cause significant problems 2. Absolute efficiency cannot be measured 3. Statistical tests are not applicable 4. Large problems can be demanding
AIRM (Aggregated Indics Randomization method)	1. Non-numeric, non-exact and non-complete expert information can be used to solve multi criteria decision making problems 2. Transparent mathematical foundation assures exactness and reliability of results	1. It aims only at complex objects multi criteria estimation under uncertainty
WPM (Weighted produced model)	1. Can remove any unit of measure 2. Relative values are used rather than actual ones	1. No solution with equal weight of DMs
WSM (Weighted Sum Model)	1. Strong in a single dimensional problems	1. Difficulty emerges on multi dimensional problems
Goal Programming	1. Handles large numbers of variables constraints and objectives 2. Simplicity and ease of use	1. Setting of appropriate weights 2. Solutions are not pair to efficient
ELECTRE	1. Outranking is used	1. Time consuming
Grey analysis	1. Perfect information has a unique solution	1. Does not provide optimal solution

Reference: Martin Aruldoss et al., A Survey on Multi Criteria Decision Making Methods and Its Applications, American Journal of Information Systems, 2013

According to hierarchical structure of MCDM Model, AHP, ELETRE, TOPSIS, PROMETHEE and Grey Theory are basic methods (<Figure 2.10>).



<Figure 2.10> Hierarchical structure of MCDM Model

1) AHP

The basic idea is to capture experts' knowledge of phenomena. Using the concepts of fuzzy set theory and hierarchical structure analysis a systematic approach is followed for alternative selection and justification problem (Martin Aruldoss et al., 2013). AHP includes the opinions of experts and multi criteria evaluation; it is not capable of reflecting human's vague thoughts. The classical AHP considers the definite judgments of decision makers, thus the fuzzy set theory makes the comparison process more flexible and capable to explain experts' preferences (Martin Aruldoss et al., 2013).

AHP is a method for ranking purpose to selecting the best option when the decision maker considered multiple criteria. This method helps the decision maker to decide best alternative from all by satisfying the minimal score to rank each alternative based on how well each alternative meets them (Martin Aruldoss et al., 2013).

Fuzzy AHP, where it helps the human to make quantitative predictions as they are not well versed, but they are equally better in making quantitative forecasting (Martin Aruldoss et al., 2013).

Classical and fuzzy methods are not the rivals with each other at same conditions. The important point is that if the information / evaluations are certain, classical method should be chosen; if the information / evaluations are not certain, fuzzy method should be chosen (Martin Aruldoss et al., 2013).

2) Fuzzy AHP

This method is used in conventional market surveys. AHP, several products and alternatives are evaluated, by means of pairwise comparisons, the weight of each item evaluation and the evaluation values for each product and alternatives are found for each item evaluation, but the result of pairwise comparisons are not 0 or 1, but rather the degree is given by a numerical value (Martin Aruldoss et al., 2013).

3) ELECTRE

ELECTRE (Elimination EtChoix Traduisant la REalite) is one of the MCDM methods and this method allows decision makers to select the best choice with utmost advantage and least conflict in the function of various criteria (Martin Aruldoss et al., 2013). The ELECTRE method is used for selecting the best option from a given set of options and referred to as ELECTRE I.

All methods are based on the same concept but differ both operationally and the type of problem.

ELECTRE creates the possibility to model a decision process by using coordination indices (Martin Aruldoss et al., 2013). These indices are concordance and discordance matrices. The decision maker uses concordance and discordance indices to analyze outranking relations among different alternatives and to choose the best alternative using the crisp data (Martin Aruldoss et al., 2013).

4) TOPSIS

This method assumes that each criterion has a tendency of monotonically increasing or decreasing utility which leads to easily define the positive and the negative ideal solutions (Martin Aruldoss et al., 2013). A series of comparisons of relative distance will provide the preference order of the alternatives. TOPSIS' concept is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution (Martin Aruldoss et al., 2013).

This used for ranking purpose and to get the best performance in multi criteria decision making (Martin Aruldoss et al., 2013).

5) PROMETHEE

It is applied to rank a set of alternatives by considering a set of criteria. The PROMETHEE I (partial ranking) and PROMETHEE II (complete ranking) were developed by J.P Brans and presented for the first time in 1982 at a conference organised by R Nadeau and M Landry at the Université Laval, Québec, Canada (L'Ingéniérie de la Décision. Elaboration d'instruments d'Aideà la Décision) (Martin Aruldoss et al., 2013).

The same year several applications using this methodology were already treated by G. Davignon in the field of Heathcare (Martin Aruldoss et al., 2013). A few years later J.P Brans and B. Mareschal developed PROMETHEEIII (ranking based on intervals) and PROMETHEE IV (continuous case) (Martin Aruldoss et al., 2013).

The same authors proposed in 1988 the visual interactive module GAIA which is providing a marvellous graphical representation supporting the PROMETHEE methodology (Martin Aruldoss et al., 2013). The success of the methodology is basically due to its mathematical property and friendliness of use.

6) Grey Theory

This method has a high mathematical analysis of the systems which are partly known and partly unknown and is defined as “insufficient data” and “weak knowledge” (Martin Aruldoss et al., 2013). When the decision-making process is not obvious Grey Theory examines the interactional analysis, there exist a great number of input data and it is distinct and insufficient (Martin Aruldoss et al., 2013). In the recent years, Grey Theory methodology in a successful manner.

7) Other methods

The VIKOR method was proposed to solve MCDM problems with conflicting and non comment surable criteria, the stakeholder want a solution that is the most close to the ideal, assuming that compromising is acceptable for conflict resolution and the alternative is evaluated according to all established criteria. Opricovic (1998) developed the initial VIKOR method. The VIKOR method is the optimization and compromise solution in MCDM, which is appropriate for estimating each alternative for each criterion. The extend VIKOR method was developed and compared with TOPSIS, PROMETHEE, and ELECTRE.

These methods are selected according to nature of the decision making. The detailed methodologies of MCDM has turned out to be diverse through the findings. The purpose of this study is not on finding the most ideal choice among various policy measures but finding the order of priority on the possibility of company’s choice on which technology to adopt. Therefore, “purge” which is AHP’s recent technology is not a suitable choice because it may distort the decision-making direction of the company.

In addition, there are limitations on the use of AHP methodology under the circumstances of many choices but in this study the choice is being made from 3 different high-efficient lighting equipments technologies.

In other words, there is no reason to use PROMETHEE because there are not many choices. By examining the advantages, disadvantages and applicability of each detail methodologies of MCDM Model, AHP has been identified as the most suitable for this study.

So, this paper employed the AHP method to explore the selection process of HEL selection for industrial and commercial sector.

2.3 Modelling methodologies for Energy and GHG emission

Energy and GHG emission models are classified into three group: instance metric models (macro econo-metric models), application general balanced models (applied general equilibrium models) and energy economy models.

The advantage of the energy economy model is that it does not express the field of energy using one or several totalizing variables as does an instance metric model or the application general balanced model, but it is the technology included in the energy consumption/convention process of each final estimate using part of the detail point that is describes (Sangwon Park at al., 2010).

The long-term model is the difference both bottom-up and top-down approaches.

A top-down model describes the macro-economic relationships between the components, while a bottom-up model starts from the technology description of supply and demand. Many research suggest methodology for further comparison of energy modelling tools.

Some of them present other modelling concept like general equilibrium models (GEM), also known as computable general equilibrium (CGE) models, and partial equilibrium models.

GEM consider economy with endogenous economic parameters (capital cost, workforce, GDP, etc).

This agree more level of detail on the part of economy to be introduced but does not take into account all economic interactions of the society.

There exist also Energy-Environment-Economy models. That model is top-down simulation.

The integrated assessment models (IAM) combine several economic and technical modules: climate, GHG emissions, economy, energy, environment, etc. Other top-down are categorized as econometrics models, accounting models, or input/output energy-economy models. And also consider the programming technic (mixed integer, linear or nonlinear, neural networks, etc) (<Table 2.7>).

<Table 2.7> Classification of energy models

Typology	Bottom-up	Hybrid	Top-down
Optimization	Sectoral optimization: MARKAL[a]	MERGE[b]	Optimal growth pathway: DICE[c]
Simulation	Recursive sectoral simulation: POLES[d]	Imaclim	Recursive general equilibrium: GREEN[e]

a Market Allocation

b Model for Estimating the Regional and Global Effects of GHG reductions

c Dynamic Integrated Climate-Economy

d Prospective Outlook on Long-term Energy Systems

e General Equilibrium Environmental model

Reference: Jacques Despres et al., Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools, Energy, 2015

In case of Long-term energy models, they have complex time scales since the investment decisions are based on annual energy balances and each year is usually seperated into several hour blocks.

The energy flows between countries and components are considered (in particular the international fuel exchanges), but the representation of the individual components is simplified.

Indeed, the systems considered spread over a large spatial horizon (the world being divided into several regions or countries) and temporal horizon (usually until 2050, sometimes 2100). Additionally, long-term energy models accept other categorization.

The first optimization models (introduced in the early 70's) are Energy Flow Optimization Model (EFOM) and MARKAL family, which are widely used in 37 countries (<Table 2.8>).

<Table 2.8> Optimization and simulation models

Typology	Model
Optimization	EFOM (Energy Flow Optimization Model) MARKAL (Market Allocation) IMES (The Integrated MARKAL-EFOM System) ETP-TIMES (Energy Technology Perspectives) PET (Pan European YTIMES) ETSAP-TIAM (TIMES Intergrated Assessment Model) MESSAGE (Model for Enegy Supply Strategy Alternatives and their General Environmental impact) OSeMOSYS (Open Source Energy modelling System)
Simulation	MEDEE POLES (Prospective Outlook on Long-term Energy Systems) PRIMES WEM (World Energy Model) Prometheus **LEAP (Long range Energy Alternatives Planning system)**

Reference: Jacques Despres et al., Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools, Energy, 2015

MARKAL is at the origin of TIMES (The Integrated MARKAL-EFOM System) and its derivatives: ETP-TIMES, PET (Pan European TIMES) ad ETSAP-TIAM, MESSAGE is also among the first optimization models, and was later enhanced by IIASA (International Institute for Applied Systems Analysis) to give MESSAGEll and MESSAGElll. OSeMOSYS is an open source model structured in blocks, which allows easy modifications to the code (<Table 2.9>).

In Korea, MARKAL modelling is used to estimate GHG emission mitigation potential for steel (Ahn Yun Ki et al., 2007), cement and oil refinery industry (No dong woon et al., 2005, 2006)

<Table 2.9> General equilibrium models

Typology	Models	Characteristics
Optimization	Edmond-Reilly-Barns, SGM (Second Generation Model), Phoenix	Top-down/ hybrid, simulation
	GREEN (General Equilibrium Environmental model)	Top-down, simulation
	EPPA (Emissions Prediction and Policy Analysis, from the MIT)	Top-down, simulation
	MARKAL-MACRO, MARKAL-EPPA	Hybrid, optimization
	NEMS (National Energy modelling System)	Hybrid, simulation
	AMIGA (All Modular Industry Growth Assessment)	Hybrid, simulation
	CIMS (Canadian Integrated Modelling System)	Hybrid, simulation
	IMACLIM	Hybrid, simulation
	NEMESIS (New Econometric Model of Evaluation by Sectorial Interdependency and Supply)	Top-down/ Hybrid, simulation

Reference: Jacques Despres et al., Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools, Energy, 2015

The main simulation models developed in the 90's, with Prospective Outlook on Long-term Energy Systems (POLES), PRIMES and World Energy Model (WEN), the International Energy Agency model used for the World Energy Outlooks. PRIMES is at the basic of Prometheus, which was using systematically stochastic variables.

LEAP (Long range Energy Alternatives Planning system) is a widely used simulation model, with an accounting framework that requires little input data.

Then, present some general equilibrium models. The main GEMs made from the Edmond-Reilly-Barns family.

It began in the 80's and was followed by the Second Generation Model (1991), now updated to Phoenix. Another family of GEM emerged from the Organization for Economic Co-operation and Development (OECD), with General Equilibrium Environmental model (GREEN) and EPPA, MARKAL was coupled to give birth to some GEM (MARKAL-MACRO and MARKAL-EPPA). Canadian Integrated Modelling System (CIMS), IMACLIM and NEMESIS have a macro-economic loop, but in a dynamic simulation framework with elements of Keynesian economic thinking.

In case of IAM (Integrated Assessment Models), DICE (Dynamic Integrated Climate-Economy) appeared in the 80's, and was later developed into RICE (Regional DICE).

MESSAGE was developed and latter coupled with MERGE to give MESSAGE-MACRO.

On the simulation side, IMAGE (Integrated Model to Assess the Greenhouse Effect) was also early developed, but with a higher level of physical detail than the optimization models. It was later linked to Targets IMage Energy Regional (TIMER).

Another family of IAM adopted the ObjECTS structure (Object-oriented Climate, Energy and Technology Systems), with the partial equilibrium models MiniCAM and Global Change Assessment Model (GCAM). AIM/CGE is a

CGE, E3 and IAM, studying the Asia-Pacific region (42 countries) (<Table 2.10>, <Table 2.11>, <Table 2.12>).

<Table 2.10> Energy-environment-economy models

Typology	Models	Characteristics
Energy Environment Economy	GEM-E3 (General Equilibrium Model for Energy, Economy and Environment) GEMINI-E3 (General National-International Economy, Energy and Environmental Equilibrium Model)	Top-down/ simulation Top-down, simulation
	E3ME, E3MG (Energy Environment Economy Model, at the European or Global level) Three-ME (Multi-sector Macroeconomic Model fro the Evaluation of Environmental and Energy policy)	Top-down, simulation Top-down, simulation

Reference: Jacques Despres et al., Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools, Energy, 2015

<Table 2.11> Previous studies on the factors affecting GHG emissions

Author	Methodology
Ramanathan (2006)	DEA (Data Envelopment Analysis)
Climent et al., (2007)	Multivariate co-integration analysis
DeFreitas et al., (2011)	LMDI (Log mean divisia index)
Harzigeorgiou et al., (2011)	Multivariate co-integration and causality analysis
Pao et al., (2011)	ARIMA
Pao et al., (2011)	Multivariate Granger causality
Al-mulali et al., (2012)	Panel model
Acaravci et al., (2010)	Causality analysis

Reference: Vatanavongs Ratanavaraha et al., Trends in Thailand CO_2 emissions in the transportation sector and Policy mitigation, 2015

<Table 2.12> Integrated assessment models

Typology	Models	Characteristics
Integrated assessment models	DICE (Dynamic Integrated Climate-Economy), RICE (Regional DICE) MERGE (Model for Estimating the Regional and Global Effects of GHG reductions) MESSAGE-MACRO	Top-down/ optimization
	IMAGE (Integrated Model to Assess the Greenhouse Effect) IMAGE/TIMER (Targets IMage Energy Regional)	Hybrid, optimization
	MiniCAM (Mini Climate Assessment Model)	Hybrid, simulation
	GCAM (Global Change Assessment Model)	Hybrid, simulation
	WITCH (a Would Induced Technical Change Hybrid System) DNE21 (Dynamic New Earth 21)	Hybrid, optimization
	MIND, ReMIND (Regional Model of Investments and Development) AIM/CGE (Asian Pacific Integrated Mode)	Hybrid, simulation

Reference: Jacques Despres et al., Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools, Energy, 2015

2.4. High efficiency lighting equipments

In industrial and commercial sector use Halogen lamp, Compact fluorescent lamp (CFL), Mercury vapour lamp, sodium vapour lamp, metal halide lamp, induction lamp and LED (<Figure 2.11>).

<Figure 2.11> Lighting equipments in industrial and commercial sector

Incandescent lamps are no longer available to use due to their bad efficiency. These lighting equipments used in theatres and auditoriums where dimming in needed. Halogen lamp is incandescent lamp. Most incandescent lamps consist a tungsten filament, gasses (argon, nitrogen) and iodine.

Fluorescent lamp come in a variety of form. Linear and compact lamp are the most common types. Fluorescent lamp contain mercury which causes tube to produce light mostly in the UV spectrum. UV light is not useful and is shifted to visible spectrum by combination of coating.

These can provide light in a variety of white shades. The fluorescent tube is known as low pressure mercury tube. Very similar to fluorescent tubes as they use phosphors and mercury. These lamp is not used in new buildings as metal halide lamp is more efficient and offer better quality.

Sodium vapour lamp is used in street lighting equipments and in car park lighting equipments. These lamp use sodium instead of mercury and the color is orange yellow.

Metal halide lamps have become popular during the last ten years due to advances in technology. That contain a number of different metal halide which produce different wavelength within the visible spectrum.

These lamps are used in a variety of practical use because they have long operating lives and are efficient.

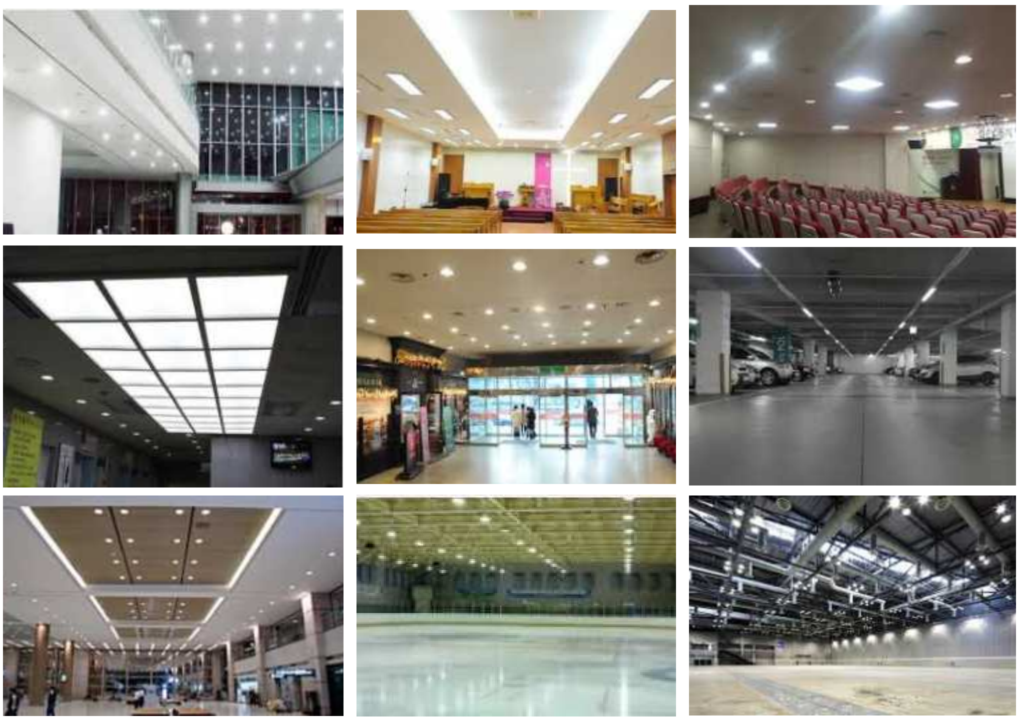
Induction Lamp is similar with fluorescent lamp, except that do not receive energy by electrodes creating arc.

2.4.1 Light Emitting Diode (LED)

LED is solid light bulbs which are extremely energy efficient. Today, LED bulb is made using as big as 180 bulbs, and encased in diffuser lens which spread more light in wide beams. Now available with standard bases which fit common light fixtures, LED is the next generation in lighting equipments. A significant feature of LED is directional, as opposed to incandescent bulb which diffuse the light more spherically. Advantage is recessed lighting equipments or under cabinet lighting equipments, but disadvantage is hard to use table lamp.

The high cost of producing LED has been a roadblock to widespread use.

However, Purdue University researchers have developed process for using inexpensive silicon wafer to replace the expensive sapphire based technology. This promises to bring LED into competitive pricing with CFL and incandescent.



<Figure 2.12> Application of LED in various places

Benefits of LED is as belows,

- Long lasting: last up to 10 times as lengthy as compact fluorescent, and far longer than typical incandescent.
- Durable: since LED do not have filament, they are not damaged under circumstance when a regular incandescent bulb would be broken. Because that is solid, LED bulb hold up well to bumping and jarring.
- Cool: do not cause heat build up; LED manufacture 3.4 btu's/hour,

compared to production of 85 for incandescent bulbs. Incandescent bulb get hot and contribute to heat in the room. LED reduce this heat build-up, thereby help to reduce air conditioning cost.

- Mercury-free: no mercury is used through manufacturing of LED.
- More efficient: use only 2 to 17 watts of electricity. and used in fixture inside home save electricity. Small LED flashlight bulb extend battery life 10-15 times longer than incandescent bulb.
- Cost-effective: although LED are expensive, the cost is covered over time and in battery saving. The cost of new bulbs has gone down considerably in the last few years. and are continued to go down. Today, there are many new light bulb for use in the home, and the cost is becoming less.
- Effective for remote areas or portable generators: through low power requirement, using solar panel becomes less expensive and more practical than using in remote or off-grid areas.

2.4.2 High efficiency metal halide

In most of general industry workplace and high altitude ceiling of the auditorium, metal halide lighting equipments are mainly used. However, many companies are replacing them with high efficient metal halide because of problems in former metal halide (lack of durability, high maintenance costs).

High efficient metal halide are specialized lamps that do not need auxiliary electrode and bimetals in the inner section of metal halide. Compared to existing lamps they are superior in luminous flux, lumen retention, color uniformity, lighting equipments speed and temperature, leading to high energy savings.

Benefits of high efficiency metal halide is as belows,

- High luminous flux and efficiency: 20~40% higher luminous flux and

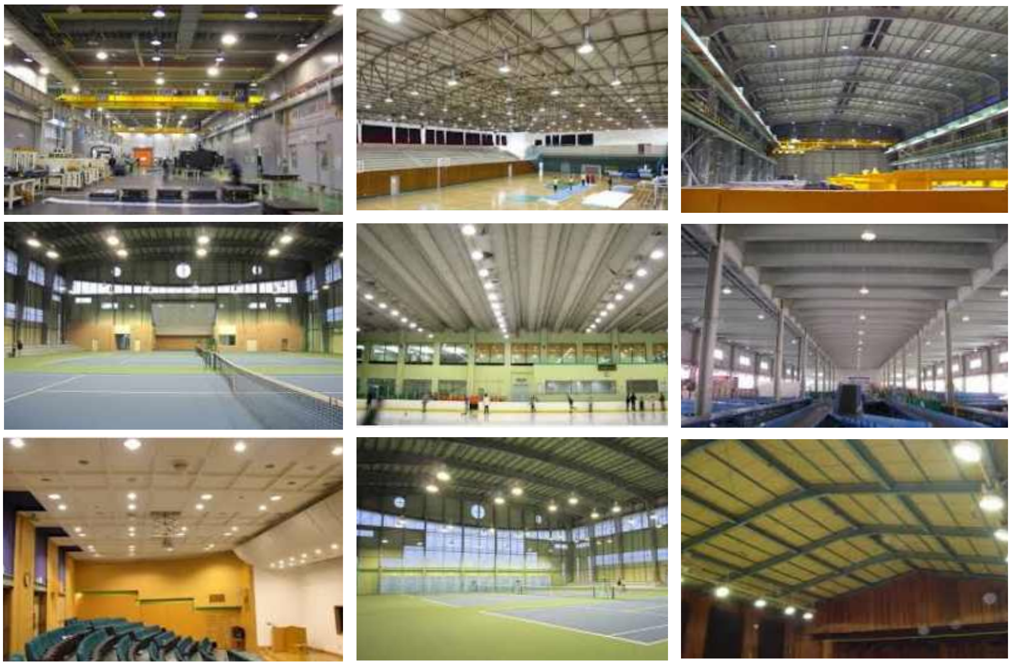
20~50% more efficient

- Service life extension: no need of auxiliary electrode, bimetal and electrical resistance. In addition, high filling pressure lead to enhancement of lumen thought reduction of abrasion of blackening. These characteristics lead to service life extension.
- Color uniformity: uniform temperature in the inner section of lamp lead to reduced fluctuation of lamp color, resuiting in uniform lamp color.
- Quick and low temperature lighting equipments: 60% faster than lighting equipments through auxiliary electrode and improved for lighting equipments to be possible even in temperatures below minus 40 degrees.
- Power saving: 25W～50W power savings through high luminous flux and high efficiency

<Table 2.13> Comparative of high efficiency and general metal halide lamp

Variable	High efficiency lamp			General lamp		
	150W	200W	350W	175	250	400
Electric energy consumption (W)	150	200	350	175	250	400
The speed of light (Lm)	14,000	20,500	34,000	14,000	20,500	34,000
Optical efficiency (lm/W)	93	103	97	80	82	85
Color temperature (K)	4,000 ± 200	4,000 ± 200	4,000 ± 200	4,000 ± 300	4,000 ± 300	4,000 ± 300

Reference: Association of LED, 2016.5



<Figure 2.13> Application of high efficiency metal halide in various places

2.4.3 Induction Lamp

The Induction Lamp is a promising technology which features good efficiency and long life. The Induction Lamp was conceived early on by Nobel laureate J.J Thomson. It was not until the 1960s～1970s when patents for a practical Induction Lamp were filed by both General Electric and Philips (more on inventors at the bottom of this page). Even then it was not until the 1990s that Induction Lamps began to see use on a wider scale. They still have not reached full market potential yet and there is still work to do to improve the lamp.

Benefits of Induction Lamp are as belows;

- Longer life: no electrodes, electrodes fail in normal fluorescent lamps shortening life, the tungsten thins and brakes.

- Longer life: sealed tube, by not having electrodes the tube can be perfectly sealed, when seals go bad in regular fluorescent lamps gas escapes through the weakness and the lamp fails.
- Energy efficient, often 80+ lumens per watt
- No flickering
- Dimmable 30～100%
- Can light both small and large areas depending on which type of Induction Lamp one uses

Workshop with induction lighting in India

Cow farm with induction lighting in France

Singapore Budger Airport

Induction lamp for road way lighting application in Chicago

Steel factory with induction lighting in USA

One Shop in Mexico

Lotus Supermarket

Guangdong Fenglu Aluminium Co.,Ltd

Shanghai Jiali food company

<Figure 2.14> Application of Induction Lamp in various places

But the disadvantages are as below;

- Bulky design for large area lighting, the discharge tube is large compared with HID lamps.
- Most companies that make the lamps are using 20 year old ballast technology copied from OSRAM and Philips. The ballasts have a high failure rate.
- The technology is under commercialized.
- Radio interference is a major problem to be worked out. The lamps are limited in use due to this issue.

2.5 Literature review

L.Chen et al., (2015) selected technical reliability, ease of operation and maintenance, initial cost, payback period, potential for operational carbon reduction.

The MCDM model based on Fuzzy PROMETHEE. Byoung-Min Kang et al., (2010) evaluate on the cooling systems of apartment house by MCDM. Choosed evaluation items are economics, space saving, rationality of charge, constructability, human comfort, landscape visibility, stability of system.

Seok-Man Han (2008) analyzed the power expansion planning model using MCDM. Seongkon Lee (2008) studied MCDM for developing GHG technologies strategically considering scale efficiency using AHP/DEA integrated model approach. Choosen criteria is Possibility of developing technology, Potential quantity of energy savings, market size, investment benefit, ease of technology spread.

The atmospheric greenhouse effect has greatly intensified the difficulties to people's lives in all countries. As a result, many studies related to factors affecting GHG emissions have been introduced.

And LEAP results have been published for numerous regions related with GHG emission reduction potential are China (Wenjia et al., 2007, Injia Cai et al., 2007, Nan Zhou et al., 2011), Thailand (Vatanavongs Ratanaveraha et al., 2015, Amit Kumar et al., 2003), India (Ezgi Akpinar-Ferrand et al., 2010), Estonia (Piret Kuldna et al., 2015), Croatia (Tomislav Puksec at al., 2014), Canada (Madeleine McPherson et al., 2014), Turkish (Seyithan et al., 2015).

Betul Ozer (2013) used LEAP model for an analysis of reduction of emissions in the electricity sector of Turkey.

Until 2007, the study of GHG emission reduction potential using LEAP modelling was done in European countries. But after 2007, the study is spread to global (<Table 2.14>).

<Table 2.14> Researches using MCDM modelling

Authors	Criteria	Method
Byoung-Min Kang et al., (2010)	economics, space saving, rationality of charge, constructability, Human comfort, Landscape visibility, stability of system.	AHP
L.Chen et al., (2015)	technical reliability, ease of operation and maintenance, initial cost, payback period, potential for operational carbon reduction	Fuzzy PROMETHEE
Seongkon Lee et al., (2008)	Possibility of developing technology, Potential quantity of energy savings, market size, Investment benefit, Ease of technology spread	AHP/DEA
Anjali Awasthia et al., (2002)	Transport, Costs, Environmental Impact, Accessibility, Security, Connectivity to multimodal Proximity to customers, Proximity to suppliers, Resource availability	TOPSIS
TuncayOzcan et al., (2011)	Unit price, Stock holding capacity, Average Distance to shops, Average distance to main supplier, Movement Flexibility	AHP, TOPSIS, ELECTRE
Mohammad SaeedZaeri et al., (2011)	Urgent delivery, On time delivery, Ordering cost, Warranty period, Product price, Financial stability, Delivery lead time, Accessibility, Reliability, Transportation cost, Rejection of defective product, Cost of support service, Testability	TOPSIS
DoraidDalalah et al., (2011)	Unit price and payment terms, delivery terms, supplier factory capacity, shipping method, lead time, location of can supplier, technical specifications, services and communications with the supplier, compensation for waste, major customers with the dame business, certificate of supplier	TOPSIS
SaharRezaiana et al., (2012)	Environment of the powerplants, health-safety risks, technological risks, the affected environment risks	AHP

Chapter 3. Methodology

3.1 KOC project

The Ministry of Environment (MOE) introduced KOC scheme for suppling carbon credits in K-ETS and gave emission reduction options to companies.

The Government opened 16 approved methodologies at 2015 and 6 more approved methodologies at 2016. Once a methodology has been approved, it may be used by other project proponents for similar project activities. However, in conducting validation, Korea Environmental Cooperation (KECO) may need to submit a request for clarification relating to the application of approved methodologies to proposed new project activities.

The Korean offset scheme allows emission-reduction projects in domestic market to earn Korea Offset Credits (KOC), each equivalent to one tonne of CO_2. These KOC can be traded and sold, and used by companies to a make up their emission reduction targets under the K-ETS.

Benefits of KOC projects include investment in climate change mitigation projects in Korea, transfer or diffusion of technology in the SMEs, as well as improvement in the livelihood of communities through the creation of employment or increased economic activity.

In approved methodologies (<Table 3.1>), demand-side activities for efficient lighting equipments technologies (03A-005) is selected. This is an area where energy savings can be easily made by replacing inefficient lighting equipments with more cost-effective and energy efficient alternatives.

In case of Fuel switching to wood pallet (01A-001) and Fuel switching to wood pallet in gardening facility (01A-002), we don't have potential project because applied condition is limited with domestic wood pallet.

But most local fuel switching project use wood pallet from overseas country because of low price.

<Table 3.1> Approved KOC methodology in K-ETS at 2015

Number	Name
01A-001	Fuel switching to wood pallet
01A-002	Fuel switching to wood pallet in gardening facility
01A-003	Fuel switching to rise husks in RPC[4] grain drier
01B-001	Grid-connected electricity generation from renewable sources
01B-002	Using geothermal energy in gardening facility
01B-003	Solar water heating systems
03A-002	Fuel switching
03A-003	electricity saving facility
03A-004	Introduction of an efficiency improvement technology in a facility
03A-005	Demand-side activities for efficient lighting technologies
03A-006	Demand-side activities for efficient outdoor and street lighting technologies
07A-001	Manufacturing Bio CNG[5] for vehicle fuel
13A-001	Generating thermal energy using waste wood
13A-002	Recovery and utilization of waste gas in sewage treatment plant
13A-003	Recovery and utilization of bio gas in gardening facility
14A-001	Afforestation and reforestation

And object of other methodologies is not common supply area. But almost every companies and buildings have light equipments. Especially, switching from low efficiency devices to high efficiency ones like LED is ongoing.

Lighting equipments accounts for approximately 17.28% (Korea Association for photonics industry development, 2014) of the total electric power consumption in Korea industrial and commercial sector. Low efficiency devices, such as incandescent lamps and ordinary fluorescent lamps, still dominate local lighting sector, leading to high electric consumption. Saving electricity on

4) Rice processing complex

5) Compressed natural gas, methane stored at high pressure

lighting equipments will both mitigate electric power supply shortages and create tremendous potential for protecting the environment.

Metal Halide downlights have become a popular choice for many plants, but are not energy efficient. Not only do they increase lighting equipments costs, but also often increase heating costs as installing downlights can cause gaps in ceiling insulation. Referring to previous research practices for high-efficiency lighting equipments replacement, Kangwon National University had assumed a situation to replace 30% of the total lighting equipments to energy efficient LED lighting equipments for calculation of GHG reduction potential.

According to Yeongjin Jeong et al, there are study results on achieving 43.4% of savings by replacing all lighting equipments of Daegu University to LED through year 2020.

This methodology comprises activities that lead to efficient use of electricity through the adoption of energy efficient light bulbs to replace less energy efficient light bulbs in plants applications.

The lamps adopted to replace existing equipment must be new equipment and not transferred from another activity. The total lumen output of a lamp should be 90% to 150% than that of the baseline lamp being replaced. The assumed baseline scenario is that lighting equipments by the project lamps would have been provided by the lamps collected and replaced by the project activity.

The project activity enhances the efficiency of lighting equipments in plants and thereby reduces electric consumption of the plants. Emission reduction amount is calculated based on grid emission factor ($EF_{CO_2 ELEC,y}$) and the electric consumption is saved by the plants as a result of the project activity, using equation. Project proponents may replace the default values by project specific values derived through research, studies or surveys, as applicable (<Table 3.2>).

<Table 3.2> Boundary of emission source and GHG

Source		GHG	Calculation	Contribution
Baseline	Power plants servicing the electricity grid	CO_2	Yes	Main source
		CH_4	No	Minor source
		N_2O	No	Minor source
Project activity	Power plants servicing the electricity grid	CO_2	Yes	Main source
		CH_4	No	Minor source
		N_2O	No	Minor source

- BEy (Baseline emission) (1)

$$\mathbf{BE_y = \eta_i \times \rho_i \times o_i \times EF_{grid}}$$

η_i = *Number of types of equipment i(unit)*

ρ_i = *Watt of types of equipment i(W/unit)*

o_j = *annual operating hours of equipment i(hour/year)*

EF_{grid} = *Emission factor in year(tCO₂eq/MWh)*

- PEy (Project emission) (2)

$$\mathbf{PE_y = \eta_i \times \rho_i \times o_i \times EF_{grid}}$$

η_i = *Number of types of equipment i(unit)*

ρ_i = *Watt of types of equipment i(W/unit)*

o_j = *annual operating hours of equipment i(hour/year)*

EF_{grid} = *Emission factor in year(tCO_2eq/MWh)*

- ERy (Emission reduction) (3)

$$\mathbf{ER = BE_y - PE_y - LE_y}$$

BE_y = *Baseline emission*

PE_y = *Project emission*

LE_y = *Leakage*

According to <Table 3.3>, the life of LED lamp is longer than other lamps. Electricity is flowed through a semiconductor, which is produced photons. Semiconductor is made with many different materials, which means that photon can be produced in a variety of colors. LED can produce more usable white light of unit energy than metal halide lamp, fluorescent, sodium vapour and halogen light sources. LED generate huge amount of light from small source, which help to control where the light shine. LED can source a great deal of glare if not manage properly.

LED, High efficiency metal halide and induction lamp have revolutionized energy efficient lighting equipments.

<Table 3.3> Type of lighting equipments and performance

Type of lighting equipments	Efficacy (lumens/w)	Lamp life (hrs)	CRI[1)]
Incandescent	11～20	750～2,000	100
Halogen	18～25	2,000～3,000	100
LED	50～100	25,000～100,000	70～90
Tubular Fluorescent	75～98	15,000～20,000	70～95
Compact Fluorescent	50～80	10,000	80～90
Metal Halide	60～94	7,500～20,000	60～80
High Pressure Sodium	63～125	15,000～24,000	20～80
High efficiency Metal Halide	80～110	3,000～10,000	65
Induction Lamp	80～	60,000～100,000	80

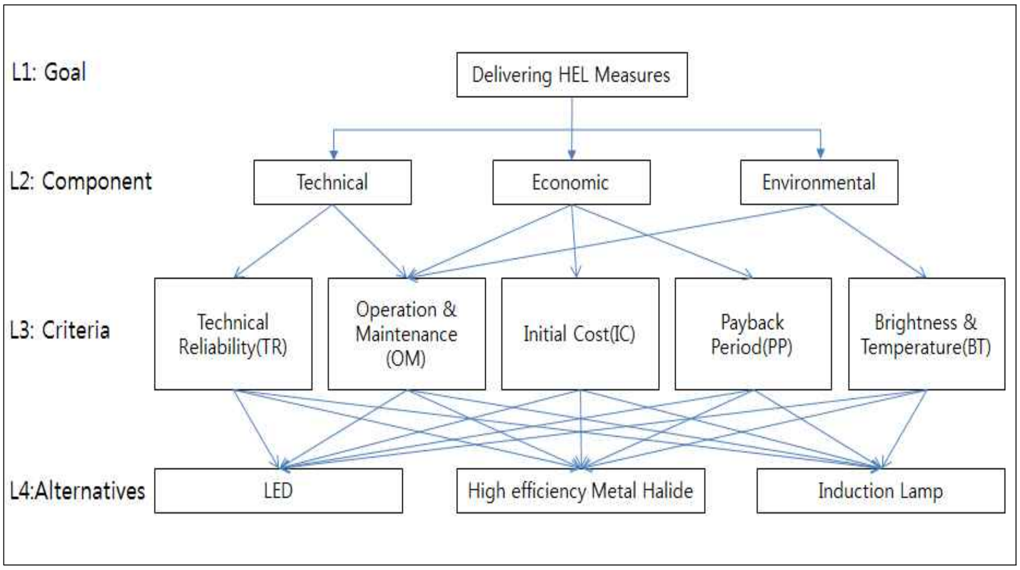
1) Color Rendering Index

Reference: American Society of Agricultural and Biological Engineers (ASABE), Lighting standard, 2016

3.2 MCDM modelling

The three candidates are LED, High efficiency metal halide and induction lamp.

Criteria is selected from the literature review which is based on a five. The criteria classify three dimensions: technical, economic and environmental related, with five criteria. Meanwhile, three High Efficiency Lamps (HEL) are also selected (<Figure 3.1>).



<Figure 3.1> AHP structure for HEL in this study

The information have collected from direct interview and a survey of companies as well as a review of the major relevant industry publications.

Iejung Choi (2014) analyzed using MCDM to quantitatively valuate the economic value of analysis model related to climate change mitigation and adaptation. The data gathered from 263 survey at May 2012.

The information gathered has been aggregated in a database of 300 survey from November 2015 to october 2016. Although the study received a very high level of cooperation from more Small and Medium-sized Enterprises (SMEs), the author are not able to obtain complete data for all SMEs.

<Table 3.4> Survey target and process

Target	· Decision maker for replace to HEL in SMEs * CEO or equipment operator
Scale	· Survey target: 300
Period	· November 2015～January 2016 · September 2016～October 2016
Approach	· E-mail, 1:1 Interview, regular mail

According to Saaty (1994), AHP method appropriate in making decision that involve decision element comparison what is difficult to assess quantitatively. This matter is based on assumption that human natural reaction when facing complex decision making, grouping the decision elements according to its common characteristic. This grouping include rank and then comparing between each group in a form of matrix. Afterward, inconsistency weight and ratio for each parts will be acquired. Thus, it will be ease in testing the data consistency.

The values are then organized using *pairwise comparison matrix*. Because of the limitation of human's brain capability, the ratio-scale is limited.

The scale range one to nine is used sufficiently representing human’s perception. The reason why the AHP method limits the ratio-scale 1–9, is according to the research conducted by a psychologist (Miller, 1956), which shows that human beings cannot simultaneity compare more than seven objects, either it increases or decreases two objects.

The Standard Preference Scale used in AHP is provided as follows (<Table 3.5>).

<Table 3.5> The pairwise comparison scale

Intensity of Importance	Definition
1	Equal importance of both elements
3	Week importance of one element over another
5	Essential or strong importance of one element over another
7	Demonstrated importance of one element over another
9	Absolute importance of one element over another
2, 3, 6, 8	Intermediate values between two adjacent judgements

Reference: http://hcil2.cs.umd.edu/trs/94-08/94-08.html

The main four steps of the AHP can be summarized as follows.

Step 1. Set up the hierarchical system by decomposing the problem into a hierarchy of interrelated elements/criteria.

Step 2. Compare the comparative weight between the attributes of the decision element to form the reciprocal matrix.

Step 3. Synthesize the individual subjective judgment and estimate the relative weight.

Step 4. Aggregate the relative weights of the elements to determine the best alternatives/strategies.

AHP is reviewed as follows. If wish to compare a set of η attributes pairwise according to relative weights, where the weight is denoted by $\omega 1$, $\omega 2$, ..., $\omega\eta$, then the matrix of weight ratios can be represented as (1).

$$\mathbf{W} = [w_{ij}]_{n \times n}, \tag{1}$$

where $\omega_{ij} = \omega^{-1}_{ji}$, $\omega_{ij} = \omega_{ik}\omega_{kj}$, and $\omega_{ij} = \omega_i/\omega_j$

Multiplying by the weight vector, ω, yields (2).

$$\mathbf{Ww} = \begin{bmatrix} \frac{w_1}{w_1} & \cdots & \frac{w_1}{w_j} & \cdots & \frac{w_1}{w_n} \\ \vdots & & \vdots & & \vdots \\ \frac{w_i}{w_1} & \cdots & \frac{w_i}{w_j} & \cdots & \frac{w_i}{w_n} \\ \vdots & & \vdots & & \vdots \\ \frac{w_n}{w_1} & \cdots & \frac{w_n}{w_j} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = n\mathbf{w} \tag{2}$$

or

$$(\mathbf{W} - n\mathbf{I})\,\mathbf{w} = \mathbf{0}. \tag{3}$$

Next, in order to estimate the weight ratio ω_{ij} by α_{ij}, where $A = [\alpha_{ij}]_{\eta\times\eta}$, we can calculate the approximate weights by finding the eigenvector w with respect to λ_{max} which satisfies (4).

$$\mathbf{Aw} = \lambda_{\max}\mathbf{w}, \tag{4}$$

Where λ_{max} is the largest eigenvalue of the matrix A. In addition, since A is approximate for W, consistency indexes (C.I) must be checked if the consistency condition is almost satisfied for A (5):

$$\text{C.I.} = \frac{\lambda_{\max} - n}{n-1}, \qquad (5)$$

Where λ_{max} is the largest eigenvalue and *n* denotes the numbers of the attributes. Saaty suggested that the value of the C.I. must not exceed 0.1.

According to Taylor III (2002), each human beings ideally wants consistent decision. The higher consistency ratio, the assessment result becomes more inconsistent. The acceptable consistency ratio is less than or equal to 10 percent, although in some cases the consistency ratio which is higher than 10 percent is still considered acceptable (Forman dan Selly, 2001)

According to Taylor III (2002), *Consistency Index (CI)* can be calculated by using formula as follows (6) (7):

$$CI = \frac{maks.\ eigenvalue - n}{n-1} \qquad (6)$$

$$maks.eigenvalue = \sum_i wi.ci \qquad (7)$$

After acquiring *Consistency Index (CI)*, the next step is calculating *Consistency Ratio* (*CR*) (8):

$$CR = CL/RI \qquad (8)$$

n	=	*Amount of items compared*
wi	=	*Weight*
ci	=	*Sum of column*
CR	=	*Consistency Ratio*
CI	=	*Consistency Index*
RI	=	*Random Consistency Index*

Random Consistency Index (*RI*) can be observed in Table 3.6 as follows (<Table 3.6>).

<Table 3.6> *Random Consistency Index*

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Reference: http://www.people.revoledu.com/kardi/tutorial/AHP/index.html, 2016

If $CR \geq 10\%$, the data acquired is inconsistent.
If $CR < 10\%$, the data acquired is consistent.

Saaty claims that an acceptable consistency ratio should be less than 0.1, although a ratio of less than 0.2 is considered tolerable. (William C. Wedley, 1993) (<Table 3.7>).

<Table 3.7> Saaty's Cut-off consistency indexes

Cases	Size of Matrix						
	3	4	5	6	7	8	9
Acceptable (10%)	0.58	0.9	0.112	0.124	0.152	0.141	0.145
Tolerable (20%)	0.116	0.18	0.224	0.248	0.264	0.282	0.290

Reference: William C. Wedley, Consistency Prediction for incomplete AHP matrices, Mathl. Comput. modelling, 1993

The test of consistency is very useful in the AHP. So in this study, Saaty's Cut-off consistency indexes <Table 3.7> is used. If the test result is inconsistent, then the result from the AHP method is of no use in decision making.

For the AHP, a near consistent matrix A with small reciprocal multiplicative perturbation of consistent matrix is given by (9).

$$\mathbf{A} = \mathbf{W} \cdot \mathbf{E}, \tag{9}$$

W=$[\omega_{ij}]_{n\times n}$ is the matrix of weight ratios, and E=$[\varepsilon_{ij}]_{n\times n}$ is the perturbation matrix, where $\varepsilon_{ij} = \varepsilon^{-1}_{ji}$.

It can be seen that (10) (11):

$$\sum_{j=1}^{n} a_{ij} w_j - \lambda_{\max} w_i = 0, \tag{10}$$

$$\lambda_{\max} = \sum_{j=1}^{n} a_{ij} \frac{w_j}{w_i} = \sum_{j=1}^{n} \varepsilon_{ij}. \tag{11}$$

On the other hand, the multiplication perturbation can be transformed to an additive perturbation of a consistent matrix such that (12):

$$\sum_{j=1}^{n} \frac{w_i}{w_j} \varepsilon_{ij} = \sum_{j=1}^{n} \frac{w_i}{w_j} + \nu_{ij}, \tag{12}$$

where ν_{ij} is the additive perturbation.

Since $\sum_{j=1}^{n} a_{ij} w_j / w_i = \sum_{j=1}^{n} \varepsilon_{ij}$, we can rewrite (12) as

$$\begin{gathered} \sum_{j=1}^{n} \left(\frac{w_i}{w_j} a_{ij} \frac{w_j}{w_i} \right) = \sum_{j=1}^{n} \left(\frac{w_i}{w_j} \varepsilon_{ij} \right) = \sum_{j=1}^{n} \left(\frac{w_i}{w_j} + \nu_{ij} \right), \\ \sum_{j=1}^{n} \nu_{ij} = \sum_{j=1}^{n} \left(a_{ij} - \frac{w_i}{w_j} \right). \end{gathered} \tag{13}$$

On the basis of (11) to (13), it can be seen that $\lambda_{max} = \eta$ if and only if all ε_{ij}=1 or v_{ij}=0, which is equivalent to having all $\alpha_{ij}=\omega_i/\omega_j$, indicates the consistent situation. Therefore, the problem of deriving relative weight among portion in the AHP is equivalent to solving the mathematical programming problem to obtain ω_i: (14):

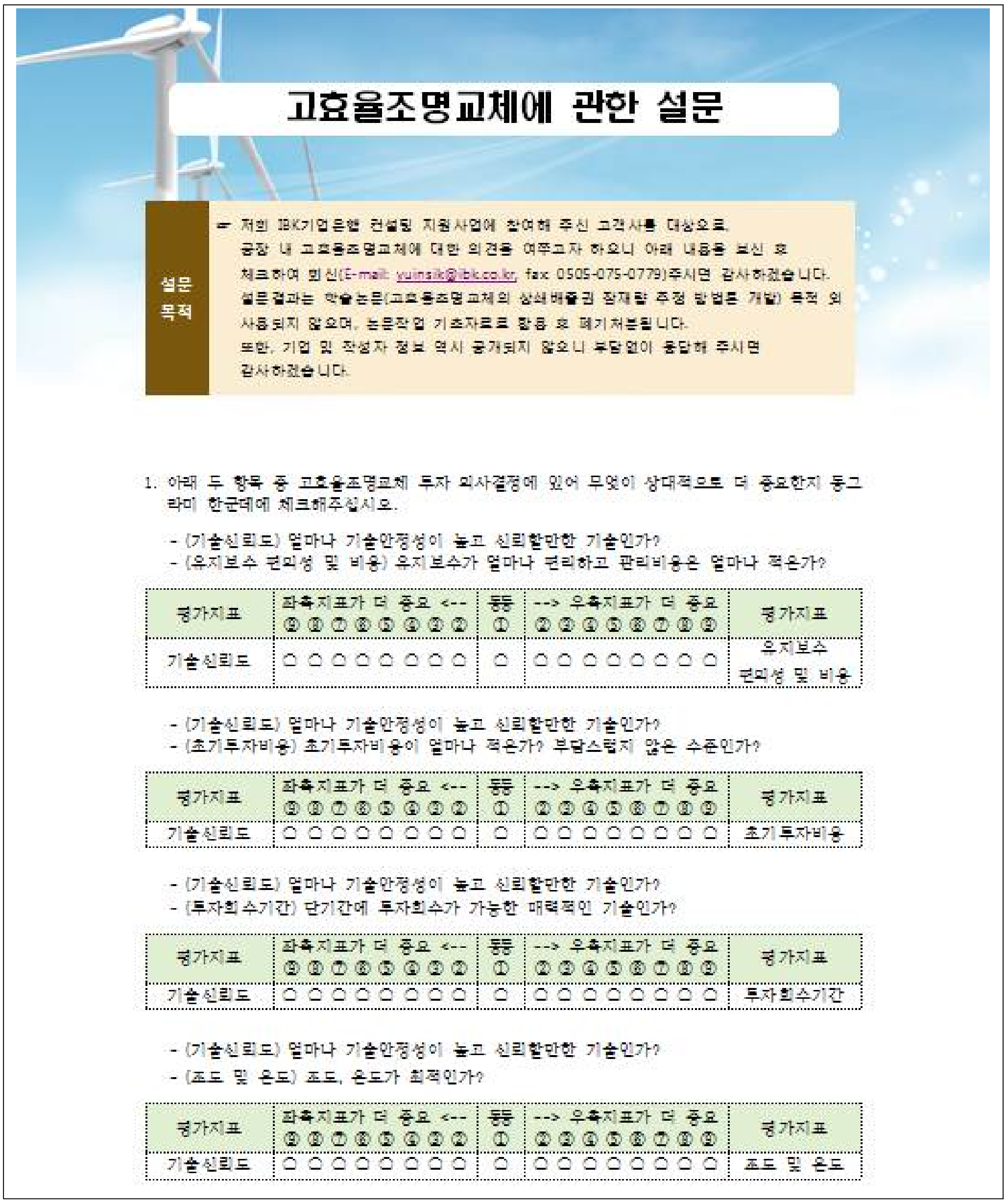
$$\min \sum_{j=1}^{n} \left\| a_{ij} - \frac{w_i}{w_j} \right\|_p \qquad \text{s.t.} \sum_{i=1}^{n} w_i = 1, \quad \forall 1 \leq i < j \leq n, \tag{14}$$

where ll·ll$_p$ denotes the ρ-norm and $\rho\epsilon \in \{1, 2, ...\}$. Note that, in this paper, we set ρ=2 in our model. and using open source from website (http://egloos.zum.com/yearjhyjh/v/33525)

<Table 3.8> AHP questions in this study

Technical Reliability (TR)									Operation and Maintenance (OM)							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Technical Reliability (TR)									Initial Cost (IC)							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Technical Reliability (TR)									Payback Period (PP)							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Technical Reliability (TR)									Brightness and Temperature (BT)							
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Although AHP is used in decision making, it cannot deal with the statement of correlation within criteria. We use <Figure 3.2> questionnaire.



고효율조명교체에 관한 설문

설문 목적

☞ 저희 IBK기업은행 컨설팅 지원사업에 참여해 주신 고객사를 대상으로,
공장 내 고효율조명교체에 대한 의견을 여쭈고자 하오니 아래 내용을 보신 후
체크하여 회신(E-mail: yuinsik@ibk.co.kr, fax 0505-075-0779)주시면 감사하겠습니다.
설문결과는 학술논문(고효율조명교체의 상쇄배출권 잠재량 추정 방법론 개발) 목적 외
사용되지 않으며, 논문작업 기초자료로 활용 후 폐기처분됩니다.
또한, 기업 및 작성자 정보 역시 공개되지 않으니 부담없이 응답해 주시면
감사하겠습니다.

1. 아래 두 항목 중 고효율조명교체 투자 의사결정에 있어 무엇이 상대적으로 더 중요한지 동그라미 한군데에 체크해주십시오.

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (유지보수 편의성 및 비용) 유지보수가 얼마나 편리하고 관리비용은 얼마나 적은가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	유지보수 편의성 및 비용

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (초기투자비용) 초기투자비용이 얼마나 적은가? 부담스럽지 않은 수준인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	초기투자비용

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (투자회수기간) 단기간에 투자회수가 가능한 매력적인 기술인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	투자회수기간

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (조도 및 온도) 조도, 온도가 최적인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	조도 및 온도

<Figure 3.2> AHP questionnaire in this study

3.3 LEAP modelling

In order to facilitate calculation of different High efficient lighting equipments profiles, a scenario based computer tool, LEAP[6] is chosen.

As such, LEAP enables top-down macroeconomic modelling simulation of the electric sector and capacity expansion planning over the medium to long-term.

Finally, LEAP incorporates a Technology and Environment Database (TED), which is a compilation of technical characteristics, costs, and environmental impacts for a range of High efficient lighting equipments from sources including the Intergovernmental Panel on Climate Change (IPCC[7]), LEAP was developed at the Stockholm Environment Institute, Boston. With the powerful accounting ability, LEAP can describe in detail about how energy is consumed, economic development, technology, price, and so on.

Furthermore, through comparing the results driven by different scenarios, the energy-saving potential in any target year or during the whole target period can be acquired.

LEAP has been widely-used in more than 150 countries, in particular for reporting to the UNFCCC (Stockholm Environment Institute, 2011).

The analytical procedure of LEAP model in this study is described in Figure 2.9～2.11. Content in the frame of broken lines should be illuminated both in baseline, abatement scenario and KOC supply scenario.

The procedure can be summarized as two steps: sectoral projection. corresponding energy demand and GHG emission.

---

6) Long range Energy Alternatives Planning System is a software tool for energy policy analysis and climate change mitigation assessment (Stockholm Environment Institute).

7) Scientific and intergovernmental body under the auspices of the United Nations, set up at the request of member governments, dedicated to the task of providing the world with an objective, scientific view of climate change and its political and economic impacts (http://www.ipcc.ch).

A baseline scenario, abatement scenario and KOC supply scenario have been generated in the model. Differences among the each scenarios are listed in (<Table 3.9>).

<Table 3.9> Scenarios in this study

Scenario	Policy and measure	Description
Baseline scenario	No mitigation options considered	- Use existing lighting equipments in industrial, commercial sector
Abatement scenario	Replacing in efficient lighting equipments with more cost effective and energy efficient alternatives	- Replace existing lighting equipments with HEL in industrial, commercial sector * Existing Metal Halide (over 150W) is consider to replace between LED, High efficiency metal halide and induction lamp
KOC supply scenario	Emission reduction amount can sell in K-ETS as KOC	- Case1: KOC potential when carbon price is 5,000 won - Case2: KOC potential when carbon price is 10,000 won - Case3: KOC potential when carbon price is 30,000 won - Case4: KOC potential when carbon price is 100,000 won

3.3.1 Baseline scenario

A baseline scenario represents the energy pathway that is implied current lighting equipments using with including basically economic growth. And no mitigation options and national GHG emission reduction road map considered.

In baseline scenario, sector information (industrial, commercial definition, sector growth rate, electric consumption, light setting status, etc) must be set up. After basic information searching, energy consumption and GHG emission will be estimated using LEAP modelling.

This study initiate by starting from acquisition of information from industrial and commercial sector (including public sector) considering the possibility of KOC project implementation. At first information from National Statistical Office is examined in order to check the percentage of electric consumption of each sector from the total electric consumption.

As a result, based on year 2013 the electric consumption of industrial sector (agriculture, forestry, mining, manufacturing and construction) is 255,854GWh which is approximately 55% of the total electric consumption (469,226GWh) (<Table 3.10>).

<Table 3.10> Electric consumption in each sector

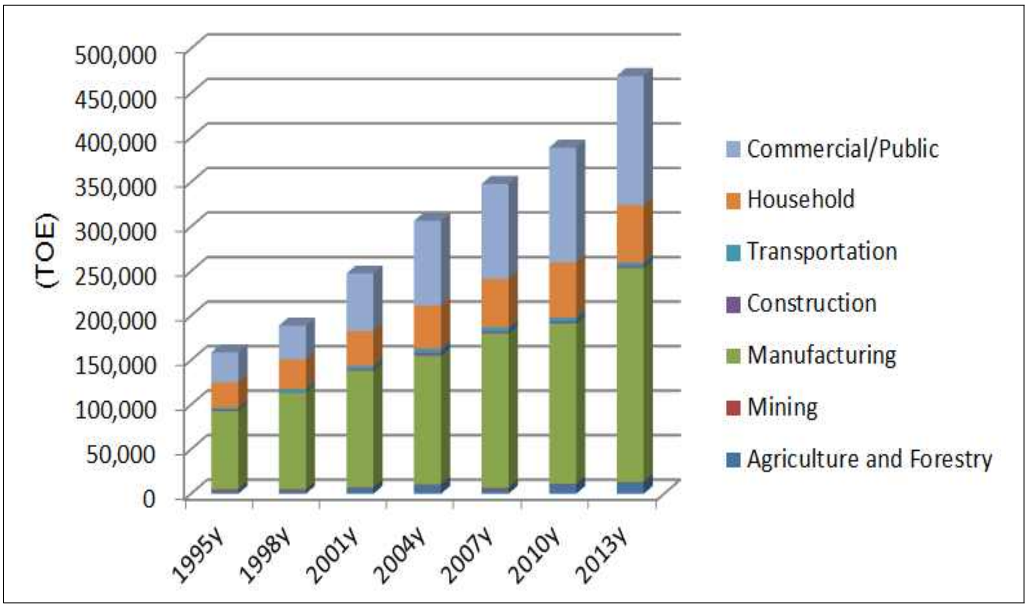
(Unit : GWh/year)

Sector		1995	1998	2001	2004	2007	2010	2013
Industry	Agriculture and Forestry	3,465	3,981	6,101	9,661	5,641	10,396	12,412
	Mining	1,437	983	905	853	991	978	1,005
	Manufacturing	88,206	108,810	131,265	144,508	173,506	179,748	240,221
	Construction	1,562	918	1,607	3,277	2,128	2,407	2,215
	Sub total	94,492	114,692	139,878	158,299	182,266	193,529	255,854
Transportation		1,966	3,243	3,855	4,563	4,735	4,551	3,744
Household		28,809	32,763	39,058	48,792	54,373	61,836	64,546
Commercial/Public		33,484	38,125	64,559	94,812	106,583	128,806	145,082
Total		15,893	188,823	247,350	306,466	347,957	388,721	469,226

Reference: Electric Power Statistics Information System (EPSIS), 2016

Among them the electric consumption in manufacturing sector is 240,221GWh, which is the major source of consumption (94%) and it can be concluded that this manufacturing sector can be considered as a major target for replacement of high efficient lighting equipments.

In turn, electric consumption in commercial sector (including public sector) recorded 145,082GWh which is about 31% of the total consumption (<Table 3.11>). The total consumption of the two sectors are 85%, which turn out to be a major source of electric consumption (<Figure 3.3>).



<Figure 3.3> Energy Consumption by sector

Reference: Korean Statistical Information Service (KOSIS), 2016

<Table 3.11> Electric consumption of industrial and commercial sector

(Unit : MWh/year; %)

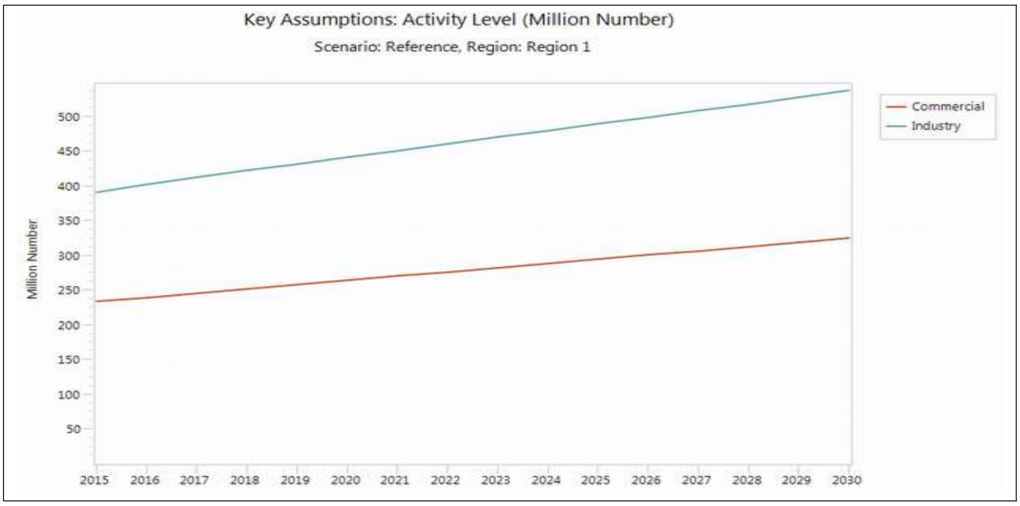
Year	industrial	Commercial
2012	249,135,684 (53.39)	153,921,115 (32.99)
2013	256,841,077 (54.1)	154,037,032 (32.4)
2014	264,617,621 (55.41)	150,298,770 (31.47)

Reference: Electric Power Statistics Information System (EPSIS), 2016

In baseline scenario, energy consumption maintains a consistent upward growth pattern. An increase in company number and electricity production are the main driving force for this.

1) Input data for industrial sector

In baseline scenario, the boundary of industry is defined from the KOSIS (Korean Statistical Information Service). The average growth rate between 2005 to 2014 is 2.1%. But, this study use forecasting data from KDI 2016 (<Figure 3.4>).



<Figure 3.4> The number of lighting instruments in baseline scenario

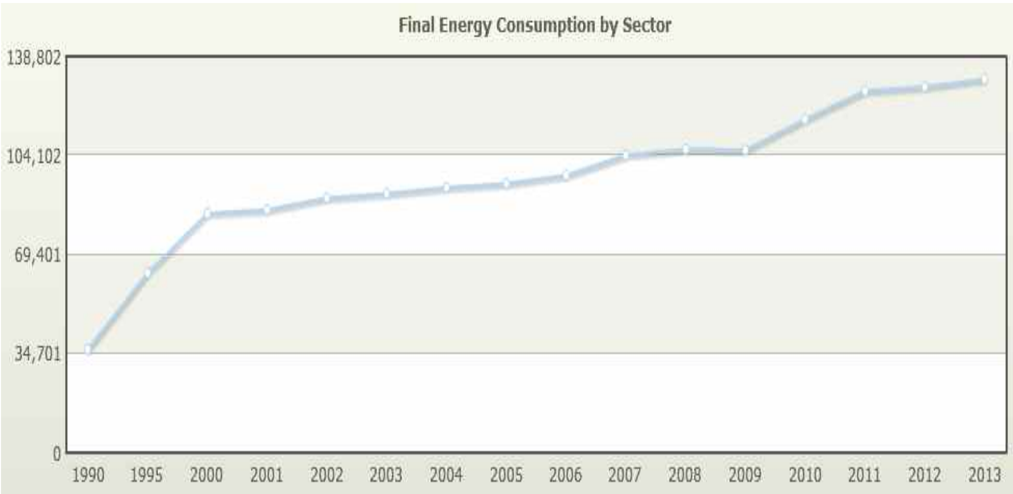
As this section includes every stakeholder including individual business, it is possible to examine the differences between this pattern. However, it is preferable to apply the rate of changes in number of manufacturing companies.

<Table 3.12> Growth rate of manufacturing sector

Scale and growth rate	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Number of companies (10^3)	2,868	2,940	2,977	3,047	3,069	3,125	3,235	3,354	3,419	3,452
Total employee (10^3)	11,902	12,234	12,613	13,070	13,398	14,135	14,534	14,891	15,345	-
Growth rate (%)	-	Δ2.51	Δ1.26	Δ2.35	Δ0.72	Δ1.82	Δ3.52	Δ3.68	Δ1.94	Δ0.95

Reference: Korean Statistical Information Service (KOSIS), 2016

Energy consumption status of industrial sector on 2014 was acquired from KOSIS (<Figure 3.5>).



<Figure 3.5> Energy consumption of industrial sector

Reference: Korean Statistical Information Service (KOSIS), 2016

The number of companies with energy consumption ranging from 0～100TOE and its electric consumption have been calculated based on the total number and total electric consumption of all companies. There is no such information on companies ranging from 500～2000TOE that has been studied or opened to the public.

The information on the number of companies (6,735 business establishment) have been obtained by survey results of KEA regarding SMEs energy diagnosis support program in the 2014. The information of electric consumption is also from KEA regarding the 1,000 companies ranging from 500-2000TOE which received energy diagnosis service. The total energy consumption is calculated under the assumption that based on the total electric consumption of 1,000 companies mentioned above (3,282,509KWh/year), the total 6,735 companies showed the same amount of electric consumption.

The results of electric consumption according to regional, sectoral and by size are only from companies exceeding 2,000TOE and the total electric consumption of companies exceeding 2,000TOE in the 2014 is 218,378MWh/year.

It can be deemed that data from application of actual data from KEA (Korea Energy Agency)’s 1,000 companies to 6,735 companies would be beyond the statistical significance level range.

This study carry out by following the guidelines from the study of 'Korea Association for Photonics Industry Development' in 2014. and the data of study proposed by 'Korea Association for Photonics Industry Development (KAPID)' and performed by 'Korea Photonics Technology Institute' in order to find methods to reduce electricity in the lighting sector through examining lighting equipments use status in industry and commercial sector.

The result is only source in Korea derived from on site study of industrial and commercial sector and the reliability of such data can be assured based on the fact that the study has been carried out from government owned agency.

This study selected total of 1,100 survey targets comprising of household, industrial and commercial sectors in 17 regions including major cities throughout Korea to find out lighting equipments use status in the industrial and commercial sector.

Basic direction of the sample design is to take advantage of the latest national energy statistics report for the reliability of the survey and the accuracy of the survey is enhanced by performing sample distribution based on idealistic standard design methodology.

The survey has been performed by distribution of survey samples to 374 samples in industrial sector and 377 samples in commercial sector by applying modified cut off method of households after stratification of industries listed in the Korean Standard Industrial Classification (KSIC) (<Table 3.13>).

<Table 3.13> Sampling scale by KAPID

Sector	Population (unit place)	Sampling size	Total volume of lamp	Extraction methodology
Industrial	Over 5 employee (1,714,380)	374	52,215	Stratified sampling
Commercial	Over 20 employee (1,755,654)	377	30,314	

Reference: Korea Association for photonics industry development (KAPID), Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3

For the industrial sector, manufacturing sector among national energy database has been selected as base line data of the population, and selection of 8 sectors as a population has been made according to the industry classification of KSIC.

As the standard deviation difference of amount of lighting equipments usage in each population was very large, complex sample survey through the distribution of companies in industrial sector in order to maintain estimation stability of each population has been performed.

For the commercial sector, commercial sector among national energy database has been selected as baseline data of the population, and selection of 11 sectors as a population has been made according to the industry classification of KSIC.

Sample extraction method by population has been performed by using stratified sampling. Allocated samples by each sector and population has been extracted such as the order of electricity usage in households and the order of the number of lighting equipments in industry and buildings.

Stratified sampling was a method of selecting companies by randomly selecting initial sets of companies in order of classification variable size then selecting next set of companies in same intervals.

The total number of lighting equipments recorded in 370 sample sites was identified as 52,215 and the majority of the numbers was linear fluorescent lamps and compact type fluorescent lamps.

The reason why the percentage of incandescent and halogen lamp is low is because most of the lighting equipments is to be turned on continuously but the efficiency of such lamp type is low compared to other types to be used.

In the investigated industrial sector, the percentage of LED is 9.3% <Table 3.14>. But still, the ratio of LED is very low compared to linear fluorescent lamps and compact type fluorescent lamps

<Table 3.14> Survey result on the utilization of lighting equipments apparatus

Incandescent lamp	Halogen lamp	Compact Fluorescent lamp	Tubular Fluorescent lamp	Metal halide	LED	Total lamp
352 (0.7%)	402 (0.8%)	19,427 (37.2%)	25,825 (49.5%)	1,343 (2.6%)	4,866 (9.3%)	52,215

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3

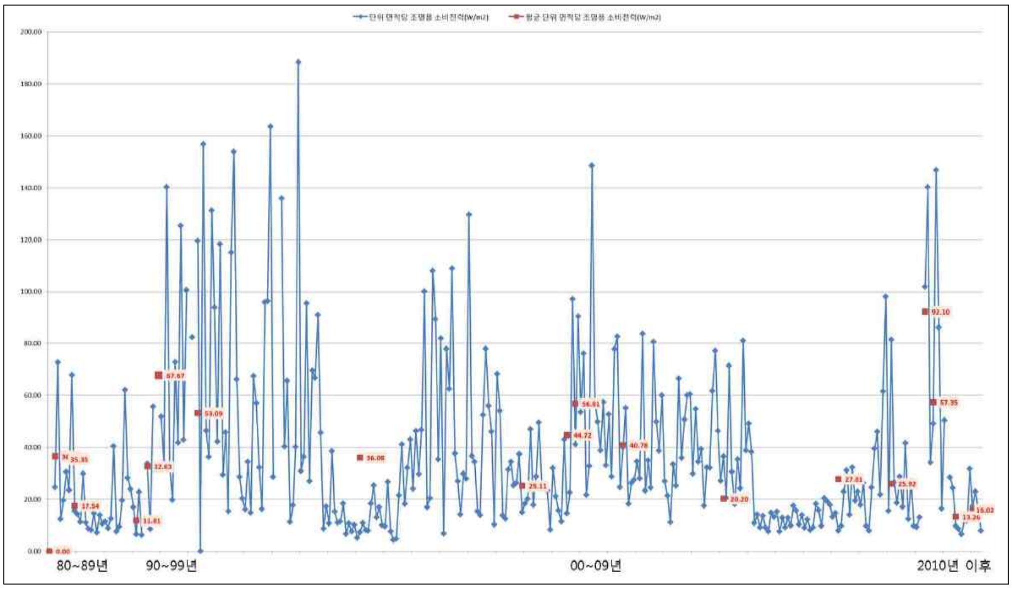
This report left out the survey for 250W and 400W metal halide. But, In manufacturing, the use of 250W and 400W metal halide is usual. The ratio should be corrected. So, raising greater emphasis on 12.34% percent by adding using of 250W and 400W metal halide (<Table 3.15>).

<Table 3.15> Corrected weight of survey result

(Unit: %)

Incandescent lamp	Halogen lamp	Compact Fluorescent lamp	Tubular Fluorescent lamp	Metal halide	LED	Total lamp
0.63	0.72	33.48	44.46	12.34	8.37	100

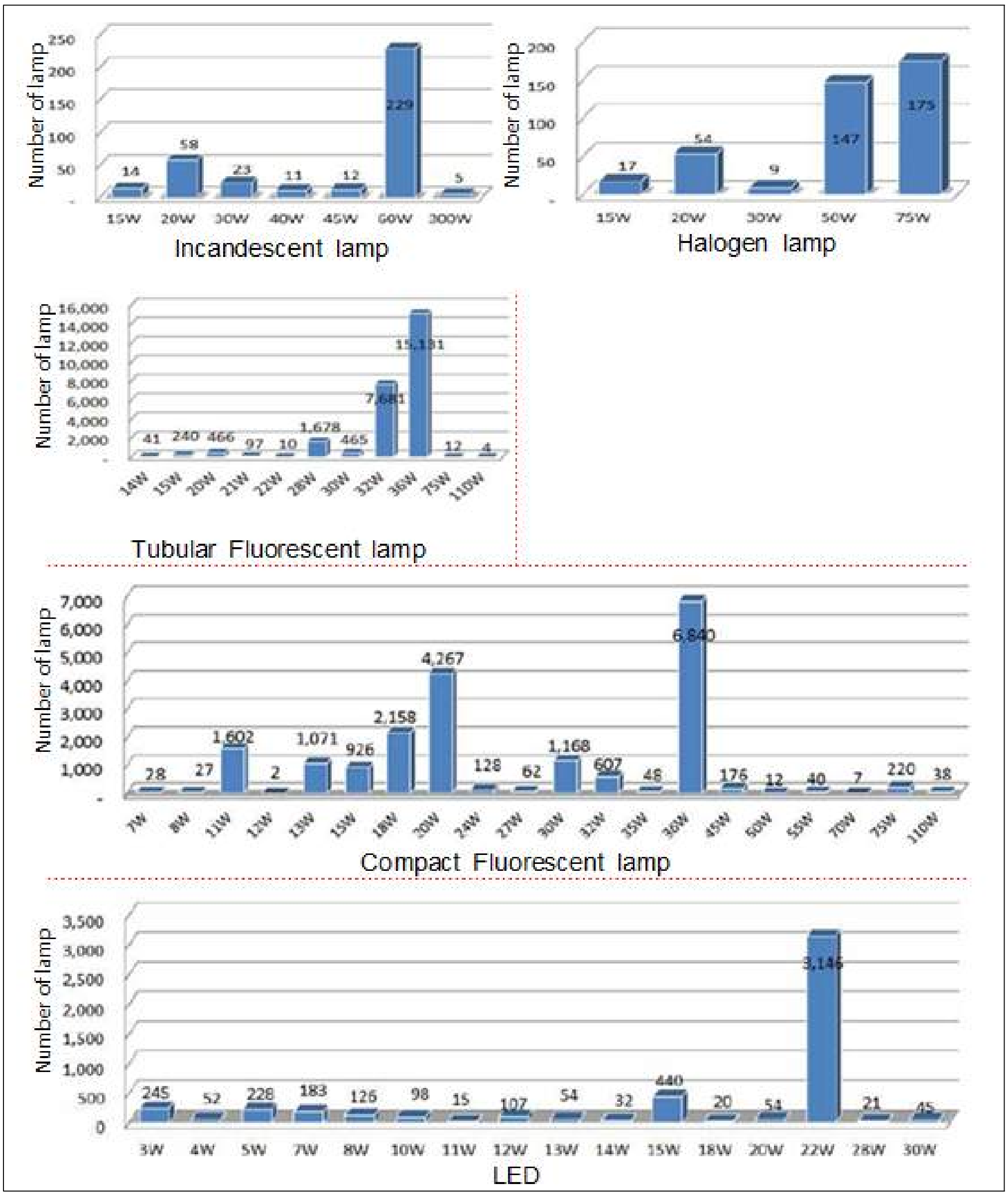
Among LED, products with power consumption of 22W are mostly used and products with power consumption of 15W are the next. According to this assessment paper, the average lighting equipments electric consumption per unit area in industrial sector is 20.86W/m^2 and there are no correlation between lighting equipments electric consumption per unit area according to its construction year.



<Figure 3.6> Electric consumption for unit area of industrial sector

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3

The number of lighting equipments by each capacity in industrial sector are as follows (<Figure 3.7>).



<Figure 3.7> The number of lighting equipments by each capacity in industrial sector

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3

<Table 3.16> Electric consumption for electric consumption

(Base year: 2014)

Variable of electric consumption (TOE)	Number of companies	Total electric consumption (KTOE/year)	Total electric consumption (MWh/year)	Source
0～100	140,069	n.a	n.a	
100～500	27,620	n.a	n.a	
500～1,000	4,522	590	14,843,506	KEA[1]
1,000～1,500	1,516	198	4,976,284	
1,500～2,000	697	91	2,287,909	
2,000～5,000	2,001	1,139	21,144,198	KOSIS[2]
5,000～10,000	824	1,149	18,028,794	
10,000～20,000	392	1,206	16,622,188	
20,000～50,000	270	1,776	22,575,709	
50,000～	290	11,387	140,007,598	
Total	178,201	-	264,617,621	

1) KEA: Korea Energy Agency
2) KOSIS: Korean Statistical Information Service
(Http://kosis.kr/statHtml/statHtml.do?orgId=115andtblId=DT_11507N_132andconn_path=I3)

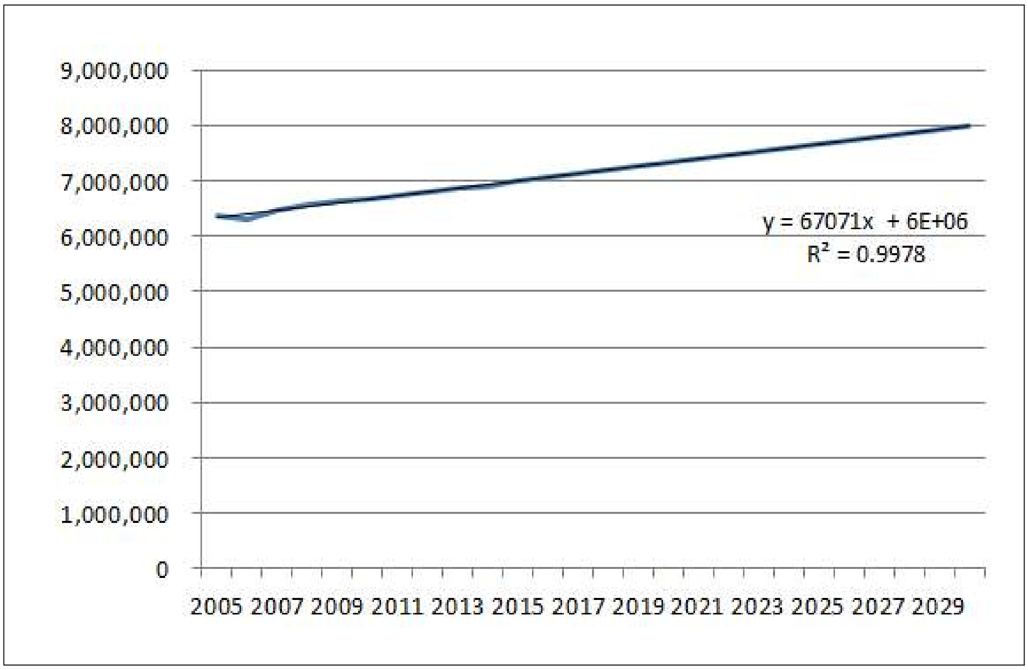
2) Input data for commercial sector

The boundary of commercial sector is defined from the KOSIS (Korean Statistical Information Service) also. The average growth rate from 2005 to 2014 is 0.9% (<Table 3.17>). But, this study use forecasting data from KDI 2016 (<Figure 3.8>).

<Table 3.17> Growth rate for commercial sector

Scale and growth rate	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14
Number of building (10^3)	6,370	6,290	6,460	6,557	6,618	6,677	6,732	6,796	6,852	6,911
Growth rate (%)	-	-1.25	Δ2.71	Δ1.49	Δ0.94	Δ0.88	Δ0.83	Δ0.96	Δ0.82	Δ0.87

Reference: Korean Statistical Information Service (KOSIS), 2016



<Figure 3.8> Forecasting curve of average growth rate of commercial sector

Reference: Korean Statistical Information Service (KOSIS), 2016

<Table 3.18> Survey result on the utilization of lighting equipments apparatus

Incandescent lamp	Halogen lamp	Compact Fluorescent lamp	Tubular Fluorescent lamp	Metal halide	LED	Total lamp
1,643 (5.4%)	2,391 (7.9%)	17,256 (56.9%)	1,639 (5.4%)	975 (3.2%)	6,393 (21.1%)	30,314

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3

The investigation on 250W and 400W metal halide have been omitted due to the fact that this study is mainly focused on lodging/food service industrial sector. In order to provide correction, the ratio of 250W and 400W metal halide have been increased (<Table 3.19>).

<Table 3.19> Corrected weight of survey result

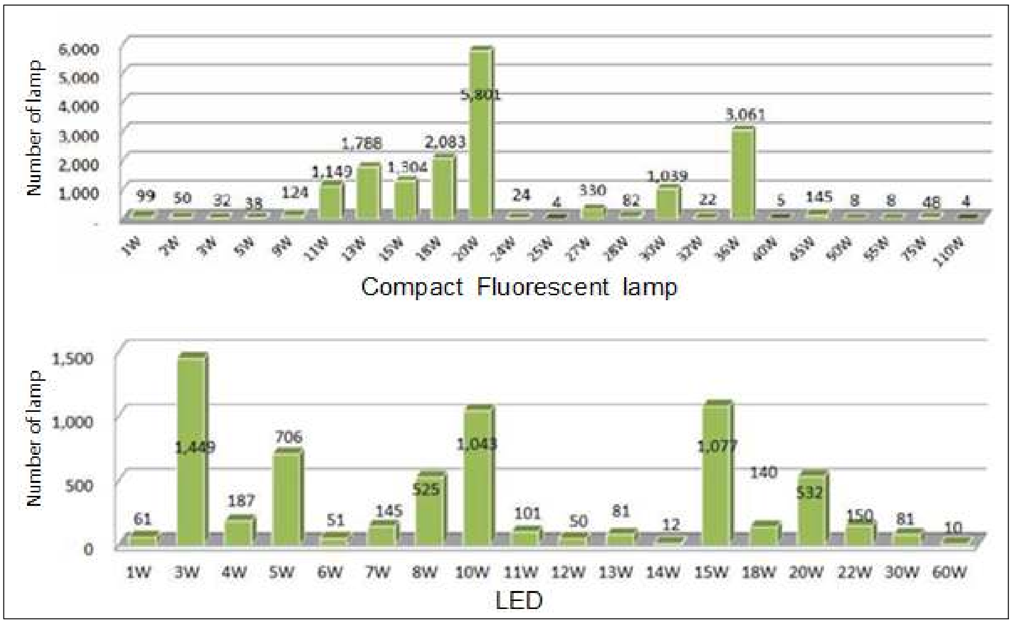
(Unit: %)

Incandescent lamp	Halogen lamp	Compact Fluorescent lamp	Tubular Fluorescent lamp	Metal halide	LED	Total lamp
5.3	7.7	56.9	6.5	5.1	18.4	100

In the case of lodging and food service industry, the use ratio of compact fluorescent lamps is high compared to other industrial sector.

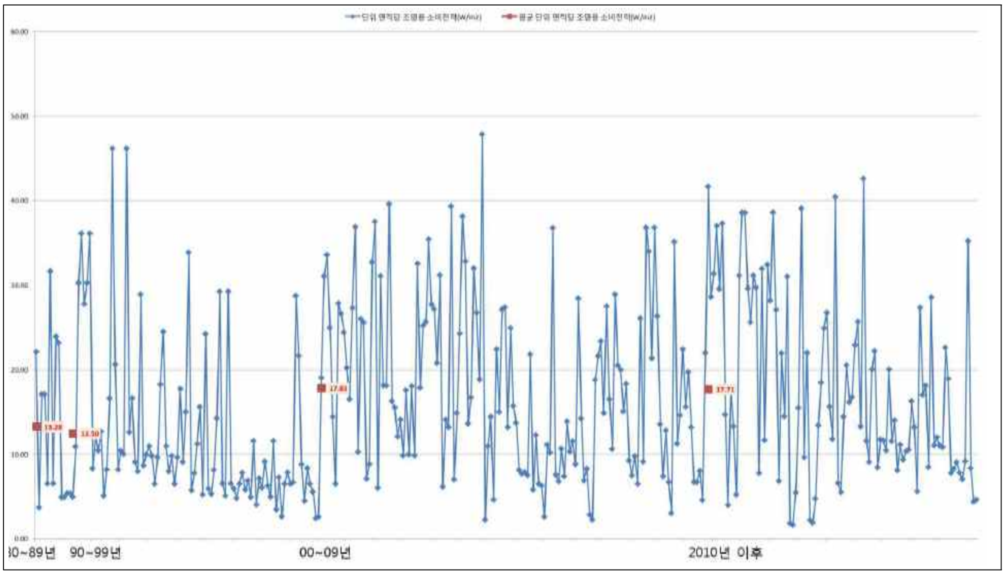
Total of 3 billion lighting equipments in all of Korea's companies have been estimated as a result of estimation based on total energy consumption and basic unit of each lighting equipments derived from 52,215 actual numbers from 370 sample sites.

The number of lighting equipments by each capacity in industrial sector are as follows (<Figure 3.9>).



<Figure 3.9> The number of lighting equipments by each capacity in commercial sector

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3



<Figure 3.10> Electric consumption for unit area of commercial sector

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014.3

<Table 3.20> Electric consumption of commercial sector

(Base year: 2014)

Variable of electric consumption (TOE)	Number of building	Total electric consumption (KTOE/year)	Unit electric consumption (KTOE/year·building)	Source
0～500	n.a	n.a	n.a	
500～1000	1,733	562	0.0561	Assumption
1000～2000	841	408	0.0838	
2000～3000	422	306	0.1253	KOSIS[1]
3000～5000	345	374	0.1873	
5000～10000	201	399	0.3430	
10000～20000	55	223	0.7006	
20000～30000	13	92	1.2229	
30000～	8	102	2.2032	

Reference: Korean Statistical Information Service (KOSIS), 2016
(Http://kosis.kr/statHtml/statHtml.do?orgId=115andtblId=DT_11507N_132andconn_path=I3)

<Table 3.21> The number of building for each type

(Number; Base year: 2014)

Building type	Energy consumption (TOE)					
	2,000 ~3,000	3,000 ~5,000	5,000 ~10,000	10,000 ~20,000	20,000 ~30,000	30,000 ~
Business	68	53	34	10	5	1
Public	14	9	10	6	-	1
Apartment	121	85	30	4	-	-
Hotel	21	23	12	6	3	1
Hospital	14	36	31	3	1	3
School	33	42	30	12	1	1
Telephone company	12	5	6	3	-	-
Research center	14	15	11	3	2	-
Department store	75	51	22	6	-	-
etc	50	26	15	2	1	-
Total	422	345	201	55	13	8

Reference: Korean Statistical Information Service (KOSIS), 2016
(Http://kosis.kr/statHtml/statHtml.do?orgId=115andtblId=DT_11507N_132andconn_path=I3)

3.3.2 Abatement scenario

The abatement scenario includes the addition of high efficiency light technologies. In abatement scenario, high efficiency lighting equipments information (MCDM approach between LED, High efficiency metal halide and Induction Lamp) will be set up. Investment payback time for each LED is used (<Table 3.22>).

<Table 3.22> Investment payback period for each type of lighting instruments

Type of lighting instruments	Energy consumption (W)	Payback period after replacing to LED (Year)															
		‘15	‘16	‘17	‘18	‘19	‘20	‘21	‘22	‘23	‘24	‘25	‘26	‘27	‘28	‘29	‘30
Incandescent lamp	15	0.5	0.4	0.3	0.2	0.2	0.1										
	20	0.5	0.4	0.3	0.2	0.2	0.1										
	60	0.4	0.3	0.2	0.2	0.1	0.1										
Halogen lamp	15	0.8	0.6	0.4	0.3	0.3	0.2	0.1									
	20	0.7	0.6	0.4	0.3	0.3	0.2	0.1									
	50	0.5	0.3	0.3	0.2	0.2	0.1										
	75	0.6	0.5	0.3	0.3	0.2	0.2	0.1									
Compact Fluorescent lamp	11	2.7	1.9	1.4	1	0.8	0.6	0.4	0.3	0.3	0.2	0.1					
	13	3.2	2.3	1.7	1.2	0.9	0.7	0.6	0.4	0.3	0.3	0.2	0.1				
	15	3	2.1	1.5	1.1	0.8	0.6	0.4	0.3	0.3	0.2	0.1					
	18	3	2.1	1.5	1.1	0.8	0.6	0.4	0.3	0.3	0.2	0.1					
	20	3.3	2.4	1.7	1.2	0.9	0.7	0.6	0.4	0.3	0.3	0.2	0.1				
	30	9	6.3	4.5	3.2	2.4	1.8	1.4	1	0.8	0.6	0.4	0.3	0.3	0.2	0.1	
	36	9.4	6.6	4.7	3.4	2.5	1.8	1.4	1	0.8	0.6	0.4	0.3	0.3	0.2	0.1	
Tubular Fluorescent lamp	28	6.6	4.5	3.2	2.3	1.7	1.2	0.9	0.7	0.6	0.4	0.3	0.3	0.2	0.1		
	32	6	4.1	2.9	2.1	1.5	1.1	0.8	0.6	0.4	0.3	0.3	0.2	0.1			
	36	5.9	4	2.8	2	1.5	1.1	0.8	0.6	0.4	0.3	0.3	0.2	0.1			
Metal halide	60	26.6	18.9	13.6	10	7.4	5.5	4	2.8	2	1.5	1.1	0.8	0.6	0.4	0.3	0.3
	70	25.9	18.3	13.2	9.7	7.2	5.4	4	2.8	2	1.5	1.1	0.8	0.6	0.4	0.3	0.3
	75	24.1	17.1	12.3	9	6.7	5	4	2.8	2	1.5	1.1	0.8	0.6	0.4	0.3	0.3
	100	21.1	15	10.8	7.9	5.9	4.4	3.2	2.3	1.7	1.2	0.9	0.7	0.6	0.4	0.3	0.3
	150	18.1	12.8	9.3	6.8	5	3.8	3.2	2.4	1.8	1.4	1	0.8	0.6	0.4	0.3	0.3
	250	15.7	11.2	8.1	5.9	4.4	3.3	2.4	1.8	1.4	1	0.8	0.6	0.4	0.3	0.3	0.2
	250	15.7	11.2	8.1	5.9	4.4	3.3	2.4	1.8	1.4	1	0.8	0.6	0.4	0.3	0.3	0.2
	400	13.1	9.3	6.8	4.9	3.6	2.8	2.1	1.5	1.1	0.8	0.6	0.4	0.3	0.3	0.2	0.1

Reference: Survey on the utilization of lighting apparatus and study on saving lighting power consumption, Korea Association for photonics industry development, 2014.3

3.3.3 KOC supply scenario

In KOC supply scenario, KOC market price and offset project risk will be searching with expert's interview.

KOC supply scenario differ from KOC carbon price in K-ETS. The average price of carbon credits in 2015 is 10,000 won and the average price increase to approximately 17,000 won in 1st half of 2016. The price of carbon credit fell after reaching 21,000 won for KAU and 20,300 won for KCU in May of 2016 to approximately 18,500 won. The price continued to fall after the market stabilization program (supply of 0.9million tons of carbon credit into the carbon market) from the government started during the first three days of June in 2016.

As seen from the results from the study mentioned earlier, the potential emission reduction potential from high efficient lighting equipments replacement is significant in terms of its absolute volume. Therefore, such emission reduction potential from these projects would have significant affect on the emission trading market.

Further details of this issue are discussed in the discussion section and in this chapter analysis on the possible amount of KOC that could be supplied into the emission trading market based on market price are performed.

In the analysis, initial costs regarding consulting services, monitoring and verification are considered and the expected lifetime of high efficient lighting equipments have been set to 10 years.

In other words, based on the assumption that the project crediting period is set to fixed (10 years which is the same to expected lifetime of high efficient lighting equipments), average administration costs are calculated as 40,000 won. If the results from the unit emission reduction of a project with carbon price reflected (revenue from carbon credits) exceeded 40,000 won annually, the project is assumed to be implemented as a KOC project.

However, due to the limitations in acquiring a suitable statistical data, it is difficult to finely perform a sensitivity analysis based on changes in carbon credit price. in this study with the limited access to the data, potential KOC projects based on carbon prices of 10,000 won (9,632) if the price has been adjusted to reflect carbon price to unit emission reduction to make up to 40,000 won, 5,000 won (4,652), 30,000 won (31,000) and 100,000 won (114,300) have been estimated.

As a result, in case of carbon price being 10,000 won (9,632) KOC project has turned out to be economically feasible for companies with energy consumption over 2,000TOE[8].

In other words, companies with energy consumption under 2,000TOE have no reason to implement such KOC projects due to the fact that the administration costs relevant to KOC project exceed the revenue from KOC or KCU sales (<Table 3.23>).

<Table 3.23> KOC sales profit of industrial sector for each KOC price

Energy Consumption (TOE)	Number of companies	Unit emission reduction (tCO_2eq/year)	KOC sales profit (10^3 won)			
			5,000 (4,652)	10,000 (9,632)	30,000 (31,000)	100,000 (114,300)
0~100	140,069	n.a	n.a	n.a	n.a	n.a
100~500	27,620	35.0	175	350	1,050	3,499
500~1,000	4,522	129.0	645	1,290	3,870	12,900
1,000~1,500	1,516	129.0	645	1,290	3,870	12,900
1,500~2,000	697	129.0	645	1,290	3,870	12,900
2,000~5,000	2,001	415.3	2,076	4,153	12,458	41,527
5,000~10,000	824	859.9	4,299	8,599	25,796	85,985
10,000~20,000	392	1666.4	8,332	16,664	49,993	166,643
20,000~50,000	270	3286.0	16,430	32,860	98,579	328,595
50,000~	290	18973.1	94,865	189,731	569,192	1,897,306

8) Unit of energy defined as the amount of energy released by burning one tonne of crude oil (http://www.aps.org)

It is possible for project sales profit to be considered as a surplus if the future carbon credit price is higher than the present. However, considering it is not a wise investment behavior by concentrating only on the positive outlook of the project and underestimating the future downside risk of carbon price, it is expected that the potential for the KOC project will drastically decrease.

<Table 3.24> Number of companies and energy consumption at each carbon price in industrial sector

Energy Consumption (TOE)	NUmber of companies and energy consumption at each carbon price (10^3 won)							
	5,000 (4,652)		10,000 (9,632)		30,000 (31,000)		100,000 (114,300)	
	a)	b)	a)	b)	a)	b)	a)	b)
0～100	0	0	0	0	0	0	0	0
100～500	0	0	0	0	0	0	27,620	4,250
500～1,000	0	0	0	0	4,522	2,565	4,522	2,565
1,000～1,500	0	0	0	0	1,516	860	1,516	860
1,500～2,000	0	0	0	0	697	395	697	395
2,000～5,000	0	0	2,001	3,654	2,001	3,654	2,001	3,654
5,000～10,000	824	3,115	824	3,115	824	3,115	824	3,115
10,000～2,0000	0	0	0	0	0	0	0	0
20,000～50,000	0	0	0	0	0	0	0	0
50,000～	0	0	0	0	0	0	0	0
Sum	824	3,115	2,825	6,769	9,560	10,589	37,180	15,894

a) Number of companie, b) Energy consumption (GWh/year)

In case of carbon price being 5,000 won (4,652) KOC project has turned out to be economically feasible for companies with energy consumption over 5,000TOE. In addition, in case of carbon price being 30,000 won (31,000) KOC project on companies with energy consumption over 500TOE turned out to be economically feasible.

Also in case of carbon price being 100,000 won (114,300) KOC project on companies with energy consumption over 200TOE turned out to be economically feasible.

Based on the analysis above, the scale (or size) of target company are calculated to examine KOC project potential by each carbon price.

In this calculation, companies not eligible to perform KOC projects such as companies under the regulation of emission trading scheme or emissions target management scheme are excluded.

The target companies are those companies with energy consumption of over 10,000TOE. As a result, companies eligible for the KOC project have significantly decreased.

The number of companies eligible for implementation of KOC changed by the price of carbon credits. 2,825 companies are eligible for KOC projects when the carbon prices reached 10,000 won (9,632) but such numbers decreased to 824 projects when the carbon price decreased are set to 5,000 won (4,652). In turn, 9,560 and 37,180 companies are eligible for KOC projects when the carbon price is set to 30,000 won (31,000) and 100,000 won (114,300) respectively. By examining the results, it can be concluded that the rate of change of KOC project potential based on different carbon price is very large because when the carbon price increased by 2,000% from 5,000 won to 100,000 won the potential KOC projects increased by 4,512%, in which the increase rate is more than 2 times larger.

As in the case of industrial sector, data for buildings showing less than 2,000TOE in the commercial sector has been analyzed through estimation because there are no such relevant statistical data available.

The number of buildings showing energy consumption rate range between 500~2,000TOE have been estimated under the assumption that the patterns regarding the number of buildings in the commercial sector would be similar to industrial sector. The electric consumption amount per unit lighting equipments has been estimated by applying the same reduction ratio of electric consumption amount per unit lighting equipments in buildings showing energy consumption amount from 3,000-5,000TOE to 2,000-3,000TOE. Such data can be deemed as the most unreliable part in performing this study.

More accurate results would hopefully be calculated in the future if the national statistical data on buildings showing less than 2,000TOE would be available or relevant research have been performed.

The results of the analysis showed KOC projects to be economically feasible for buildings showing over 3,000TOE when the carbon price is set to 10,000 won (11,087) in the emission trading market. In other words, there is no reason for buildings showing less than 3,000TOE to implement KOC projects due to the fact that the administration cost for KOC projects are larger than revenues from KOC or KCU. There is a possibility of surplus in revenue under the circumstance of carbon price increase, but there is also a possibility of downside risk. Therefore, it is expected that KOC project potential would drastically decrease due to the fact that consideration of only positive outlook for implementation of KOC projects is not an idealistic investment strategy.

When the carbon price is set to 5,000 won (6,062), buildings showing more than 5,000TOE are economically feasible for the implementation of KOC project. In addition, eligible buildings for implementation of KOC projects extend to buildings showing more than 1,000TOE when the carbon price is set to 30,000 won (31,250). Eligible buildings for KOC projects extended even further to buildings showing more than 500TOE when the carbon price is set to 100,000 won.

To be precise, buildings economically feasible for KOC projects under the carbon price of over 100,000 won are not exactly only the buildings showing more than 500TOE. In fact, there are buildings showing less than 500TOE economically feasible for implementation of KOC project but analysis on such buildings could not be performed due to lack of data for number of eligible buildings between 62,500~100,000 won carbon price range and unit emission reduction in Korea (Estimated revenue of buildings showing more than 500

TOE is 6.4million won when the carbon price is set to 100,000 won and the overall break-even point is carbon price at 62,500 won). However, it is difficult to implement such high efficient lighting equipments replacement project on buildings showing less than 500TOE based due to the fact that in terms of buildings the owner and the user of a building is usually different and it differs much compared to companies in which the owner and the user is usually the same. Based on this fact, it is assumed that in case of carbon price being 100,000 won, eligible candidates for KOC projects would reasonably be the ones showing more than 500TOE (<Table 3.25>).

<Table 3.25> KOC sales profit of commercial sector for each KOC price

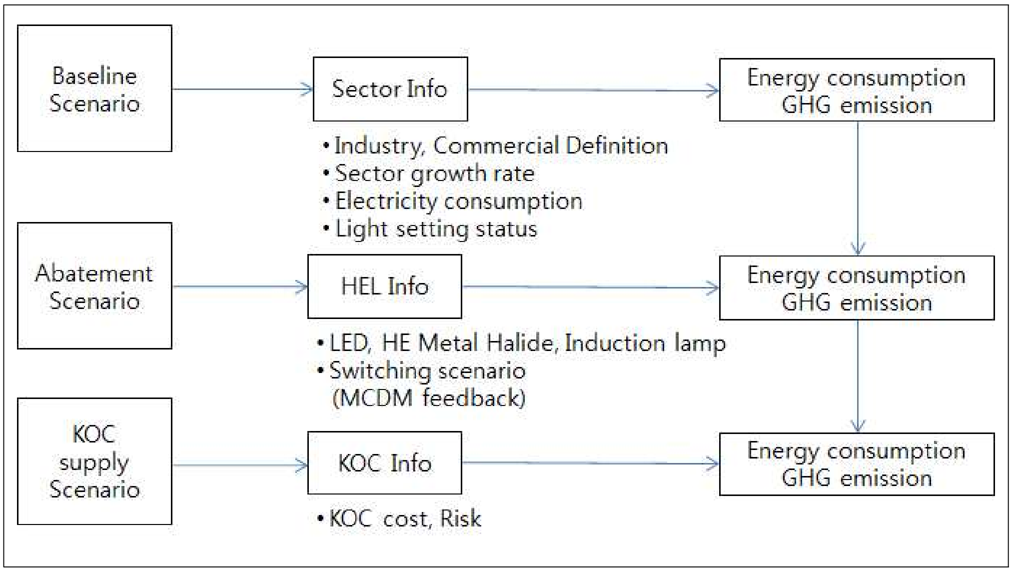
Energy Consumption (TOE)	Number of buildings	Unit emission reduction (tCO_2eq /year)	KOC sales profit (10^3 won)			
			5,000 (5,708)	10,000 (10,451)	30,000 (23,360)	100,000 (34,923)
0~500	n.a	n.a	n.a	n.a	n.a	n.a
500~1,000	1,733	114.5	573	1,145	3,436	11,454
1,000~2,000	841	171.2	856	1,712	5,137	17,124
2,000~3,000	422	256.0	1,280	2,560	7,680	25,600
3,000~5,000	345	382.7	1,914	3,827	11,482	38,272
5,000~10,000	201	700.8	3,504	7,008	21,025	70,082
10,000~20,000	55	1,431.4	7,157	14,314	42,943	143,144
20,000~30,000	13	2,498.5	12,492	24,985	74,954	249,848
30,000~	8	4,501.3	22,507	45,013	135,040	450,133

Based on the analysis above, the scale (or size) of target company are calculated to examine KOC project potential by each carbon price. In this calculation, companies not eligible to perform KOC projects such as companies under the regulation of emission trading scheme or emissions target management scheme are excluded. As a result, the number of eligible buildings for the implementation of KOC projects have drastically decreased similar to results on companies (<Table 3.26>)

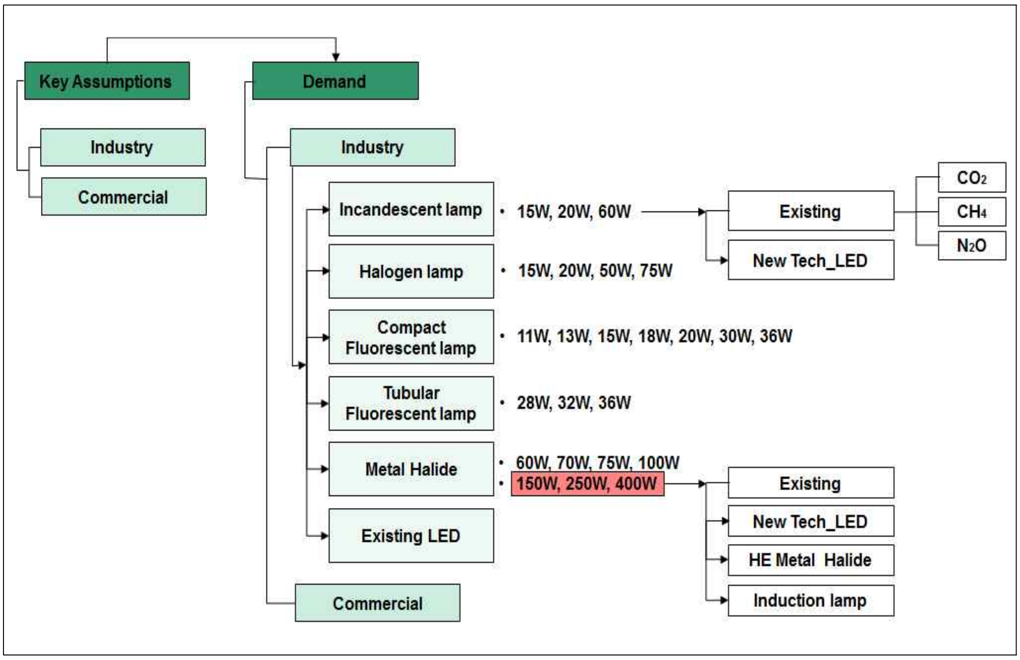
<Table 3.26> Number of companies and energy consumption at each carbon price in building sector

Energy Consumption (TOE)	Number of companies and energy consumption at each carbon price (10^3 won)							
	5,000 (5,708)		10,000 (10,451)		30,000 (23,360)		100,000 (34,923)	
	a)	b)	a)	b)	a)	b)	a)	b)
0~500	0	0	0	0	0	0	0	0
500~1,000	0	0	0	0	0	0	1,733	97,173
1,000~2,000	0	0	0	0	841	70,452	841	70,452
2,000~3,000	0	0	0	0	422	52,877	422	52,877
3,000~5,000	0	0	345	64,627	345	64,627	345	64,627
5,000~10,000	201	68,947	201	68,947	201	68,947	201	68,947
10,000~20,000	0	0	0	0	0	0	0	0
20,000~30,000	0	0	0	0	0	0	0	0
30,000~	0	0	0	0	0	0	0	0
Sum	201	68,947	546	133,574	1,809	256,904	3,542	354,076

a) Number of companie, b) Energy consumption (GWh/year)



<Figure 3.11> Modelling Structure of scenarios in this study



<Figure 3.12> LEAP modelling structure for each lighting equipments

3.4 Decision making factor for KOC Project

KOC project and GHG reduction potential is a completely different concept. However, in many cases KOC project and GHG reduction potential are deemed as a similar one.

It is true that KOC originated from GHG reduction but two are distinctly different. In terms of potential scale GHG emission reduction potential is larger than KOC potential. The reason for this is that there are additional costs in order to generate KOC.

Therefore, the amount of potential GHG reduction that can be switched to KOC based on the amount of additional cost is important. However, there are still many cases of incorrect estimation through misunderstanding of differences between potential GHG reduction and KOC potential.

Park (2010) have calculated GHG emission reduction and expected CER through replacement of 99% of incandescent lamps in public institutions in Korea (Park, Youn mi et al, 2010).

The results came out to be over estimated because the administration costs regarding CER is not considered. in the study, procedure, methodology, investment cost and relevant risks of KOC project have been collected and analysed through interviews with companies in the relevant industry.

KOC potential scenario will be developed by incorporating concerns of what can be achievable. It considers many factors (economic, institutional, cultural, legal, etc) that may limit the implementability of the technically available options (X.Zhao, A. Michaelowa, 2006).

In case of selected KOC methodology, such projects would still be relatively small scale compared with other KOC projects in the Korean offset scheme. The main barrier for high efficiency lighting equipments project is relatively large consulting and verification fee.

Despite the co-benefits of KOC, companies should bear in mind that KOC is not a panacea of all funding needs.

In order to assist the project developers in demonstrating the additionality of the proposed KOC project activities meaning that they are happening due to the revenues earned from the KOC, a tool introduced by the KECO, called the additionality test, is normally adopted.

The test comprises series of steps that include identification of alternatives to the project activity, barriers analysis.

In general, loans (debt), grants and equity are usual.

A loan (debt) provided by a third party to project, person or organization that must be repaid during its agreed term with interest over the period of the borrowing. The majority of loan to project is provided by banks like IBK (Industrial Bank of Korea).

There are many different types of loans, including:

1) Low interest loan (debt): obtained from government organization or government banks for projects. In korea, we have special low interest loans (ESCO[9]) for KOC project.
2) Lease finance: similar to senior debt. Often provided by equipment manufacturer in order to purchase of an asset by the project. But now, Korea don't have any special lase finance instruments for changing with high efficiency light.

So, in this project, companies will use their own money or loans (debt) or ESCO. Because, the investment size is relatively small.

9) Commercial or non-profit business providing a broad range of energy solutions including designs and implementation of energy savings projects, retrofitting, energy conservation, energy infrastructure outsourcing, power generation and energy supply, and risk management (http://coolmaine.org)

The most general structures used to finance projects are PF, corporate financing, lease financing, bridge financing, leveraged finance and ESCO.

Corporate financing and ESCO are usual. Corporate financing, also know as on-balance sheet financing or the use of internal company asset as collateral to obtain loan from bank or other lender.

An ESCO is an Energy Service Company, being model of service provision to customer. ESCO is typically used to deliver energy efficiency project, where the result of investment is energy saving for customer.

The performance contract may establish. baseline of energy consumption and identify saving as deviation below this level, which it has incentive to meet at least cost. The financing of the ESCO comes under the description of corporate financing.

The financing requirements of a KOC project can vary tremendously depending on each project type.

The selected HEL for the thesis are mostly small scale project types due to its low GHG reduction amount compared to project investment size.

In order to calculate the KOC offset credit potential costs relevant to the whole KOC project cycle must be identified. However, the KOC project mechanism has not yet been elapsed at least an year and there are only 20 methodologies that can be used.

In order to compensate for such limitations in data on KOC project implementation costs, average costs have been analyzes through interviews with relevant companies which are involved in KOC projects such as Ecoeye, Eco and Partners, Ecosian, CRIK and also the project verifiers such as KSA (Koren Standards Association), SGS, TUV, KFQ (Korea Foundation for Quality).

The consulting companies and verifiers being interviewed in this study are virtually almost all the companies that engage in business related to KOC in the Korea.

<Table 3.27> Unit cost associated with KOC stages

(10^6 won)

Cases	Unit cost		Type
	Large scale	Small scale	
Planning, registration Phase			
- Initial feasibility study	n.a	n.a	Consultancy fee or internal
- Project design document	over 20	5	Consultancy fee or internal
- New methodology	over 100	30～100	Consultancy fee or internal
- Validation	0	0	Validation fee
Construction phase			
- Construction	Variable, depending on project type		Constructors fees
- Installation of monitoring equipment	Usually minimal relative to total plant and equipment cost		Constructors fees
Operation Phase			
- Monitoring report	1	1	Consultancy fee or internal
- Verification	5 (per year)	3 (per year)	Auditing fee

Exceptional firms of KOC

Companies and facilities with high levels of GHG emissions and energy consumption are designated as controlled entities and subject to management under the Framework Act on Low Carbon Green Growth (enforcement on April 14, 2010) and Guideline the Operation of Target Management Scheme (amended on November 5, 2011 by Notification No. 2012-211 of ministry of Environment).

<Table 3.28> Designation standard for Target Management Scheme

Factor	~'11.12.31		'12.1.1~		'14.1.1~	
	Firm based	Installation based	Firm based	Installation based	Firm based	Installation based
GHG (tCO_2eq)	125,000	25,000	87,500	20,000	50,000	15,000
Energy (TJ)	500	100	350	90	200	80

Reference: Korea Environmental Policy Bulletin, KEI

Target firm is designated each year, and if GHG emissions and energy consumption can not accept to the standard, the firm should be excluded from the target firm even of it is selected in the previous year.

<Table 3.29> The number of companies in Target Management Scheme

Sector	Notification No.	Notification date	Number
Building, construction, traffic	Ministry of Land, Infrastructure and Transport 2015-14	'15.6.30	78
Agriculture, forestry, livestock products	Ministry of Agriculture, Food and Rural Affairs 2015-43	'15.6.30	25
Industrial, power generation	Ministry of Trade, Industry and Energy 2015-141	'15.7.15	230
Waste	Ministry of Environment 2015-84	'15.6.30	28
Building, construction, traffic	Ministry of Land, Infrastructure and Transport 2015-618	'15.8.28	2
Total			359

Reference: GIR (GHG Inventory and Research Center of Korea)

At of 2015, 359 firms are designated at the Target Management Scheme. Each firms can not use KOC in their own business boundary. So, in KOC potential, 359 firms must be excluded.

<Table 3.30> The number of companies in K-ETS

(based in 2015)

Category	Business type	Number
Conversion	Power generation/energy	38
Industry	Mining	2
	Food and beverages	23
	Wood and Wood productions	7
	Paper	44
	Oil refining	5
	Petrochemical	84
	Glass and Ceramics	24
	Cement	25
	Iron and Steel	40
	Non-ferrous metals	24
	Machinery	19
	Semi-conductor	20
	Display	5
	Electronics	20
	Motor vehicles	24
	Ship building	8
	Textile	15
Building	Building	40
	Telecommunication	6
Transportation	Aviation	5
Public sector and Waste	Water service	3
	Waste	44
Total		525

Reference: The 1st Allocation Plan (MOE, September 2014)

525 firms (522 firms at 2016) consisting of 243 companies and 283 facilities in 23 sub sectors have been given a fixed amount of permits for their emissions. The cap for the first commitment period (2015～2017) is 1.687 million tons of CO_2eq.

Each firms can not use KOC in their own business boundary. So, in KOC potential, 522 firms must be excluded.

Chapter 4. Results and Discussion

4.1 Weighted score for each technologies

Through a survey involving CEO or working staff from 120 companies analysis is performed through AHP analysis method.

120 stakeholder implemented the pair-wise comparison method of AHP. To reduce the impact of these inconsistencies, I decide to delete largest value and then calculate the average of the remaining CR (Consistency Ratio).

<Table 4.1> AHP analysis tool

	질문	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
1	기술신뢰성'이 '유지보수 편의성 및 비용' 보다 얼마나 중요하다고 생각하십니까?			1														
2	기술신뢰성'이 '초기투자비용' 보다 얼마나 중요하다고 생각하십니까?		1															
3	기술신뢰성'이 '투자회수기간' 보다 얼마나 중요하다고 생각하십니까?			1														
4	기술신뢰성'이 '조도 및 온도' 보다 얼마나 중요하다고 생각하십니까?										1							
5	유지보수 편의성 및 비용'이 '초기투자비용' 보다 얼마나 중요하다고 생각하십니까?								1									
6	유지보스 편의성 및 비용'이 '투자회수기간' 보다 얼마나 중요하다고 생각하십니까?								1									
7	유지보수 편의성 및 비용'이 '조도 및 온도' 보다 얼마나 중요하다고 생각하십니까?										1							
8	초기투자비용'이 '투자회수기간' 보다 얼마나 중요하다고 생각하십니까?									1								
9	초기투자비용'이 '조도 및 온도' 보다 얼마나 중요하다고 생각하십니까?											1						
10	투자회수기간'이 '조도 및 온도' 보다 얼마나 중요하다고 생각하십니까?													1				

AHP Calculating Start

C.R	0.1230
Consistency Index	0.1008

1) 가중치 산정 결과

	기술신뢰성	유지보수 편의성 및 비용	초기투자비용	투자회수기간	조도 및 온도	Factor 11	Factor 12	Factor 13	Factor 14	Factor 15
Weight	0.427	0.102	0.060	0.055	0.356					

2) 비교 행렬

	기술신뢰성	유지보수 편의성 및 비용	초기투자비용	투자회수기간	조도 및 온도	Factor 11	Factor 12	Factor 13	Factor 14	Factor 15
기술신뢰성	1	7	8	7	0.5					
유지보수 편의성 및 비용	0.142857143	1	2	2	0.5					
초기투자비용	0.125	0.5	1	1	0.333333333					
투자회수기간	0.142857143	0.5	1	1	0.2					
조도 및 온도	2	2	3	5	1					
Factor 06	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
Factor 07	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
Factor 08	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
Factor 09	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
Factor 10	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!					
Factor 11	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1				
Factor 12	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1			
Factor 13	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1		
Factor 14	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1	
Factor 15	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1

Reference: http://egloos.zum.com/yearjhyjh/v/33525

Out of 74 recent studies using AHP method, 47 of them have stated its rate of response and the ratio of the survey results being used in the analysis is 68.7% in which the 31.3% of the survey result is not suitable for its use (Songkeun won et al., 2013).

<Figure 4.1> Inconsistent ratio for each criteria

In this study, the ratio of valid survey response is 6~22% regardless of the simplicity of questionnaire (3 choices) and relevant knowledge of target persons involved in the survey (<Figure 4.1>). All of unsuitable survey results to be used in this study have been removed before the analysis.

Overall scores with weighted values showed investment decision patterns in order of LED (0.5103), IL (0.2441) and HEM (0.2444) (<Table 4.2>).

<Table 4.2> Weighted score for each lighting equipments

Criteria[1)]	Evaluating weight	Evaluating score for			C.I	C.R
		LED	HEM	IL		
TR	0.2733	0.6180	0.1857	0.1963	0.0375	0.0457
OM	0.1706	0.7003	0.1203	0.1794	0.0306	0.0373
IC	0.1540	0.2774	0.4603	0.2546	0.0332	0.0405
PP	0.2065	0.2821	0.4068	0.3111	0.0269	0.0328
BT	0.1957	0.6184	0.0919	0.2897	0.0259	0.0316
Final score		0.5103	0.2441	0.2444		

1) (TR) Technical Reliability, (OM) Operation and Maintenance, (IC) Initial Cost, (PP) Payback Period, (BT) Brightness and Temperature

Based on the procedure of AHP, the overall weighted score for each technology is calculated and shown in Table .

As a result of AHP analysis, CEO or person in charge of energy efficient lighting equipments replacement regarded TR as the most important criteria (0.2733) and PP is the second most important criteria (0.2065). In turn, BT (0.1957), OM (0.1706) and IC (0.1540) is regarded as less important.

In terms of TR, LED (0.6180) showed a significantly high preference compared to HEM and IL.

Also in the case of OM, LED (0.7003) showed a significantly high preference. However in the case of IC, HEM showed a relatively high score (0.4603) compared to LED or IL, indicating that there are still many companies highly concerned about the initial cost.

In the case of PP, the 3 technologies had similar survey results. For BT, LED scored the highest with IL also having a high score.

BT is an area that has been increasing in importance as the social interest on enhancement of workplace environment. Particularly, through interviews with site personnels the high temperature lighting equipments are somewhat non preferred as high temperature lighting equipments such as metal halide lamps have negative effect on work efficiency.

By looking at the overall score results, the awareness and reliance of companies on IL is not as high as expected and the majority of companies showed willingness on investing in LED. This is an indication that companies preferred LED in terms of investment.

It can be seen as an indication that the reliance of companies on LED have been increased compared to times when technological setbacks and reliance issues on LED have been raised several years ago.

4.2 Electric consumption, GHG emission and emission reduction

4.2.1 LEAP modelling result for baseline scenario

Through the baseline scenario analysis, because of increase in overall energy consumption, the electric consumption from lighting equipments in industrial and commercial is predicted as 68,905.7GWh in 2017 as the last year of phase 1, 73,693.5GWh in 2020 as the last year of phase 2 and 89,602.4GWh in 2030 (<Table 4.3>).

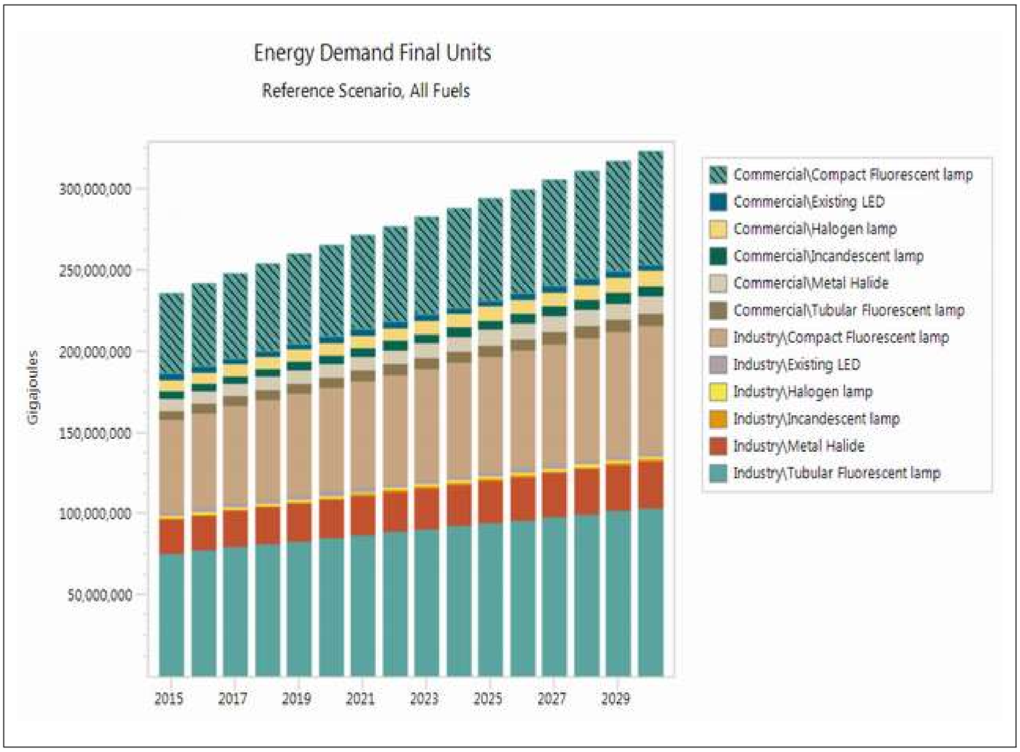
Because this scenario is based on the assumption that the current replacement rate of lighting equipments would continue in the future, by considering attrition rate of incandescent lamps and gradual expansion of LED replacement. This BAU scenario can be seen as somewhat unrealistic. However, this is an assumption of the worst scenario in terms of energy consumption.

<Table 4.3> Electric consumption in baseline scenario

(Unit: GWh)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	46,199.6	49,371.1	54,650.3	59,922.3
- Incandescent lamp	312.8	334.5	370.8	407.1
- Halogen lamp	357.3	382.2	423.6	465.1
- Compact Fluorescent lamp	16,614.8	17,771.9	19,700.3	21,628.8
- Tubular Fluorescent lamp	22,061.8	23,598.2	26,158.9	28,719.5
- Metal Halide	6,123.8	6,550.3	7,261.1	7,971.9
- Existing LED	729.1	734.0	735.5	729.9
Commercial sector	22,706.1	24,322.4	27,006.4	29,680.0
- Incandescent lamp	1,354.9	1,455.0	1,621.7	1,788.5
- Halogen lamp	1,981.8	2,128.1	2,372.0	2,615.9
- Compact Fluorescent lamp	14,574.6	15,650.9	17,444.7	19,238.5
- Tubular Fluorescent lamp	1,652.4	1,774.5	1,977.8	2,181.2
- Metal Halide	2,184.5	2,345.8	2,614.7	2,883.5
- Existing LED	957.9	968.2	975.4	972.4
Total	68,905.7	73,693.5	81,656.6	89,602.4

Electric consumption in industrial sector is higher than commercial sector. In industrial sector, electric consumption ratio of compact fluorescent lamps and tubular fluorescent lamps are the highest, whereas electric consumption ratio of compact fluorescent lamps are the highest in the commercial sector.



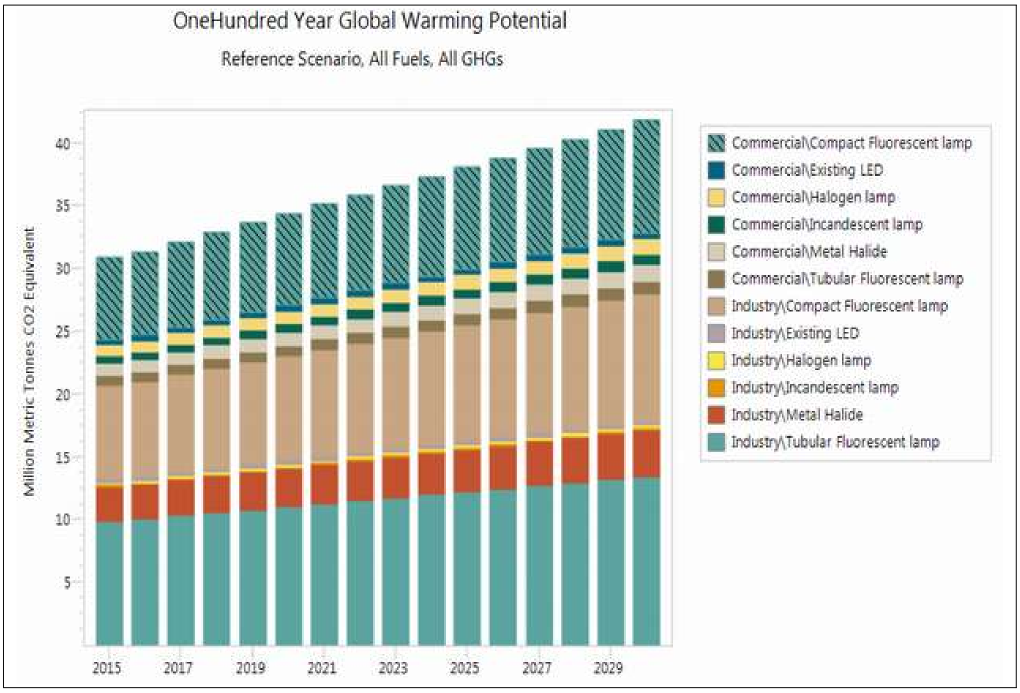
<Figure 4.2> Electric consumption in baseline scenario

The GHG emission from lighting equipments in industrial and commercial sector is predicted as 34,360KtCO_2eq in 2017 as the last year of phase 1, 38,072KtCO_2eq in 2020 as the last year of phase 2 and 41,777KtCO_2eq in 2030 (<Table 4.4>).

<Table 4.4> GHG emission in baseline scenario

(Unit: $KtCO_2eq$/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	21,540.6	23,019.3	25,480.7	27,938.8
- Incandescent lamp	145.8	156.0	172.9	189.8
- Halogen lamp	166.6	178.2	197.5	216.8
- Compact Fluorescent lamp	7,746.7	8,286.2	9,185.3	10,084.4
- Tubular Fluorescent lamp	10,286.3	11,002.7	12,196.6	13,390.5
- Metal Halide	2,855.2	3,054.1	3,385.5	3,716.9
- Existing LED	339.9	342.2	342.9	340.3
Commercial sector	10,586.7	11,340.3	12,591.7	13,838.3
- Incandescent lamp	631.7	678.4	756.1	833.9
- Halogen lamp	924.0	992.2	1,105.9	1,219.7
- Compact Fluorescent lamp	6,795.4	7,297.2	8,133.6	8,969.9
- Tubular Fluorescent lamp	770.4	827,3	922.2	1,017.0
- Metal Halide	1,018.5	1,093.7	1,219.1	1,344.5
- Existing LED	446.6	451.4	454.8	453.4
Total	32,127.3	34,359.6	38,072.4	41,777.1



<Figure 4.3> GHG emission in baseline scenario

4.2.2 LEAP modelling result for abatement scenario

In abatement scenario, energy consumption decreases because of high efficiency light equipment replacement and improvements in technology. This overshadows even increase in company number and electricity production.

Electric consumption of lighting equipments in the industrial and commercial sector is predicted to reach 64,613GWh in 2017 (last year of phase1), 60,318GWh in 2020 (last year of phase2) and 31,472GWh in 2030 (<Table 4.5>).

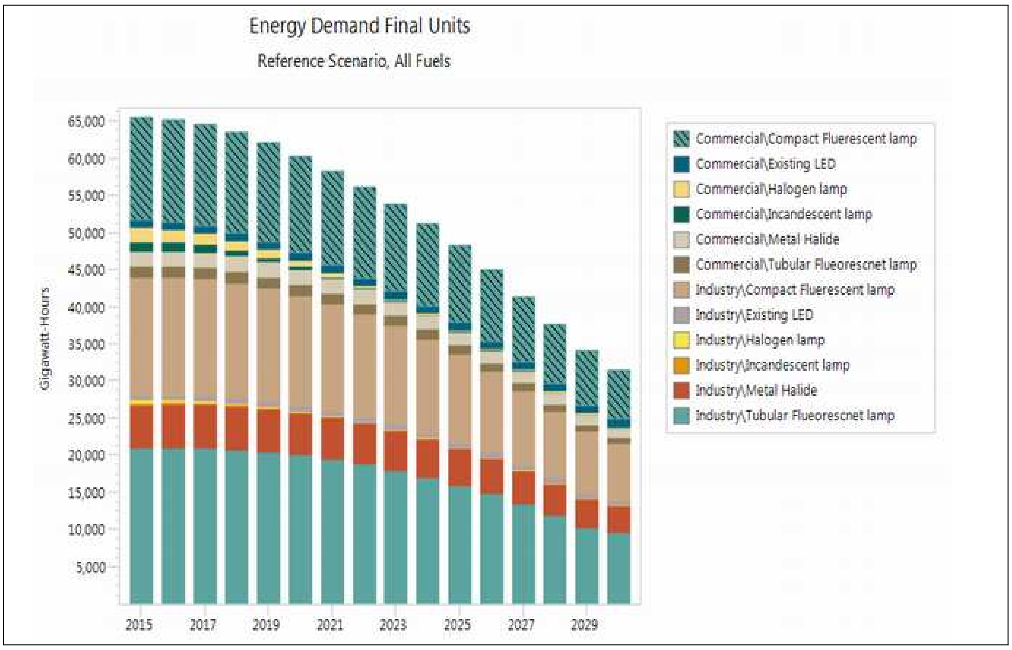
Based on the results from the prediction, the industrial and commercial sector each showed 49.7% and 40.9% of electric consumption rate compared to electric consumption levels in the year 2017.

<Table 4.5> Electric consumption in abatement scenario

(Unit: GWh)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	43,742.1	41,553.1	33,638.7	21,593.9
- Incandescent lamp	220.6	82.4	23.8	17.5
- Halogen lamp	276.6	158.6	40.7	29.9
- Compact Fluorescent lamp	15,695.0	14,865.9	11,861.7	7,645.6
- Tubular Fluorescent	20,955.3	19,979.2	15,957.7	9,599.4
- Metal Halide	5,865.5	5,733.0	5,019.2	3,571.7
- Existing LED	729.1	734.0	735.5	729.9
Commercial sector	20,870.4	18,764.6	14,659.7	9,878.4
- Incandescent lamp	955.7	356.9	103.3	75.7
- Halogen lamp	1,534.3	879.5	226.0	165.6
- Compact Fluorescent lamp	13,767.7	13,040.5	10,405.2	6,706.8
- Tubular Fluorescent	1,569.5	1,496.4	1,195.2	719.0
- Metal Halide	2,085.3	2,026.9	1,763.7	1,252.4
- Existing LED	957.9	964.4	966.3	959.0
Total	64,612.5	60,317.7	48,298.4	31,472.3

Results has shown does not indicate that the effect of high efficient lighting equipments replacement is higher in commercial sector compared to industrial sector. It is the higher growth rate of industrial sector compared to commercial sector that affected the outcome of such result.



<Figure 4.4> Electric consumption in abatement scenario

The GHG emission is calculated as 29,579KtCO_2eq in 2017 (last year of phase1), 27,191KtCO_2eq in 2020 (last year of phase2) and 13,866KtCO_2eq in 2030 (<Table 4.6>).

The reduction rate (%) of GHG from 2017 until 2030 is 8% for incandescent lamp and 10.9% for halogen lamps in the industrial sector. The reason why the average GHG reduction rate is low (49.7%) regardless of high reduction rate from incandescent and halogen lamps is that reduction rate of metal halide lamp (61.2%), compact fluorescent lamp (49%) and tubular fluorescent lamp (46.1%) which contribute to the largest portion of GHG emission is relatively low compared to other lamp types.

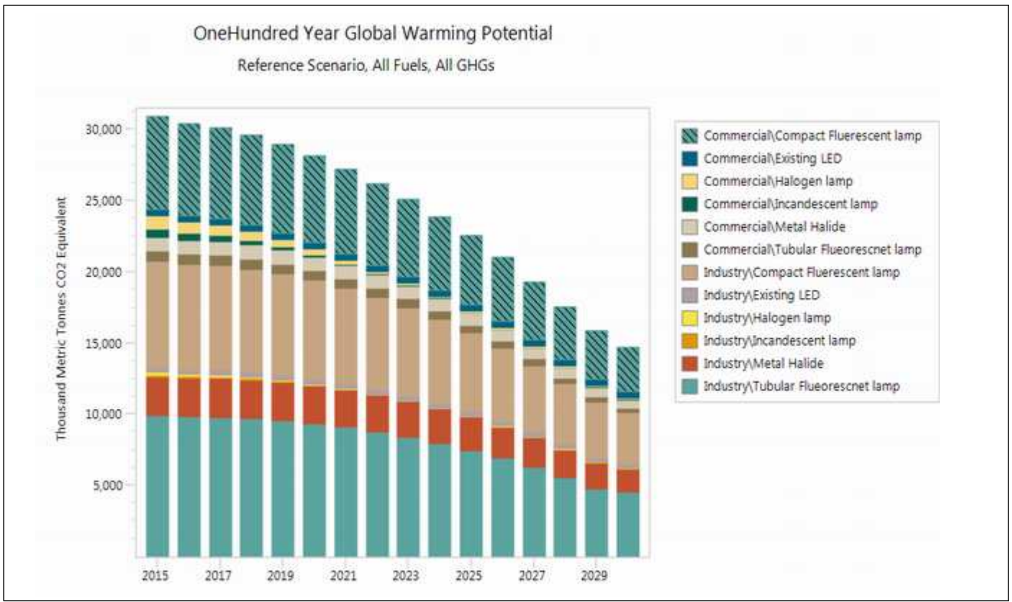
Commercial sector also showed the same characteristics as industrial sector.

<Table 4.6> GHG emission in abatement scenario

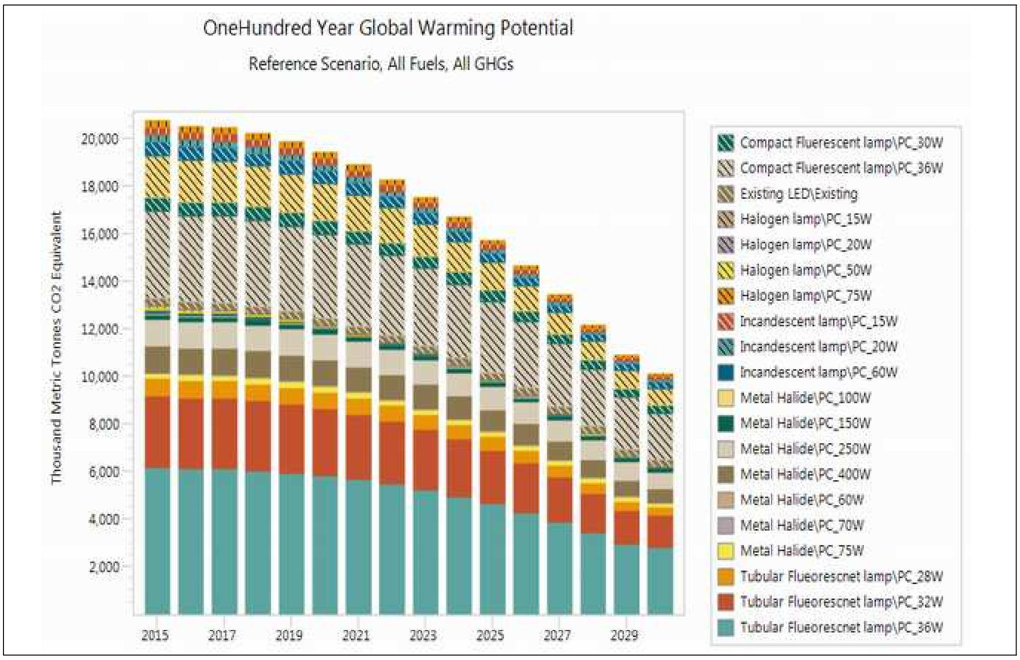
(Unit: $KtCO_2eq$/year)

Type of lighting instruments	2017	2020	2025	2030	%[1)]
Industrial sector	20,176.8	19,072.0	15,453.2	10,024.9	50.3
- Incandescent lamp	101.8	37.8	11.0	8.1	92.0
- Halogen lamp	127.6	72.8	18.7	13.9	89.1
- Compact Fluorescent lamp	7,239.6	6,823.1	5,449.2	3,549.5	51.0
- Tubular Fluorescent	9,666.0	9,170.0	7,330.8	4,456.5	53.9
- Metal Halide	2,705.6	2,631.3	2,305.7	1,658.1	38.7
- Existing LED	336.3	336.9	337.9	338.9	0
Commercial sector	9,401.9	8,118.2	5,983.6	3,840.8	59.1
- Incandescent lamp	430.5	154.4	42.2	29.4	93.2
- Halogen lamp	691.2	380.5	92.2	64.4	90.7
- Compact Fluorescent lamp	6,202.2	5,641.7	4,247.0	2,607.6	58.0
- Tubular Fluorescent	707.1	647.4	487.8	279.5	60.5
- Metal Halide	939.4	876.9	719.9	486.9	48.2
- Existing LED	431.5	417.2	394.4	372.9	13.6
Total	29,578.6	27,190.7	21,436.8	13,865.7	53.1

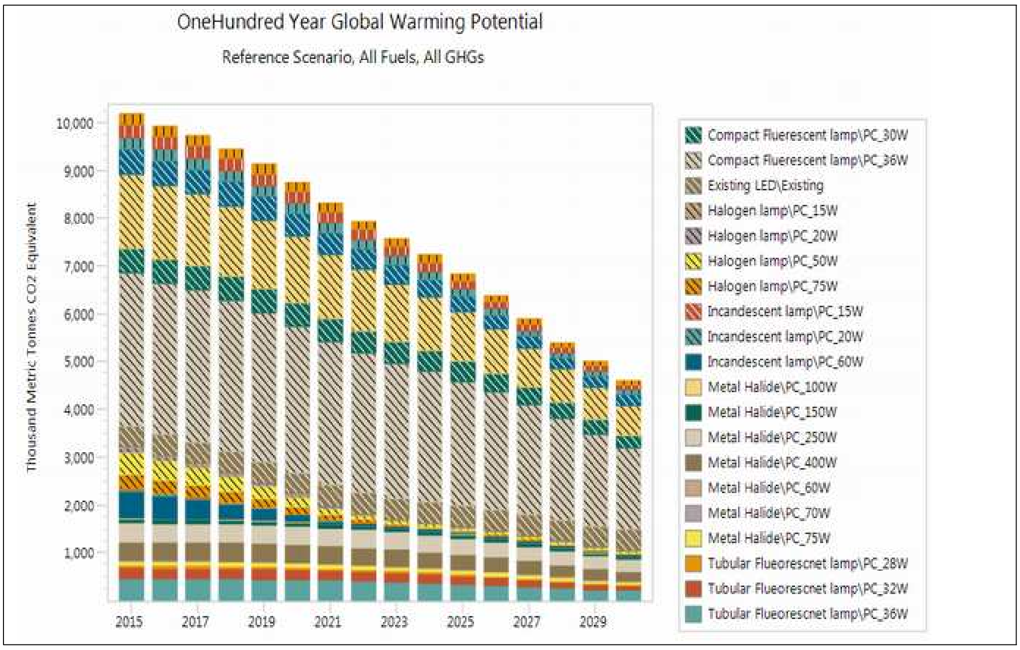
1) Reduction rate: (2030-2017)/2017 * 100



<Figure 4.5> GHG emission in abatement scenario



<Figure 4.6> GHG emission of industrial sector



<Figure 4.7> GHG emission of commercial sector

If electric cost increase up to 10%, GHG emission of 29,385.5KtCO_2eq in 2017 and 26,820.5KtCO_2eq in 2020 have been forecasted. Reduction rate of payback period is 9.1% and reduction period is 1.4 year. Emission amount deceased 2.5% at 2017 and 4.6% at 2020 (<Table 4.7>).

<Table 4.7> Increasing effect of electric cost to payback period

Increase rate of electric cost	Reduction rate of P.P (%)	Reduction period of P.P (y; during 15y)
10%	9.1	1.4
50%	33	5
100%	50	7.5

If electric cost increase up to 50%, GHG emission of 26,147.3KtCO_2eq in 2017 and 22,519.2KtCO_2eq in 2020 have been forecasted. Reduction rate of payback period is 33% and reduction period is 5 year. Emission amount deceased 13.2% at 2017 and 20% at 2020.

If electric cost increase up to 100%, GHG emission of 23,197.3KtCO_2eq in 2017 and 18,395KtCO_2eq in 2020 have been forecasted. Reduction rate of payback period is 50% and reduction period is 7.5 year. Emission amount deceased 20% at 2017 and 35% at 2020 (<Table 4.8>).

<Table 4.8> Increasing effect of electric cost to GHG emission

(Unit: increasing rate of GHG emission; %)

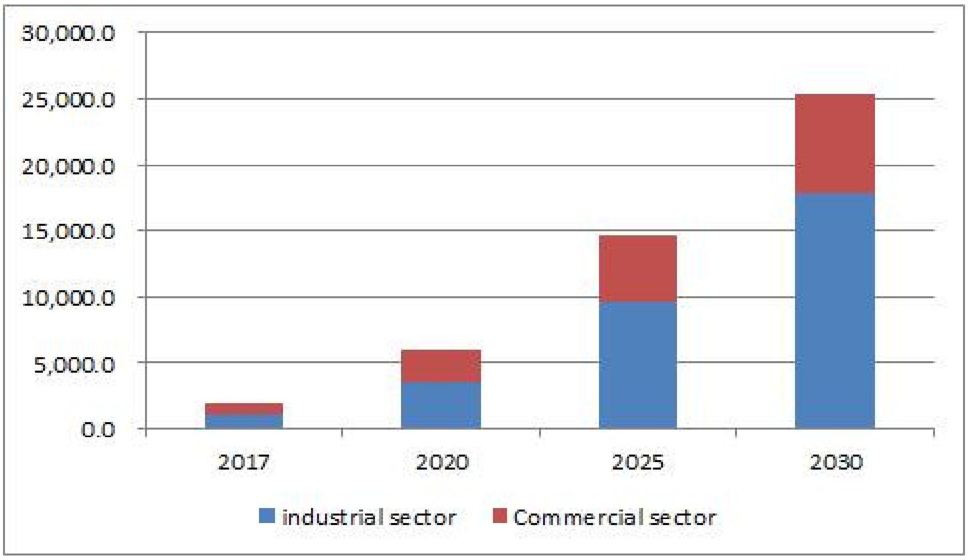
Increase rate of electric cost	2017	2020
10%	-2.5	-4.6
50%	-13.2	-20
100%	-20	-35

Through the energy efficient lighting equipments replacement, potential GHG reduction calculated to 2,548.7KtCO_2eq until 2017, 7,168.9KtCO_2eq until 2020 and 27,911.4KtCO_2eq until 2030.

The potential emission reduction of industrial sector is 1,363.8KtCO_2eq in 2017 and 3,947.3KtCO_2eq in 2020 which is approximately three times larger. Moreover, the potential emission reduction of industrial sector in 2030 is 17,913.9KtCO_2eq which grew 16 times larger than the potential emission reduction in 2017.

The potential emission reduction of commercial sector is 1,184.8KtCO_2eq in 2017 and 3,222.1KtCO_2eq in 2020. In 2030, the potential emission reduction is 9,997.5KtCO_2eq in which the increase rate is relatively lower than the industrial sector (<Figure 4.8>).

Compared to the annual allocation amount of about 5 billion tons in the 1st phase of Korea emission trading scheme, the average amount of potential emission reduction from 2015 to 2030 correspond to 2.4% of the total allocation.



<Figure 4.8> GHG emission reduction of industrial and commercial sector

However, based on 2030 the value increases to 5.4%. The importance or meaning of the size of potential emission reduction derived through this study to K-ETS will be covered in the discussion section. Total potential emission reduction is 2,548.7KtCO_2eq in the 1st phase of K-ETS

<Table 4.9> GHG emission reduction in abatement scenario

(Unit: KtCO_2eq/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	1,363.8	3,947.3	10,027.5	17,913.9
- Incandescent lamp	44.0	118.2	161.9	181.7
- Halogen lamp	39.0	105.4	178.8	202.9
- Compact Fluorescent lamp	507.1	1,463.1	3,736.1	6,534.9
- Tubular Fluorescent	620.3	1,832.7	4,865.8	8,934.0
- Metal Halide	149.6	422.8	1,079.8	2,058.8
- Existing LED	3.6	5.3	5.0	1.4
Commercial sector	1,184.8	3,222.1	6,608.1	9,997.5
- Incandescent lamp	201.2	524.0	713.9	804.5
- Halogen lamp	232.8	611.7	1,013.7	1,155.3
- Compact Fluorescent lamp	593.2	1,655.5	3,886.6	6,362.3
- Tubular Fluorescent	63.3	179.9	434.4	737.5
- Metal Halide	79.1	216.8	499.2	857.6
- Existing LED	15.1	34.2	60.4	80.5
Total	2,548.7	7,168.9	16,635.6	27,911.4

According to detailed action plan for Supply of high efficiency light in '5th National Energy usage rationalization plan' (Ministry of Trade, Industry and Energy, 2010), until 2017 supply LED light target is 40%, 50% at 2020 (11.9 $MtCO_2eq$ emission reduction). and at 2030 16.7 $MtCO_2eq$ emission reduction is predicted (<Table 4.10>).

<Table 4.10> 5th National Energy Plan

The amount of energy saving and CO_2 emission reduction	2017	2020	2025	2030
Energy saving (KTOE/year)	4,560	5,785	6,942	8,099
CO_2 emission reduction ($KtCO_2eq$)	9,435	11,967	14,362	16,756

Reference: Ministry of Trade, Industry and Energy, 5th National Energy usage rationalization plan, 2010

4.2.3 LEAP modelling result for KOC supply scenario

The potential GHG emission from high efficient lighting equipments replacement in the industrial sector when the carbon price is set to 5,000 won is calculated as 1,926KtCO_2eq by the year 2017, which is approximately 6.7% of the total emission reduction potential (20,176.2KtCO_2eq) <Table 4.11>.

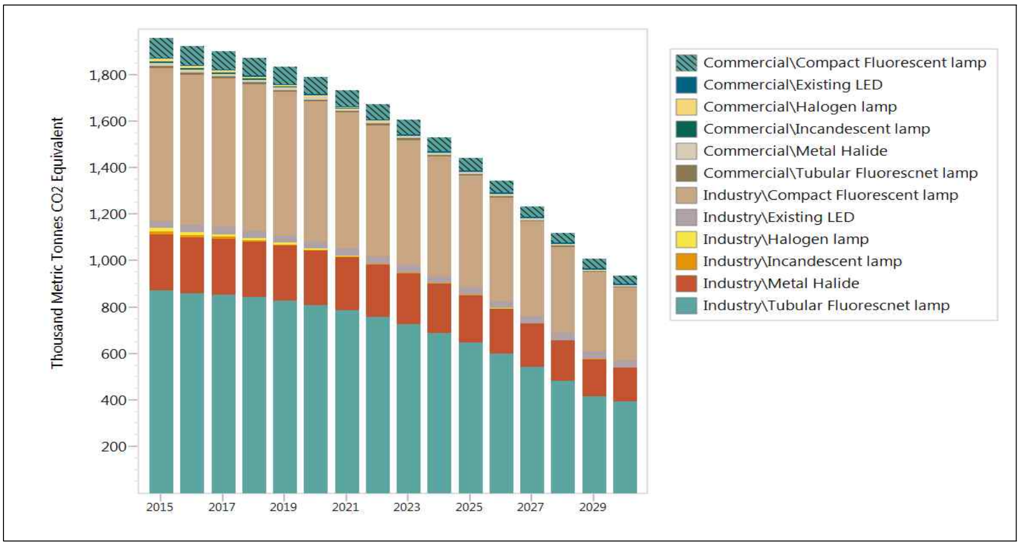
The potential GHG emission from high efficient lighting equipments replacement in the commercial sector is calculated as 128KtCO_2eq by the year 2017, which is approximately 1.4% of the total emission reduction potential (9,401.9KtCO_2eq).

The potential KOC amount of commercial sector is less than industrial sector. The average KOC potential of industrial and commercial sector is 6.7%.

<Table 4.11> GHG emission reduction in KOC supply scenario (Case1)

(Unit: KtCO_2eq/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	1,806.0	1,715.6	1,388.8	891.6
- Incandescent lamp	9.1	3.4	1.0	0.7
- Halogen lamp	11.4	6.5	1.7	1.2
- Compact Fluorescent lamp	648.0	613.8	489.7	315.7
- Tubular Fluorescent	865.2	824.9	658.8	396.3
- Metal Halide	242.2	236.7	207.2	147.5
- Existing LED	30.1	30.3	30.4	30.1
Commercial sector	120.1	108.0	84.3	56.8
- Incandescent lamp	5.5	2.1	0.6	0.4
- Halogen lamp	8.8	5.1	1.3	1.0
- Compact Fluorescent lamp	79.2	75.0	59.9	38.6
- Tubular Fluorescent	9.0	8.6	6.9	4.1
- Metal Halide	12.0	11.7	10.1	7.2
- Existing LED	5.5	5.5	5.6	5.5
Total	1,926.1	1,823.6	1,473.2	948.4



<Figure 4.9> GHG emission in KOC supply scenario (Case1)

KOC potential is calculated as 166KtCO_2eq by the year 2017, 481KtCO_2eq by the year 2020 and 1,909KtCO_2eq by the year 2030 (<Table 4.12>).

<Table 4.12> GHG emission reduction in KOC supply scenario (Case1)

(Unit: KtCO_2eq/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	122.1	355.1	901.2	1,593.2
- Incandescent lamp	3.9	10.6	14.7	15.7
- Halogen lamp	3.5	9.4	16.3	17.5
- Compact Fluorescent lamp	45.4	131.6	335.7	581.2
- Tubular Fluorescent	55.5	164.9	437.3	794.5
- Metal Halide	13.4	38.0	97.0	183.1
- Existing LED	0.3	0.5	0.4	0.1
Commercial sector	15.1	42.9	93.1	147.8
- Incandescent lamp	2.6	7.1	10.2	10.9
- Halogen lamp	3.0	8.2	14.3	17.9
- Compact Fluorescent lamp	7.6	22.0	54.8	94.2
- Tubular Fluorescent	0.8	2.4	6.1	10.8
- Metal Halide	1.0	2.9	7.0	12.7
- Existing LED	0.2	0.5	0.9	1.2
Total	166.0	480.8	1,143.2	1,909.1

The potential GHG emission from high efficient lighting equipments replacement in the industrial sector when the carbon price is set to 10,000 won is calculated as 3,621KtCO_2eq by the year 2017, which is approximately 12.7% of the total emission reduction potential (20,176.2KtCO_2eq) (<Table 4.13>).

The potential GHG emission from high efficient lighting equipments replacement in the commercial sector is calculated as 312KtCO_2eq by the year 2017, which is approximately 3.3% of the total emission reduction potential (9,401.9KtCO_2eq). The potential KOC amount of commercial sector is less than industrial sector. The average KOC potential of industrial and commercial sector is 12.7%.

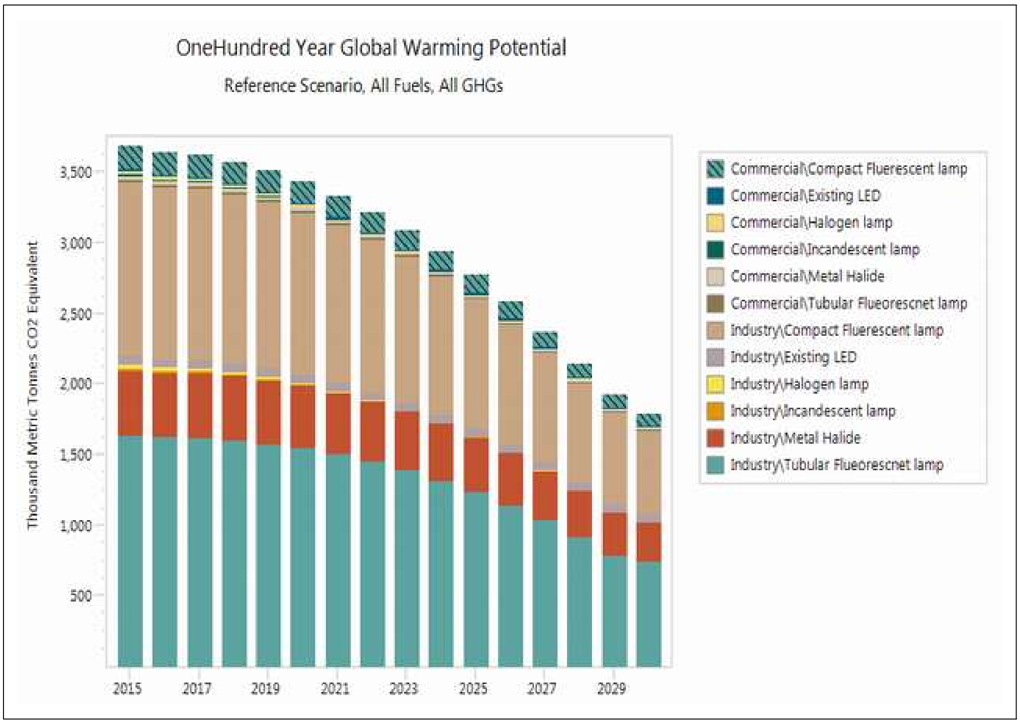
<Table 4.13> GHG emission in KOC supply scenario (Case2)

(Unit: KtCO_2eq/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	3,388.2	3,218.6	2,605.6	1,672.6
- Incandescent lamp	17.1	6.4	1.8	1.4
- Halogen lamp	21.4	12.3	3.2	2.3
- Compact Fluorescent lamp	1,215.7	1,151.5	918.8	592.2
- Tubular Fluorescent	1,623.2	1,547.6	1,236.1	743.6
- Metal Halide	454.3	444.1	388.8	276.7
- Existing LED	56.5	56.9	57.0	56.5
Commercial sector	232.6	210.0	165.0	111.7
- Incandescent lamp	10.7	4.0	1.2	0.9
- Halogen lamp	17.1	9.8	2.5	1.9
- Compact Fluorescent lamp	153.5	145.9	117.1	75.8
- Tubular Fluorescent	17.5	16.7	13.4	8.1
- Metal Halide	23.2	22.7	19.8	14.2
- Existing LED	10.7	10.8	10.9	10.8
Total	3,620.8	3,428.6	2,770.5	1,784.3

By considering the carbon credit contract price of 16,200 won during June of 2016, the price of carbon credit remains high compared to the Korean government's threshold on market stabilization price of 10,000 won.

However, if the price of carbon in the future stabilize around 10,000 won by the government as predicted by many companies, the KOC project potential by using energy efficient lighting equipments replacement methodology will be very low compared to total potential GHG emission reduction.



<Figure 4.10> GHG emission in KOC supply scenario (Case2)

KOC potential is calculated as 312KtCO_2eq by the year 2017, 904KtCO_2eq by the year 2020 and 3,592KtCO_2eq by the year 2030 (<Table 4.14>).

<Table 4.14> GHG emission reduction in KOC supply scenario (Case2)

(Unit: $KtCO_2eq$/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	229.0	666.2	1,690.8	2,988.9
- Incandescent lamp	7.4	20.0	27.2	30.3
- Halogen lamp	6.5	17.8	30.2	33.8
- Compact Fluorescent lamp	85.2	246.9	629.9	1,090.3
- Tubular Fluorescent	104.2	309.3	820.4	1,490.6
- Metal Halide	25.1	71.4	182.1	343.5
- Existing LED	0.6	0.9	0.8	0.2
Commercial sector	29.3	83.3	182.2	290.6
- Incandescent lamp	5.0	13.6	19.7	23.4
- Halogen lamp	5.8	15.8	28.0	33.6
- Compact Fluorescent lamp	14.7	42.8	107.1	185.0
- Tubular Fluorescent	1.6	4.7	12.0	21.4
- Metal Halide	2.0	5.6	13.8	24.9
- Existing LED	0.4	0.9	1.7	2.3
Total	312.0	904.0	2,150.0	3,591.7

The potential GHG emission from high efficient lighting equipments replacement in the industrial sector when the carbon price is set to 30,000 won is calculated as 5,490$KtCO_2eq$ by the year 2017, which is approximately 192.% of the total emission reduction potential (20,176.2$KtCO_2eq$) (<Table 4.15>).

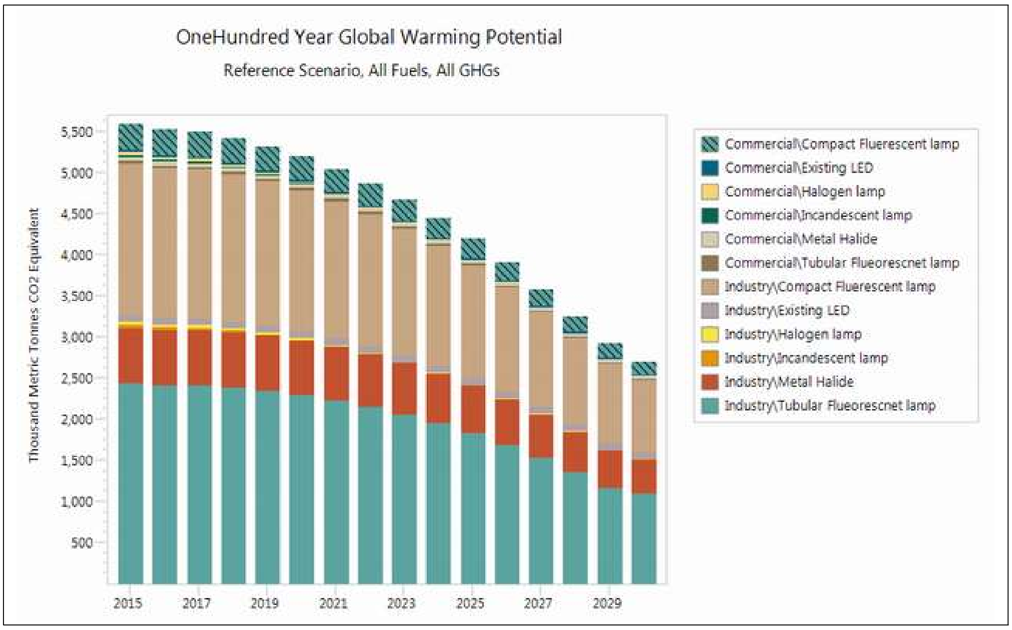
The potential GHG emission from high efficient lighting equipments replacement in the commercial sector is calculated as 473$KtCO_2eq$ by the year 2017, which is approximately 5.0% of the total emission reduction potential (9,401.9$KtCO_2eq$).

The potential KOC amount of commercial sector is less than industrial sector. The average KOC potential of industrial and commercial sector is 19.2%.

<Table 4.15> GHG emission in KOC supply scenario (Case3)

(Unit: $KtCO_2eq$/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	5,042.5	4,790.1	3,877.8	2,489.3
- Incandescent lamp	25.4	9.5	2.7	2.0
- Halogen lamp	31.9	18.3	4.7	3.4
- Compact Fluorescent lamp	1,809.3	1,713.7	1,367.4	881.4
- Tubular Fluorescent	2,415.7	2,303.2	1,839.6	1,106.6
- Metal Halide	676.2	660.9	578.6	411.7
- Existing LED	84.0	84.6	84.8	84.1
Commercial sector	447.4	402.3	314.3	211.8
- Incandescent lamp	20.5	7.7	2.2	1.6
- Halogen lamp	32.9	18.9	4.8	3.6
- Compact Fluorescent lamp	295.2	279.6	223.1	143.8
- Tubular Fluorescent	33.6	32.1	25.6	15.4
- Metal Halide	44.7	43.5	37.8	26.8
- Existing LED	20.5	20.7	20.7	20.6
Total	5,489.9	5,192.4	4,192.1	2,701.1



<Figure 4.11> GHG emission in KOC supply scenario (Case3)

KOC potential is calculated as 473KtCO_2eq by the year 2017, 1,369KtCO_2eq by the year 2020 and 5,437KtCO_2eq by the year 2030 (<Table 4.16>).

<Table 4.16> GHG emission reduction in KOC supply scenario (Case3)

(Unit: KtCO_2eq/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	340.8	991.4	2,516.3	4,448.2
- Incandescent lamp	11.0	29.7	40.5	45.2
- Halogen lamp	9.7	26.5	44.9	50.2
- Compact Fluorescent lamp	126.7	367.5	937.5	1,622.7
- Tubular Fluorescent	155.0	460.3	1,221.0	2,218.4
- Metal Halide	37.4	106.2	271.0	511.2
- Existing LED	0.9	1.3	1.3	0.3
Commercial sector	56.4	159.7	347.1	551.2
- Incandescent lamp	9.6	26.0	37.5	44.4
- Halogen lamp	11.1	30.3	53.3	63.7
- Compact Fluorescent lamp	28.2	82.0	204.1	350.8
- Tubular Fluorescent	3.0	8.9	22.8	40.7
- Metal Halide	3.8	10.7	26.2	47.3
- Existing LED	0.7	1.7	3.2	4.4
Total	473.0	1,369.0	3,253.2	5,437.2

The potential GHG emission from high efficient lighting equipments replacement in the industrial sector when the carbon price is set to 100,000 won is calculated as 7,500KtCO_2eq by the year 2017, which is approximately 26.2% of the total emission reduction potential (20,176.2KtCO_2eq) (<Table 4.17>).

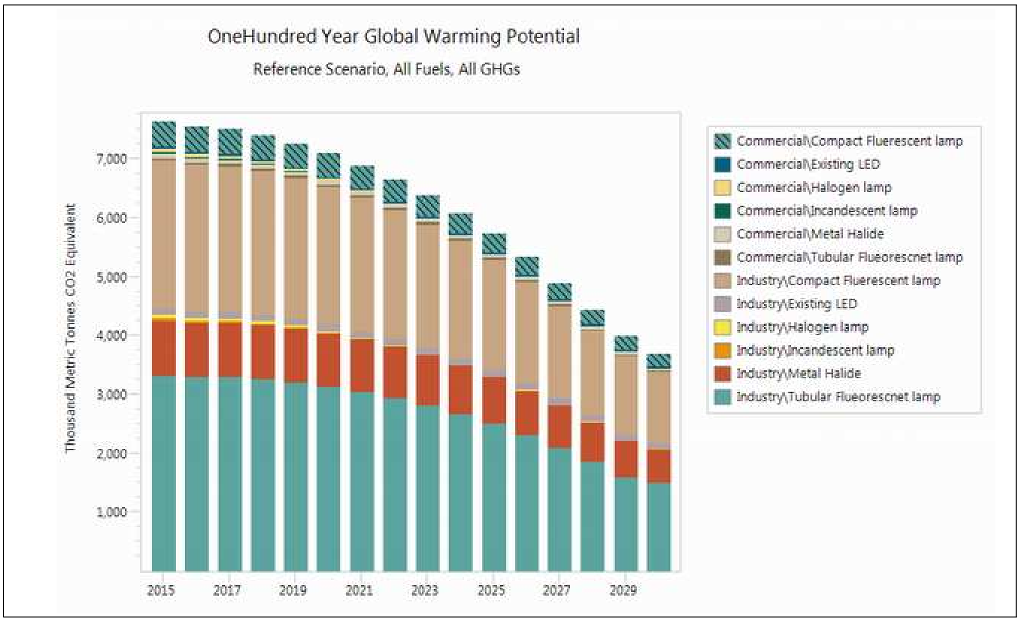
The potential GHG emission from high efficient lighting equipments replacement in the commercial sector is calculated as 646KtCO_2eq by the year 2017, which is approximately 6.9% of the total emission reduction potential (9,401.9KtCO_2eq).

The potential KOC amount of commercial sector is less than industrial sector. The average KOC potential of industrial and commercial sector is 26.2%.

<Table 4.17> GHG emission in KOC supply scenario (Case4)

(Unit: $KtCO_2eq$/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	6,882.9	6,538.4	5,293.1	3,397.8
- Incandescent lamp	34.7	13.0	3.8	2.7
- Halogen lamp	43.5	24.9	6.4	4.7
- Compact Fluorescent lamp	2,469.6	2,339.2	1,866.5	1,203.0
- Tubular Fluorescent	3,297.3	3,143.7	2,511.0	1,510.5
- Metal Halide	922.9	902.1	789.8	562.0
- Existing LED	114.7	115.5	115.7	114.8
Commercial sector	616.7	554.4	433.1	291.9
- Incandescent lamp	28.2	10.5	3.1	2.2
- Halogen lamp	45.3	26.0	6.7	4.9
- Compact Fluorescent lamp	406.8	385.3	307.4	198.2
- Tubular Fluorescent	46.4	44.2	35.3	21.2
- Metal Halide	61.6	59.9	52.1	37.0
- Existing LED	28.3	28.5	28.6	28.3
Total	7,499.5	7,092.9	5,726.2	3,689.7



<Figure 4.12> GHG emission in KOC supply scenario (Case4)

KOC potential is calculated as 646KtCO_2eq by the year 2017, 1,870KtCO_2eq by the year 2020 and 7,427KtCO_2eq by the year 2030 (<Table 4.18>).

<Table 4.18> GHG emission reduction in KOC supply scenario (Case4)

(Unit: KtCO_2eq/year)

Type of lighting instruments	2017	2020	2025	2030
Industrial sector	465.2	1,353.2	3,434.6	6,071.7
- Incandescent lamp	15.0	40.5	55.2	61.6
- Halogen lamp	13.3	36.1	61.3	68.6
- Compact Fluorescent lamp	173.0	501.6	1,279.7	2,214.9
- Tubular Fluorescent	211.6	628.3	1,666.6	3,028.1
- Metal Halide	51.0	144.9	369.9	697.8
- Existing LED	0	0	0	0
Commercial sector	77.7	220.1	478.4	759.7
- Incandescent lamp	13.2	35.8	51.6	61.2
- Halogen lamp	15.3	41.8	73.4	87.8
- Compact Fluorescent lamp	38.9	113.1	281.4	483.5
- Tubular Fluorescent	4.2	12.3	31.4	56.1
- Metal Halide	5.2	14.8	36.1	65.2
- Existing LED	1	2	4	6
Total	646.2	1,870.0	4,443.7	7,427.3

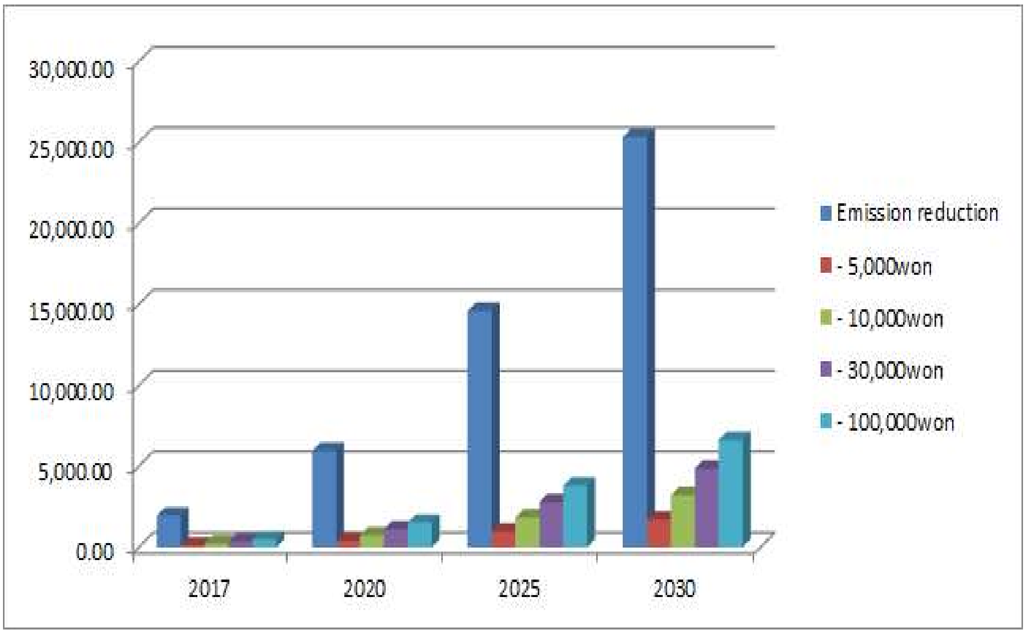
Through the sensitivity analysis the changes in potential KOC amount and carbon price fluctuation showed similar patterns. If the carbon price increased by 50% from 5,000 won the potential KOC amount also increased by the same ratio. However, when the price increased from 10,000 won to 30,000 won the potential amount increased by 151% and it also increased by 207% when the price increased from 10,000 won to 100,000 won (1,000% increase).

The potential KOC amount also showed similar patterns when the carbon price increased but the rate of increase is relatively small. In other words, there is low possibility of a presence of critical carbon price level showing drastic increase in potential KOC amount or higher rate of increase in potential KOC amount compared to the increase rate of carbon price (<Table 4.19>).

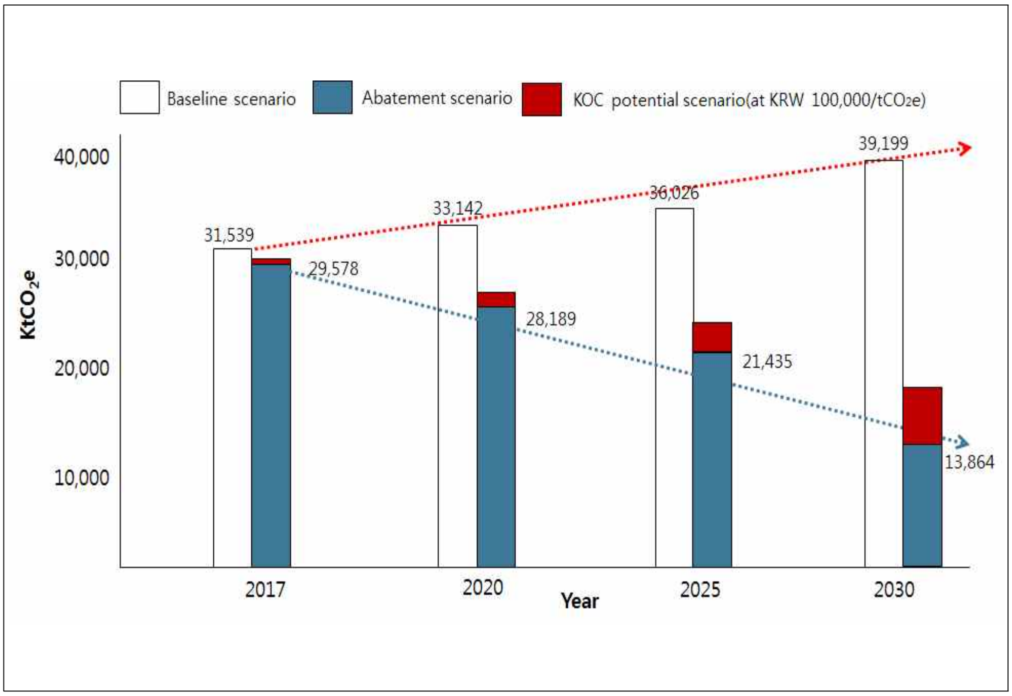
<Table 4.19> GHG emission reduction of scenarios in this study

(Unit: $KtCO_2eq$/year (%))

Scenario	2017	2020	2025	2030	(%)
Abatement scenario	2,5486.7	7,168.9	16,635.6	27,911.4	
KOC supply scenario					
- Case1 (5,000 won/$KtCO_2eq$)	166.0	480.8	1,143.2	1,909.1	6.7
- Case2 (10,000 won/$KtCO_2eq$)	312.0	904.0	2,150.0	3,591.7	12.7
- Case3 (30,000 won/$KtCO_2eq$)	473.0	1,369.0	3,253.2	5,437.2	19.2
- Case4 (100,000 won/$KtCO_2eq$)	646.2	1,870.0	4,443.7	7,427.3	26.2



<Figure 4.13> GHG emission reduction of scenarios in this study



<Figure 4.14> GHG emission of scenarios in this study

This analysis has been done based on the LED replacement rate outlook from the 2014 report. However the potential KOC amount would be supplied at a more faster rate until 2030 by assuming that the replacement rate would be shortened through the technological advances and cost reduction of LED.

If the replacement rate of the LED would be shortened by 10 years due to technological advances and cost reduction, the potential KOC amount would increase by 1,909KtCO_2eq at carbon price of 5,000 won, 3,592KtCO_2eq at carbon price of 10,000 won, 5,437KtCO_2eq at carbon price of 30,000 won and 7,427KtCO_2eq at carbon price of 100,000 won in 2020.

4.3 Mutual effect of KOC potential and K-ETS

4.3.1 The value of KOC potential in K-ETS

The average potential KOC amount in industrial and commercial sector compared to total potential GHG emission reduction amount from relevant study is 12.1% when the carbon price is set to 10,000 won.

Based on the result above, it is not the only meaningful conclusion that the KOC potential of high efficient lighting equipments replacement compared to total potential GHG emission reduction is very low, but also in K-ETS's point of view even low level of KOC potential compared to total potential amount can still significantly affect the carbon market, if the market have few KOC selling amount situation like 1st year.

The total potential GHG emission reduction amount of 2,548.7KtCO_2eq is a very significant amount of supply into the carbon market.

Under the consideration of the fact that 1) average daily trading amount during late May to early June in 2016 is 300~400KtCO_2eq, 2) there is a allocation shortage of 7,000KtCO_2eq from the result of evaluation on 'Emissions and Implementation Reports' and 3) total of 12,000KtCO_2eq KOC have been supplied to the carbon market, the potential KOC amount contribution of 312KtCO_2eq to the carbon market based on year 2017 is very low as it is approximately 2% of the total KOC amount supplied to the carbon market for the past year.

The potential buyers of KOC are companies. In order to predict the supply demand forecast, actual emission data compared to allocation of each companies need. However, such data is not open to the public.

Nevertheless, alternative reference data for supply demand forecast have been achieved from the press release from Office for Government Policy Coordination ('16.5.16).

According to the press release, by considering all of carbon offsets owned by companies and additional allocation requested from companies due to new installation or expansion of existing installations, total allocated allowance (5.5 billion ton) is larger than actual emission (5.43 billion ton) in the 2015. The press release stated that on an individual company basis, 288 companies (55% of total) had 20 million tons of surplus allowance and on the other hand 235 companies (45% of total) is short of 13 million tons of allowance.

Among the companies short of credits, 82 companies is short of more than 10% of its allocated allowance amount (total of 1.1 million tons).

Further, 22 companies is short of more than 20% of its allocated allowance amount (total of 0.2 million tons). In other words, allowance shortage of 153 companies will be solved through borrowing of allowance by 10% and in the case of borrowing of allowance by 20% the allowance shortage of 213 companies will be solved.

Apart from the first year, there is a growing need of relevant projections on the second ('16.7~'17.6) and third year ('17.7~'18.6) of phase 1.

For this analysis the analysis on the short-term economic outlook of the domestic market in Korea must be performed.

According to the short-term economic outlook by the IBK (Industrial Bank of Korea) economic research institute, there would be no signs of turnaround in the economy until 2018. In other words, there is no significant difference compared to the first year ('15.1~'16.6) of K-ETS in phase 1.

Under the assumption that the shortages in allowance during the first year of phase 1 continue to occur during second and third year, it is expected that approximately 7 million tons of carbon credit demand would occur annually.

In order to examine the correlation and effect of the potential GHG reduction amount and potential KOC amount derived from this study to the carbon market, estimation of KOC amount to be supplied to the K-ETS market is needed.

The KOC supply amount during the 1st year ('15.1~'16.6) of K-ETS Phase 1 is 10KtCO_2eq. However, this Figure includes CER issued since 2010 and it is expected that the future potential supply of KOC would not reach 12,000KtCO_2eq as of 1st year.

KOC supply consists of CER from CDM (Clean Development Mechanism) projects approved by the UNFCCC and KOC from domestic offset projects in Korea. Currently there are no such data for supply estimates on domestic offsets (<Table 4.20>).

<Table 4.20> UN CDM project registered in Korea

(Unit: KtCO_2eq/year)

Category	Business type	Availability in K-ETS	CER amount
HFCs	HFC23	Disabled	0
N_2O	Adipic acid	Disabled	0
	Nitric acid	Enabled	2,129
	Caprolactam	Enabled	661
Wind	Wind	Disabled	0
Tidal	Tidal	Enabled	315
Hydro	Existing dam	Disabled	0
Hydro	Run of river	Disabled	0
Fossil fuel switch	Oil to natural gas	Enabled	91
Solar	Solar PV	Disabled	0
Mixed renewable	Solar and wind	Disabled	0
	Wind and hydro	Disabled	0
	Solar and wind and other	Disabled	0
Landfill gas	Landfill power	Enabled	1,715
Biomass energy	Industrial waste	Enabled	21
PFCs and SF6	SF6	Except	0
EE service	Water pumping	Enabled	7
Geothermal	Geothermal heating	Enabled	5
Methane avoidance	Manure	Enabled	2
Reforestation	Reforestation	Enabled	1
Total			4,947

This study is the first one which performed the estimation of such data. All KOC supplied to the K-ETS in 2015 are CDM based CER. Currently there is no KOC supply based on domestic offset projects yet.

The market stakeholder are aware that much more time is needed for KOC based on domestic offsets to be supplied to the carbon market.

Therefore, estimated results of KOC supply based on UN CDM has been regarded as KOC supply status and future outlook. Data for the analysis are based on UNFCCC CDM website.

Annual amount of CER stated in total of 93 CDM PDD (Project Design Document) are examined and eligible projects that could be used in the K-ETS before 2020 has been sorted by project types. According to the current regulation on KOC projects, the use of CER from HFC23, Adipic acid, renewable energy and etc are prohibited.

Apart from these project types, possible amount of future CER supply on an annual basis is at least 4,947KtCO_2eq.

Such supply would increase to 8.538KtCO_2eq if the SF6 project of LG International Co. restarted.

However, by considering the fact that LG International Co. had no plans of restarting the project even at the KAU price reached 21,000 won (‘16.5), there is a low possibility of the project being restarted due to the fact that the current price of KAU, KCU and KOC are all decreasing. In other words, the most realistic Figure for the potential supply amount is 4,947KtCO_2eq which is the minimum potential amount.

522 of Korea’s biggest GHG emitters, which in total emit some 500million tonnes carbon dioxide equivalent (CO_2eq), are demand side. Companies covered by the ETS can meet up to 10 percent of their obligations with domestic offsets (KOC/KCU) and up to 50 percent with international credits such as CER after 2020. I expect the largest portion of this demand to be filled by

CER in line with the Korea's limits on offsets after 2016. Korean carbon market players have only been involved in CER transaction to a limited extent.

Under the assumption that the overall environment of the year 2015 continues throughout the second and third year, the KAU shortage would is expected to be 102.5% of 5,000KtCO_2eq in 2016 and 105% of 5,000KtCO_2eq in 2017.

If the value of 4,947KtCO_2eq, which is the carbon credits from CDM projects almost certain to be supplied to the market is applied shortage of 178KtCO_2eq in 2016 and 303KtCO_2eq in 2017 is expected. In turn, if the surplus amount of 7,000KtCO_2eq in the year 2015 mentioned earlier is applied 6,519KtCO_2eq of carbon credit oversupply is expected (<Table 4.21>).

<Table 4.21> Supply demand balancing of carbon credit

(Unit: KtCO_2eq/year)

Credit type	2015	2016	2017	Total
KAU	-5,000	-5,125	-5,250	-15,375
KOC, KCU	12,000	4,947	4,947	21,894
Total	7,000	-178	-303	6,519

However, the two types of carbon credit sources which are Early Action Credits (EAC) and Market Stability Reserve (MSR) are not considered in this analysis. During the period between 1st and 3rd of June in 2016, the Korean government has sold KAU worth 300,000 tons each everyday through Korea Development Bank (KDB), Industrial Bank of Korea (IBK) and Export·Import Bank of Korea (EXIM bank). The government have adopted bidding method and only the 82 companies short of allocation for more than 10% of their allocated amount are allowed to bid. The total shortage of 82 companies is 1.1 million tons but only 15 companies participated in the bidding and total of 289,118 tons are traded.

The market price is 16,200 won on day 1, 16,200 won on day 2 and 16,958 won on day 3. The average market price is 16,314 won and 32.12% of total credits supplied by the government is sold.

However, the amount of MSR is minimal compared to EAC. Deadline for companies to apply for EAC is '16.8 and the decision would be finalized in '16.10 by the government. Then the finalized amount would be allocated in '16.12 and would be able to be used from 2016.

The government held 41,391KtCO_2eq as EAC and through the pre-investigation in 2015 522 companies have applied for EAC worth 98,000KtCO_2eq. In other words, all of 41,391KtCO_2eq EAC held by the government are expected to be supplied into the market (<Table 4.22>).

<Table 4.22> Amount of reserves which owned by government

(Unit: KtCO_2eq/year)

Total	MSR[1)]	EAC[2)]	Etc
88,821.7	14,316.2	41,391.9	33,113.5

1) Market Stability Reserve, 2) Early Action Credits

However, the government has deregulated the criteria of EAC use restriction to 3% of its total allocation through revision of emission trading act. Further, the government plans to extend the restriction on EAC use to more than 3% of its total allocation. Under the assumption that all of EAC requested by the companies are being accepted by the government, maximum of 98,000KtCO_2eq carbon credits can be supplied to the market. In other words, KAU ranging from 47,819KtCO_2eq to 105,819KtCO_2eq would be supplied to the market after '16.12.

Ministry of Strategy and Finance (MOSF) has set out to reform its emissions trading scheme in a bid to boost market liquidity, a move that could include bringing in speculative trading and establishing a futures market.

The MOSF took over responsibility for the K-ETS from the Ministry of Environment (MoE), and established a climate finance division, which will be responsible for new policy developments for the market. The market has been marred by poor liquidity since it opened in Jan. 2015, partly due to strong opposition from covered industries that claim the emissions cap in the scheme is far too strict.

Government moves in regards to the K-ETS - doubling the amount emitters can borrow from next year's allocation, increasing the number of early action credits, and releasing 900,000 KAU from the reserve - all suggest that future rule changes will most likely be designed to help emitters. The current trends in the K-ETS shows what can happen if third-party speculation is not allowed and the government sends out inconsistent signals. Credits are not coming out into the market, despite the market being 7 mission tonnes long.

Supply and demand projection of K-ETS Phase1 based on current situation is shown in the above Table and the results shows that oversupply of carbon credits ranging from 47,808KtCO_2eq to 110,808KtCO_2eq for three years are expected (<Table 4.23>).

<Table 4.23> Supply demand balancing with Early Action Credits (EAC)

(Unit: KtCO_2eq/year)

Credit type	2015	2016	2017	Total
KAU	-5,000	-5,125	-5,250	-15,375
KOC, KCU	12,000	4,947	4,947	21,894
MSR		289		289
EAC		41,000～103,000		41,000～103,000
Total	7,000	41,111～104,111	-303	47,808～110,808

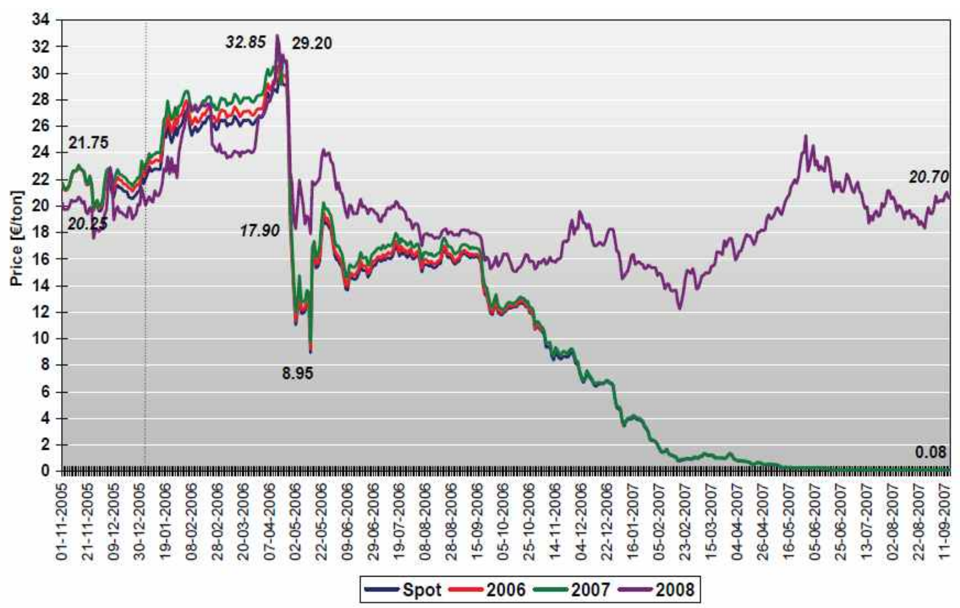
As mentioned earlier, the potential KOC supply amount from domestic offset projects are not considered in the analysis. It shows similar supply/demand pattern as of EU-ETS.

In other words, the results are showing that the current situation would more likely to be in a oversupply of carbon credits rather than shortage of carbon credits as pointed out by the press and allocated companies. If there are no such limitations on banking of carbon credits from Phase1 to Phase2 (2018-2020) in the K-ETS, the surplus carbon credits would be sent over to phase2 and would act as a burden on the emission trading scheme design.

Through the analysis influence on market and supply contribution rate of KOC potential derived through this study is expected to be very low.

4.3.2 Supply and demand balancing of K-ETS

The first release of verified emission data which is for effect on EUA price, as shown by sharp break in the price of maturity of EUA that can be observed in 2006 depicted on below (<Figure 4.15>).

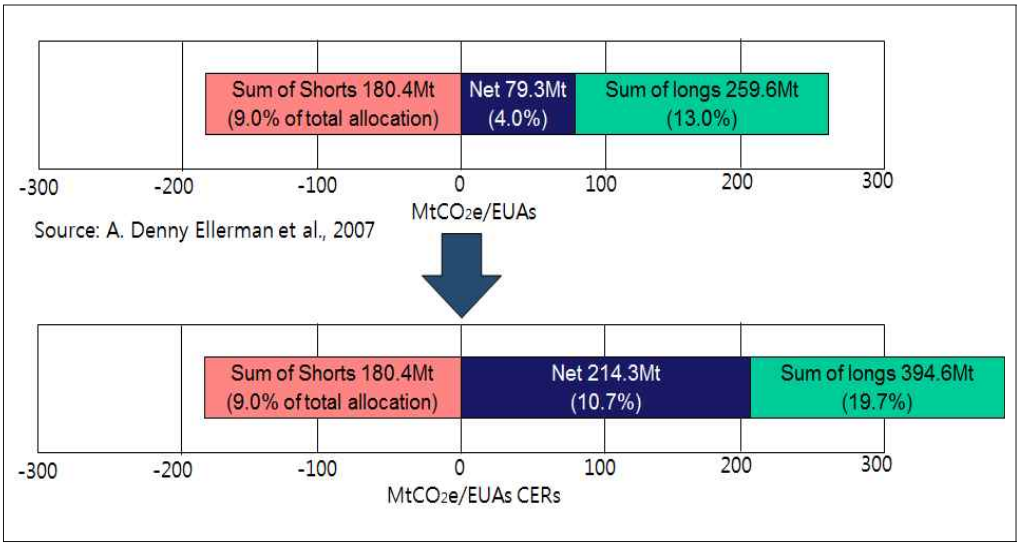


<Figure 4.15> EUA price on the EU carbon market

Reference: Pointcarbon, 2016

Following announcements of Netherlands and the Czech Republic, their emissions are 7 to 15% below the respective allocation to installations, EUA prices fell down about 10%. Subsequent announcements from the Wallon region of Belgium, Spain and France revealing similarly long position for the first two and smaller than expected shortage (<Figure 4.16>).

There are less severe fluctuation of price until the complete data are released on May. However, the essential adjustment is made in there 4 days and after May 15 the price remained close to EUR15 until late September when first period allowance began what would be steady fall to near zero price in 2007.



<Figure 4.16> Aggregate EU25 position, 2005

Reference 1) A. Denny Ellerman et al., Over-Allocation or Abatement? A preliminary analysis of the EU emissions trading scheme based on the 2006 emission data, 2006, 2) World bank, State and trends of the carbon market, 2006

The April 2006 price 'collapse' demonstrated a readily observable characteristic of markets. The cap is always known, but until aggregate emission data is released no one has a really good idea of what aggregate emissions are and of the resulting demand for allowances (A. Denny Ellerman et al., 2007). The same phenomenon is observed in the US SO2 emissions trading program when the first auction revealed emissions and the implied demand for allowances to be much less than expected (Ellerman et al., 2000).

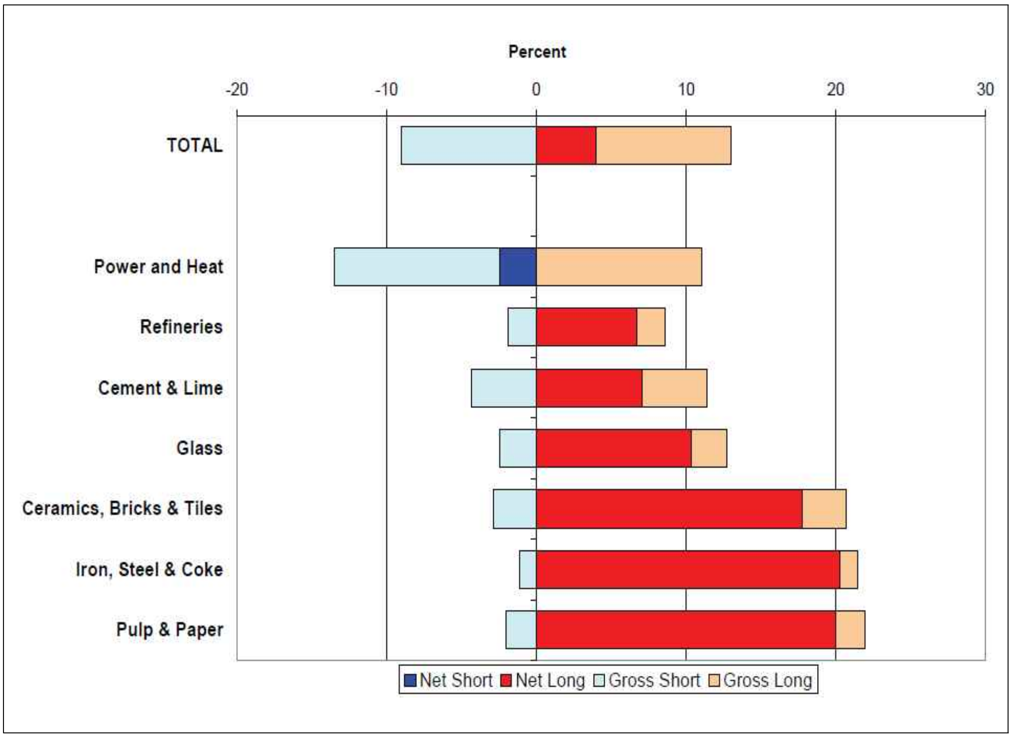
A measure of the likelihood of over-allocation can be calculated from this data based on the earlier discussion of what might cause long positions (A. Denny Ellerman et al., 2007). Any aggregate of installation data will typically shows the group to be either long or net on balance and to have some component long and others short (A. Denny Ellerman et al., 2007). For each, a ratio can be calculated from the net position in relation to the corresponding long or short position, such as indicated below (A. Denny Ellerman et al., 2006).

Net Ratio = Net Long or Short/Gross Long or short

Lithuania would have a ratio of +1.0 since it was long and its net long position is identical to its gross long position. Conversely, the UK has a ration of -0.72 since its net short position is 72% of the sum of the amounts by which all short installations are short (A. Denny Ellerman et al., 2007). By definition, the net ratio is limited to values between -1.0 and +1.0 with negative numbers indicated that the aggregate or member state is short over all and positive values indicating the opposite (A. Denny Ellerman et al., 2007).

A negative net ratio suggest that no obvious over allocation has taken place. Sectors within a member state may be over-allocated, but if the member state as a whole is not, the over allocation is compensated by an implied under-allocation to other sectors (A. Denny Ellerman et al., 2007).

In here, JI (Joint Implementation project) was not considered because such project was not introduced until 2005. According to the Worldbank report (The state and trends of carbon market 2006), total of 554.5MtCO_2eq are transacted during 2004~1st half of 2006. However, such Figure cannot be regarded as actual supply of carbon credits because primary and secondary market have all been reflected in the result. For CDM project data, the total amount available for issuance from 2000 until 1st half of 2006 have been analyzed based on CDM pipeline data provided by CD4CDM (www.cd4cdm.org). As a result of the analysis, the total amount of supply available in the primary market was predicted as 135MtCO_2eq. In addition, as a result of the recalculation on supply-demand balancing by applying CER supply during '05.1~'06.4 period, the oversupply ratio of carbon credits was 10.7% as shown below.



<Figure 4.17> Short and long positions by EU-wide sectors

Reference: A. Denny Ellerman et al., Over-Allocation or Abatement? A preliminary analysis of the EU emissions trading scheme based on the 2006 emission data, 2006

By industrial classification, all but power and heat sector showed net long position. The allocation pattern of EU-ETS in 2006 and 2007 was identical. The supply-demand balancing was always identical.

In the EU-ETS and US SO_2 emission trading program, it was known that most of the stakeholder are all aware of the allocation amount but did not have any access to the aggregate emissions data in the first year of the program.

Therefore they are unable to understand the actual demand for allowances. However, the price of carbon credit fell after the relevant information has been open to the public indicating that the demand for carbon credits was not as high as expected.

In the case of EU-ETS, the price plunged even more because 75% of the stakeholder which took part in the carbon transaction are not one of the 12,000 allocated companies but are third party financial institutions.

These financial institutions accelerated the price fall by performing loss-cuts under the consideration that the future price would fall because of oversupply and decrease in demand.

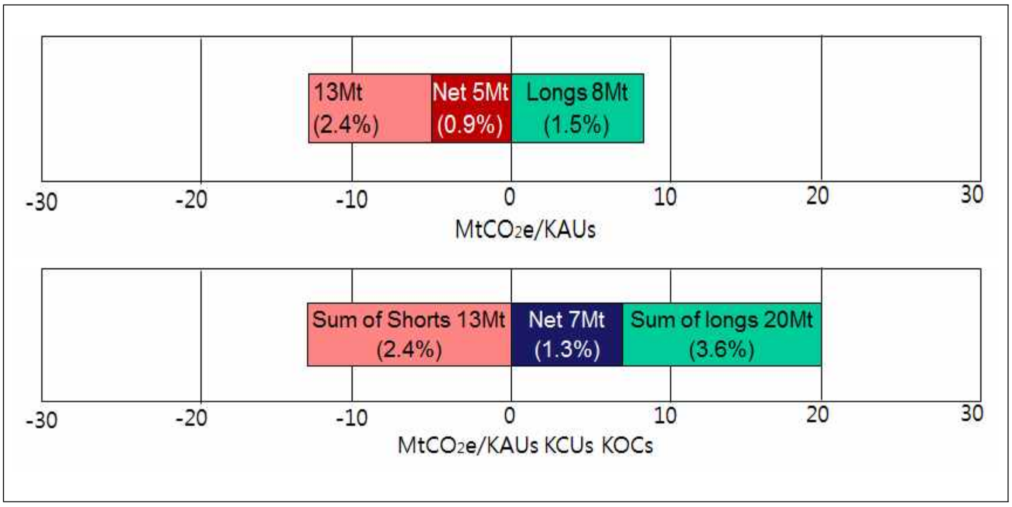
There is a question of how this situation would occur in Korea.

First, after the sum up of the first year the results of the short and long position has turned out to be a shortage in supply which is the opposite compared to the case of EU-ETS. The net emission was net short supply status by 0.9% of allocated amount (5.5 billion tons) in the year 2015.

By considering the 4% net surplus supply status of EU-ETS, the problem of short supply as well as carbon credit price fall would not occur in Korea because the starting point itself was different. Theoretically, the price of carbon credit should continue to rise.

In EU-ETS net ratio higher than +0.6 include the member states for which the evidence of over allocation in much stronger (A. Denny Ellerman et al., 2007). In K-ETS, net ratio (+0.35) lower than +0.6.

However, in the case of KOC supply being applied, there would be a net surplus supply by 1.3% of allocated amount (5.5 billion tons) in the year 2015. Such result (1.3%) is still relatively lower than the case of EU-ETS (4%) but it was predicted to shows similar patterns (<Figure 4.18>).

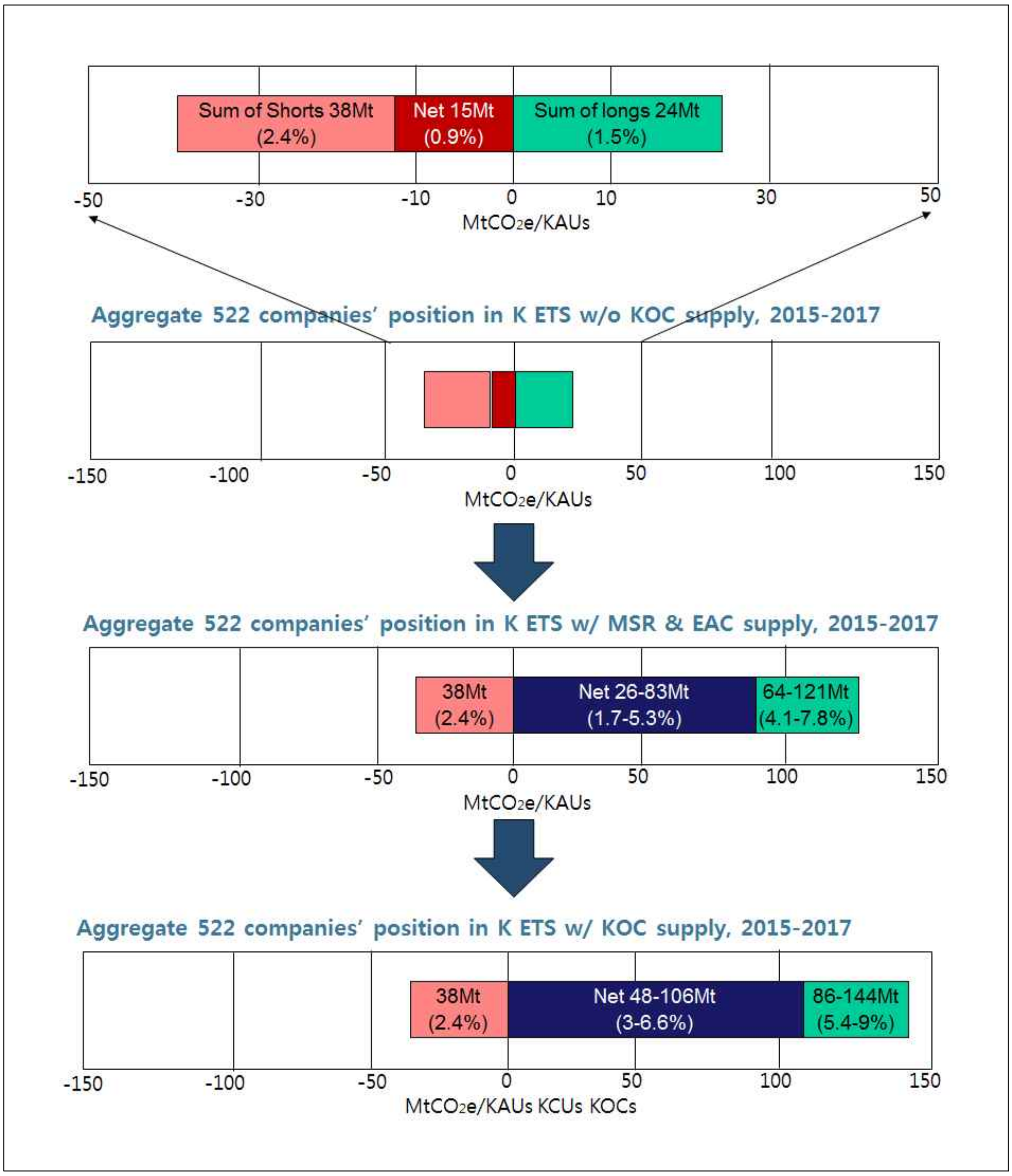


<Figure 4.18> Aggregate companies' position in K-ETS, 2015

In the first year, as seen from the analysis above there was no drastic rise in price from supply shortage and price plunge from oversupply. The market stabilization program from the government had no affect on solving supply shortage problems.

Instead the program caused unusual carbon credit price fall problems leading to complaints from the stakeholder in the carbon market. The factor that should be considered for the explanation of the result in this study is supply-demand balance of K-ETS Phase1. The result on the estimation of supply-demand balance during 2015～2017 period is the following.

In other words, if the situation in 2015 continues as the estimation result in the future carbon credit shortage of 14MtCO_2eq would occur.



<Figure 4.19> Aggregate companies' position in K-ETS phase1

In this case the domestic KOC supply would be the key to success of the emission trading scheme in Korea and there is a need for the government of Korea to actively perform relevant supporting policies. The whole shortage of carbon credits cannot all be covered only by current supply of UN CER.

However, a totally different situation is expected to occur when the additional allocation regarding early action emission credits to be provided to relevant companies on December of 2016 are applied.

As a result, it is predicted that the oversupply of approximately 3~6.6% of 16 billion tons of K-ETS Phase1 total allocation amount would occur. Such result indicated that the ratio of oversupply is somewhat lower than the case of EU-ETS (10.7%).

It is possible to predict that there is a possibility of carbon credit price fall in Korea as of EU-ETS if the results indicate similar or higher rate of carbon credit oversupply.

However, the current result shows oversupply rate of approximately 50% level of oversupply rate in EU-ETS and it is difficult to conclude that the current status of the carbon market in Korea is experiencing serious oversupply of carbon credits. But using net ratio, the max result (+0.79) is higher than +0.6 include the evidence of over-allocation in much stronger like EU-ETS (A. Denny Ellerman et al., 2006) (<Table 4.24>).

<Table 4.24> Net ratio for each statement

(Unit: KtCO_2eq/year; %)

Credit type	Net long/short		Statement	Gross long/ short		Net ratio*	
	Max	Min		Max	Min	Max	Min
KAU only	n.a	-15,375	short	n.a	38,000	n.a	-0.4
KAU with MSR and EAC	25,914	88,510	long	49,289	111,885	0.53	0.79
KAU, KCU, KOC	47,808	110,404	long	71,183	133,779	0.67	0.83

* Net Long or Short/Gross Long or short

4.3.3 Effect of KOC potential to K-ETS

Under the current situation of oversupply of carbon credits in the market, KOC potential through high efficient lighting equipments replacement methodology would not be able to give significant affect on the carbon market.

This is because additional supply to the already oversupplied market would not be able to give any meaningful affect and the additional supply through such KOC project is minimal.

If so, does the KOC potential through domestic offset project have significant implications on the carbon market? In addition, are there any interaction between KOC potential and carbon price?

For the analysis on finding answers to these questions, there is a need of examining the understanding of carbon credits in company’s point of view. Therefore, case interviews on 60 companies out of 522 currently in the emission trading scheme have been performed.

In addition, interviews with relevant local consulting firms in the climate change business sector has also been performed to gather opinions regarding strategy on entering the emission trading scheme in Korea. As a result, there are implications somewhat different from oversupply of KAU and KOC supply.

Among the interviewed companies, most companies short of carbon credits decided to borrow allocation credits from the following year and some companies with surplus carbon credits sold their surplus amount while most of them decided to bank their surplus amount.

The most interesting thing to be pointed out is that the main reason for borrowing and banking action by companies is due to the uncertainty on future carbon market as well as low confidence in the government’s relevant policies. Many companies have decided to borrow instead of purchasing credits through the carbon market based on their judgement that passive action rather than proactive action are desirable because the relevant government policies are highly volatile.

When viewed in terms of finance, borrowing is the worst choice to be taken as an alternative among various response strategies companies should undertake. This is because borrowing is a method that transfer risk to future.

However, many companies have changed their attitude from proactive to passive through experiencing difficult situation after taking proactive actions in coping with their emission targets.

The carbon price rose to 21,000 won since January of 2016 and most of the companies which are short of allocation and took early proactive actions for compliance purchased carbon credits mostly at around 18,000 won. These companies are good companies which all have taken careful examination on the carbon market and proactively participated in the emission trading scheme.

However, nevertheless of their efforts the government have released its allocation credits which are to be used for market stabilization at around 16,200 won.

Eventually, the proactive actions by the companies which purchased carbon credits at around 18,000 won turned out to be a failed market strategy. Through this experience companies came to conclusion that proactive actions are unnecessary and instead borrowing would be a more effective method.

Also, by considering the current oversupply state it cannot be regarded that borrowing is not just a passive risk avoidance method. In fact, borrowing might be the most effective and realistic method companies may take.

There is a question of why companies with surplus carbon credits more likely to maintain carbon credit retention policy rather than selling surplus credits.

Before the proclamation of the revision of emission trading law which took place on march of 2016, most of allocated companies and relevant stakeholder expected the continuous rise of carbon price because of strict operation of the program by ministry of environment and predicted that the shortage of carbon credits would extend as the emission trading scheme is to be strengthened according to the initial design.

For these two reasons, it has been observed that the companies tended to keep their surplus amount of carbon credits to sell when the carbon price is high or to comply with strengthened emission targets in the future. Therefore, the supply of KAU in the carbon market is scarce.

If so, there is a question of why do the companies intend to possess carbon credits even when the oversupply of carbon credits is expected in the carbon market. The answer to the question is it has been examined that most of the companies are still judging that the current market is short of carbon credits and even when there is a oversupply of credits they tend to possess the carbon credits in order to use them in the uncertain future.

This issue overturn the logic derived from prior analysis in this study that oversupply of carbon credits worth 1 billion ton during K-ETS Phase1 is expected and there is a possibility of carbon price fall.

No matter how much oversupply of carbon credits are present in the market, there is a possibility of signs of oversupply not occurring in the market as long as the companies with surplus carbon credits do not release them in the carbon market.

As long as there are no restriction policies on the banking of carbon credits, companies with surplus carbon credits would remain reluctant to sell their surplus amount in the market and companies short of carbon credits would be willing to buy credits in the market. However, in the last year of Phase 1 (2017) borrowing from Phase 2 is restricted and it is expected that the market participation of companies to buy carbon credits for compliance would increase, leading to rise in carbon credit price.

In order to induce psychological change of companies with surplus carbon credits to sell their surplus amount in the market, banking restriction policies as well as showing signs of selling significant amount of KAU from companies with the highest amount of surplus credits would be necessary. Such measures would lead to more selling action of other companies with surplus credits, leading to carbon credit price fall.

The similar situation has already been witnessed in EU-ETS in the year 2006. However, the same situation experienced in EU-ETS is not expected to happen in Korea. Approximately 75% of EU-ETS's stakeholder are financial institutions. These financial institutions perform loss-cuts when they expect the carbon price fall. However, in K-ETS the government has prohibited the participation of financial institutions until 2020.

Therefore there is a low possibility of companies performing loss-cuts by selling all of possessed carbon credits in Korea even when the carbon price fall is predicted.

The current status of EU-ETS is under significant of carbon credits oversupply. And unlike with the price of CER and ERU, that of EUA is maintaining constant price level. On other words, EU-ETS is under oversupply condition but due to the scheme design there is a low possibility of drastic price fluctuation.

By summing up the past argument mentioned in this study, because of trading characteristics of allocated companies in Korea there are little chances for the carbon market collapse due to supply of KAU. In addition, the KOC have unique characteristics which differs much from KAU/KCU and is a crucial factor for the soft landing of the carbon market in Korea.

Nevertheless, there is a possibility of opinions opposing the idea of supplying additional carbon credits into the market due to concerns regarding oversupplying of credits and possibility of carbon market collapse. There is a question of whether the support program for the supply of additional carbon credits into the market is inappropriate.

What is the essential aspect of the ETS?

It is the reduction of GHG emissions. The ETS is a policy which utilizes market mechanism in order to reduce GHG emissions in a cost-effective manner. In other words, the ideal market status in the ETS is when the GHG emissions is being reduced. However the main reason for the oversupply issue during K-ETS Phase1 is early action emission reduction and CER. Early action emission reduction is a type of incentive in a form of carbon credit given to companies which took voluntary and early actions before the start of the Emission Trading Scheme to reduce GHG.

Also most of the CER already supplied to the carbon market is originated from emission reductions before the start of the ETS which are acknowledged retroactively by the government. In other words the current carbon market is under oversupply of carbon credit which are originated not from ideal emission reductions by voluntary effort of companies but from carbon credits which its origin is not related to emission reductions through the scheme. In this state the market would be flooded with surplus carbon credits even if the companies do not put their efforts on reducing GHG emissions.

Therefore it is rather difficult to conclude that actual GHG emission reduction occurred through the K-ETS. Whether the fact that actual GHG emission reduction has occurred in Korea through K-ETS needs to be further examined after sufficient amount of relevant data have been accumulated in the future.

So there is a question of what has to be done for the Emission Trading Scheme to achieve its primary goal of actual GHG emission reduction.

The answer to the question would be making the social atmosphere which enables not only the 522 allocated companies but also other companies and citizens to actively perform GHG emission reduction actions. The best method to achieve this goal is by supporting the revitalization of domestic KOC projects.

In other words, domestic KOC differs much from other types of carbon credits based on the fact that the domestic KOC itself has achieved actual GHG emission reduction effect.

In addition, the last sets of information needed for the analysis is factor of decision making for implementation of KOC project.

Based on the result of the analysis mentioned above, the estimated potential KOC amount is small compared to the total transaction amount but in terms of carbon credit type the KOC itself had different characteristics compared to other carbon credit types and also had different influence on the carbon market. In other words, the influence of domestic KOC credit on the carbon market is higher than other types of carbon credits.

So, in accordance to the result of the analysis investigation on finding market support methods in order to enable the domestic KOC project are performed. For the analysis, examination on influence factor regarding KOC project implementation decision making process are performed at first.

Most companies have not yet entered the offset market. There is significant uncertainty related to how the price floor of Korean's ETS will be structured. When the fixed-price portion (10,000 won/tCO_2eq) of the programme moves to a flexible-price (up to 18,000 won/tCO_2eq) ETS in 2016, the stakeholder hope to hold for at least the first three years of trading until mid-2018. If offsets cost less than this, emitters will have to pay a “Surrender Charge” - the difference between the price floor and the value of the offset - for each KOC they surrender to the Korean government for compliance.

The other reason why Korean companies are reluctant to buy KOC at this point is related to the uncertainty on future KOC prices. KOC prices have been at a historically same level (small increase) lately, implying companies should be making massive investments to catch these assets while they are cheap. I expect the KOC price to decrease from its current level of around

18,000 won/tCO_2eq, and expect an average price for eligible KOC of 15,000 won/tCO_2eq over the 2016～2017 period.

I do not expect KOC investments to pick up before there is full certainty on the price for credits. I expect the level of KOC purchase to increase in late 2017 or early 2018 when parts of the Korean power sector start to hedge their electricity production for 2017. However, I expect most of the emitters to stay away from KOC before 2017 when there is full clarity on all aspects of the ETS.

The key steps in the financial assessment process are development of a project model, financial indicators, sensitivity analysis, risk assessment and mitigation.

The principal unique feature of a KOC project is that some revenue may generate from the sales of KOC. If a project has other revenue streams apart from KOC (such as electricity reduction from high efficiency light). However, in most case the revenue stream that exist is not sufficient to generate the project financially viable, and therefore the revenue from KOC will be critical to the financial viability. Consequently, the volume and cost of production of KOC, as well as the price are key inputs to financial model for KOC project.

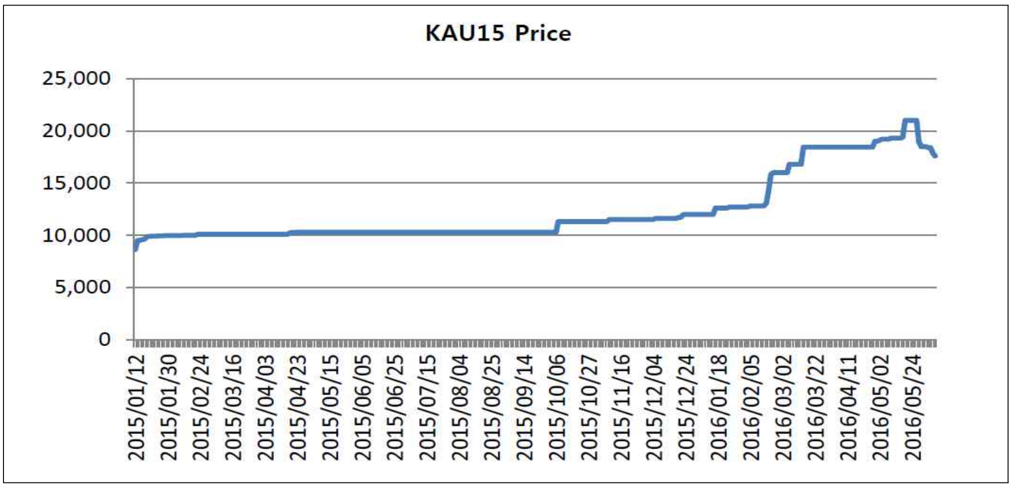
The factors affect the cost and volume of production of the KOC that may be generated by a KOC project. The most important variables are the scale of offset project, KOC price, emission factor, investment cost, time scale of project development

1) Project scale

Projects in the KOC pipeline are small-scale according to the KOC definition of this term. Within the 03A-005 (Demand-side activities for efficient lighting equipments technologies) project type, larger projects will generate more KOC and benefit from economy of scale in the cost of production of KOC.

2) KOC price

The market view on the future value of KOC is also volatile. Until 2014, the prevailing view is that KOC would be worth no more than around 10,000 won. With the coming of high price (up to 18,000 won/tCO_2eq) for allowances in the K-ETS in 2016, project developer of KOC expect higher price for KOC.



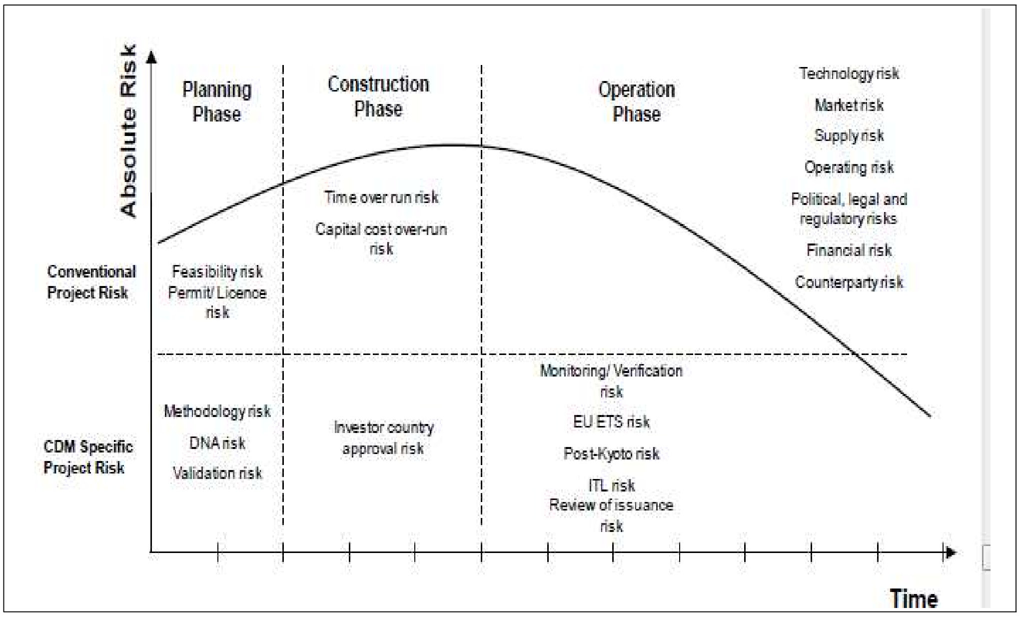
<Figure 4.20> Status of KAU15 price (2015.1.~2016.5.)

3) Emission factor

The emissions factor applicable to the KOC activity is critical to the volume of KOC produced, particularly because it is so highly variable. For projects generating electricity of export to grid, or reduction electric consumption through energy efficiency, the emission factor of the grid determine the emission reduction of the project. In case of 03A-005-Ver01, the impact of electricity emission factor is not high.

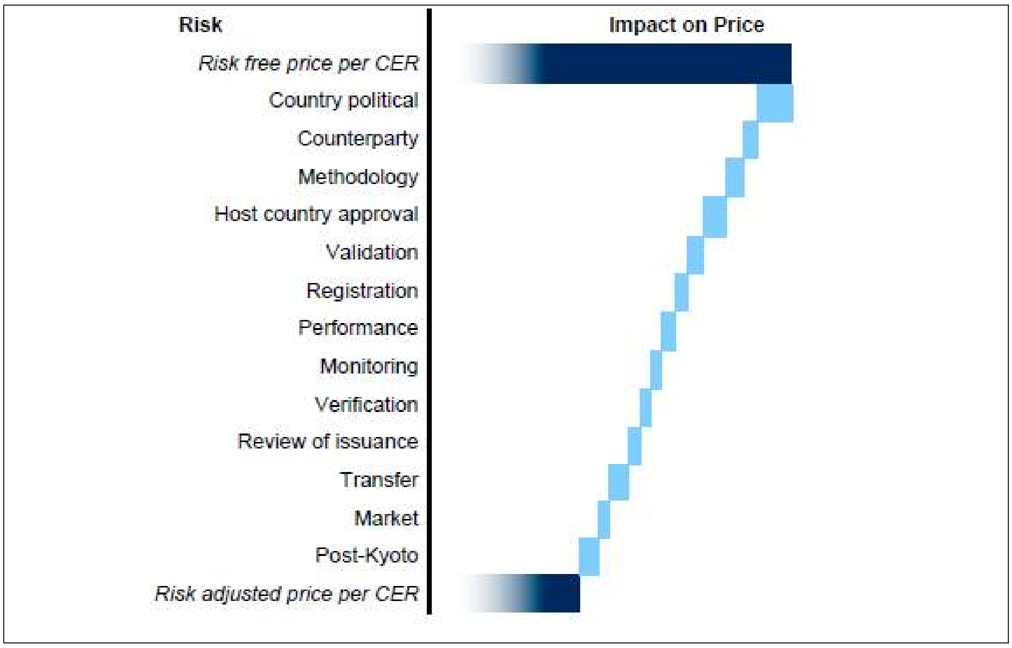
4) Risk assessment and management

Investors concern to assess all of the risk associated with a project and to agree to manage and mitigate of all risks.



<Figure 4.21> KOC project risk

Reference: Guidebook to financing CDM projects, CD4CDM



<Figure 4.22> KOC project risk profile and its impact on KOC price

Reference: Guidebook to financing CDM projects, CD4CDM

In the present context, consider the counter-party to be the KOC seller, when making forward contract with a KOC buyer. When a KOC buyer consider the price it pay for the promised future delivery of KOC under a forward contract, it want to assess the credit rating of KOC seller, as an indicator of the counter party risk. Many KOC buyers have internal credit committee which will impose strict counter party credit rating requirements on contract negotiators.

If a KOC project is possible to use existing approved methodology is costly, time-consuming and risky. Even developer using only approved methodology need to bear in mind the risk that the KECO may withdraw or put on hold a approved methodology.

Validation risk. Every KOC project has to be validated by a KECO in order to be registered with the GIR. Validation, registration, monitoring, verification are grouped into rejection or non-issuance.

But another risk can appear in KOC project. approval process delay risk (including validation and registration delays) and issuance delay risk (including monitoring duration and certification delay).

Approval process delay. This is the risk of delay before registration, corresponding to the time between first publication of the project for public consultation and its registration. Delay may occur both at the validation and at the registration steps. These delays may stem from the project developer, KECO, the DOE. This delay often impacts the start date for the crediting period (Alain Cormier et al, 2013)

Issuance delay. This is the risk related to length of the period between registration and the actual issuance of KOC. This time is divided between monitoring period and the certification duration, corresponding to the time between the end of monitoring period and the corresponding issuance. The monitoring period depends on project developers. who choose their time to verify their project, and the certification and requests issuance, and the KECO and GIR who eventually approves the issuance and delivers the credits on the developer's account.

5) Sensitivity analysis

The objective is to establish which of the assumption to the financial model has the great impact on the outcome.

6) Project financial model

A financial model is the most critical element in KOC project development. Small-scale high efficiency lighting equipments replacement are helping to alleviate poverty and foster sustainable development. However, the low emission reductions per installation are making it difficult for such projects to derive value from participating in the KOC (Pallav Purohit et al, 2008). The parties involved in financing a KOC project are with the following unique elements.

<Table 4.25> Role and responsibility of each Entities

Entity	Role/responsibility
Project host	The project host is the entity providing the facilities or resources that are required to undertake the KOC project in the location of the project. Project hosts may be companies or local government institution.
KOC project developer	The KOC project developer is the entity responsible for driving the project through the KOC project cycle. The project host may take on this role, or it may be provided by a specialized KOC project developer company.
KOC buyer	Any entity may purchase KOC from a project. However, in order to be able to use the KOC for compliance under K-ETS, the purchaser of the KOC must either be a 525 Party or be authorized by the government (MOE)
Designated operational entity (DOE)	The DOE is required to verify the project prior to issuance of KOC. Essentially, it plays the role of independent auditor. But, validation is role of KECO (Korea Environmental Corporation).

Reference: Guidebook to financing CDM projects, CD4CDM

It observed that the majority of the KOC-specific project cost occur during the planning and operation phase. The buyer of the KOC is another potential source of finance for a KOC project. This is effectively a loan provided by the KOC buyer.

The financial barrier is importance for the development of KOC activities in Korea. A significant number of the proposed KOC projects are small scale which is not attractiveness for investor.

And the long and complex KOC project cycle discourages some investors and project promoters, as well as the high transaction costs associated to KOC project proposals development make it, especially SMEs, difficult to afford expensive specialized consultancy for the preparation of project design documents. Michaelowa and Jotzo (2005) estimated that the minimum fixed transaction cost for a typical CDM project is 150,000 Euro.

Economies of scale play an important role in ensuring that the generation of CER is adequate to cover at least the fixed costs. The higher ratio of transaction costs per total savings is clearly one of the key factors that explains why the CDM approach is not so attractive or viable (Ken L. Mok et al, 2014). In case of KOC cycle, the minimum fixed transaction cost for a typical KOC project is about 3,000,000won.

7) Future market

According to Climate Action Tracker's report, A 2.7°C warming by the end of this century if all governments fully implemented their intended nationally determined contributions. 2.7°C is only met with a 50% chance and temperature would continue to rise after 2100.

This is much better than before the Paris process, but still far away from “well below” 2°C, let alone 1.5°C. Most governments and observers called for increasing the ambition of the long term goal from that of limiting global temperature increase by the end of the century to a maximum of 2°C compared to pre-industrial times in Paris 2015.12, to a more ambitious goal of 1.5°C, in recognition of the IPCC's Fifth Assessment Report. The report finds that the impacts of a 2°C temperature increase entail grave consequences in many parts of the world, including the likely disappearance of many small island states.

Important achievement of the Paris Agreement is to have set in place a process for tracking progress, both globally towards the long term goal of the convention, and nationally towards achievement of national contributions.

This is particularly relevant, as the current bottom-up process with nationally determined actions turns out not to be sufficient for the agreed global goal.

A global stocktaker has been agreed to regularly monitor the progress towards the long-term goals every 5 years starting 2018. The exact modalities of the review will be determined in future meetings. The implementation of the national actions will be ensured by a facilitative implementation committee.[1] This means that no sanctions will be applied if a country does not fulfil its contribution, but rather that the countries are supported to implement their contributions.

The agreement also calls for reporting requirements for all countries, in order to increase the transparency of actions. The recent process on intended nationally determined contributions (INDC) showed that countries need assistance in monitoring their emissions and to better understand technical options to increase ambition, in the context of their specific development objectives. Raising ambition is possible, as technological and economically viable options exist. Emissions could be much lower if good practice policies are applied across the board. Energy efficiency, for example, could cut costs significantly.

The Paris Agreement has legal force and is considered to be an international treaty under the Vienna Convention. The legal form of the agreement is of great importance with regards to the signal it provides on the degree of political will behind it. On the other hand, there are no international enforcement mechanisms in place which would allow any form of penalization for non-compliance.

While some elements within the Paris Agreement are legally binding, others are not. The long term goals and the national reporting requirements are legally binding. National mitigation targets submitted as INDCs for the post-2020 period, on the other hand, ended up as not legally binding: countries "are to undertake" these contributions, a departure from the much stronger language "shall undertake".

4.3.4 Policy proposal for KOC supply

As summarized earlier, potential KOC supply through domestic offset projects have different aspects compared to the current oversupply issues and there is a clear reason and cause for activation of implementing such KOC projects.

Then, there is a question of how to extend the potential KOC supply from replacement of high efficient lighting equipments in the carbon market. SMEs are a major target of KOC projects. The most important factor for these SMEs to implement such KOC projects is funding. However, it is difficult for SMEs to receive funds for equipment to implement KOC projects under good loan conditions from commercial banks because the investment payback period is longer than other types. Also, from company's point of view there is no reason for them to implement such projects when there are no financial merits. So there is a need for political finance in this issue.

The government should create financial inducements which to enable diverse GHG reduction projects to be implemented through policy banks such as KDB, IBK, EXIM and guarantee organizations such as KIBO.

However, as examined in this study, it should be noted that not all GHG emission amount can be verified as KOC and supplied to the K-ETS.

In other words, if the policy finance support program is made for the successful operation of ETS, it should not be simply a program only intended for the activation of GHG emission reduction projects.

The key focus would be on the how the choice and concentration strategy on the efficient use of limited policy budget and physical resources. As mentioned before, methods for the improving replacement rate of high efficient lighting equipments replacement actions through financial and technical support for GHG emission reduction actions are effective in increasing KOC supply. If that is so, how about the idea of concentrating the limited resources and manpower on the administrational support of the KOC policy? Through the past study it is confirmed that nevertheless of many high efficient lighting replacement projects done so far, such projects to be implemented as KOC project would be less attractive due to high administration costs.

In other words, revenues from KOC cannot act as a decisive decision making factor for the implementation of high efficient lighting equipments replacement project. Therefore, KOC revenues also cannot be a decision making factor for the implementation of high efficient lighting equipments replacement actions registered as a KOC project.

In other words, if the focus is being made on the administrational support of the KOC policy, its effect would likely be minimal compared to financial and technical support for GHG emission reduction action.

Given the limited resources, the government has to make a choice and concentration. in this study, the two methods to support the soft landing of KOC in the Emission Trading Scheme which are direct support on emission reduction projects through high efficient lighting equipments replacement itself and administrational support on KOC policy have been examined.

In order to enhance the administrational support effect on the KOC, the change of potential KOC amount should be sensitive to the carbon price fluctuation. However, as examined through the modelling results of this study the potential KOC amount did not shows any significant changes according to the carbon price fluctuation. Instead the potential KOC amount showed significant changes when the replacement rate of high efficient lighting equipments increased. Therefore, if there are limitations in supporting resources direct support on emission reduction projects itself would be more effective. If the support is focused on the administrational support of KOC to increase the supply of KOC carbon credits, it would probably not be successful in contributing to the activation of high efficient lighting equipments replacement project and would be more llikely to increase only a small amount of KOC supply.

In conclusion, the policy to support the activation of domestic KOC projects for the soft landing of KOC in the Emission Trading Scheme is essential and the type of support should be oriented on the direct support on emission reduction projects itself. Through these support methods the replacement rate of high energy efficient actions as well as supply of KOC carbon credits would both increase significantly.

This is the best method of achieving both actual GHG emission reduction goal and supply of meaningful carbon credits into the market.

But select and concentration strategy should be used under the circumstances of limited resources. In this case, direct investment on the high energy efficient lighting equipments technology itself and providing technological support are much more effective method than providing administrational support of KOC.

Nevertheless, increasing of electric cost is most powerful method of achieving both actual GHG emission reduction goal and supply of meaningful carbon credits into the market. Increasing up to 10%, emission amount deceased 2.5% at 2017 and 4.6% at 2020. And Increasing up to 50%, emission amount deceased 13.2% at 2017 and 20% at 2020. And Increasing up to 100%, emission amount deceased 20% at 2017 and 35% at 2020.

Chapter 5. Conclusion

5.1 Conclusion

As the K-ETS began in 2015 and the Paris Agreement has been signed in December of 2015, social interest on the effective value and necessity of ETS has been expanded. The soft landing of K-ETS is important for the Korean government to gain policy legitimacy in the international community through achievement of INDC target. In addition, the success of ETS is also important in achieving actual target of GHG emission reduction in Korea.

However, the K-ETS has not been properly operating since the start of the scheme.

The companies which are under the scheme are dissatisfied about the compliance cost due to shortage of allocation compared to their emissions and some are even facing a lawsuit with the government. Carbon market broker and trader's point of view, they are also complaining about the slow progress on market making due to the government's failure on K-ETS operation. The center issue of this is that insufficient amount of carbon credits are being supplied to the carbon market. There is a growing concern among companies which are short of allocation and failed to buy carbon credits in the market due to insufficient liquidity because they must pay 3 times more than the market price per amount for penalty.

However, the current situation in the end of the first year in Phase 1 shows that the under allocation issue raised from companies is not to be worried. The overall allocation is done appropriately and total of 7 millions tons of surplus carbon credits are present in the market.

During May and June of 2016 the carbon market is a seller dominant market which the amount of carbon credit for sale exceeded the buyer's demand. However the government has released additional 900,000 tons of market stabilization carbon credits into the carbon market.

The reason for this action is that the government intended to give companies short of carbon credits an opportunity to buy credits in the market by providing them with reserve carbon credits because there are insufficient amount of surplus carbon credits put on sale in the carbon market.

There are numerous controversies over the government's action in the market. In case of companies short of allocation for more than 10% of their emissions, they are welcoming the government's actions because they are able to purchase their shortage amount at around 16,200 won, which the price is lower than the market price of 18,500 won. But companies which took proactive action by purchasing their shortage amount in the market at a higher price are dissatisfied about the government's action. Brokers and traders also are negative about the government's market stabilization action.

So there is a question of which path K-ETS is to take for the overall success of the scheme.

Carbon credit supply is the most important factor for soft landing of K-ETS. There is a need to motivate companies with surplus KAU to sell their carbon credits in the market but it cannot be forced by policy measures and also there are no drivers in terms of company management to encourage companies sell their surplus amount.

Currently, supplying KOC to the market through transforming of CER from CDM projects is on the limits.

The current price of CER sold in EU is lower than 1 Euro and what is more critical is that CER that could be used in K-ETS is only from domestic CDM projects. The CER from CDM projects hosted in countries except least developing countries could not be sold in the EU.

CDM projects are administered by UNFCCC CDM EB (Executive Board) and due to its strict rules and procedures the administration cost and time needed is very high.

In many cases CDM project administrations costs are larger than revenues from carbon credits. Hence, it is very difficult for companies in Korea to implement such CDM project by just considering the domestic carbon market.

In other words, CER from CDM projects implemented so far can only be the source of total potential KOC amount and it can be regarded that currently such amount is almost fixed.

The only method in order to increase the supply in the K-ETS is by generation of KOC through implementation of domestic offset projects.

In accordance to this, the government has announced 22 methodologies to be used for the KOC projects. KOC can be achieved through projects using these methodologies.

It is possible for companies to develop new methodologies but due to high cost and time spending the potential KOC supply amount through new methodology cannot grow in short term.

Currently, potential KOC supply through 22 existing methodologies is the most realistic one.

in this study, high efficient lighting equipments replacement project methodology among 22 existing methodologies has been selected as the one with the largest range of applicability and influence in Korea and through this methodology the potential KOC until 2030 has been examined.

First, study and analysis on high efficient lighting equipments technology has been performed. Then lighting equipments technologies with high applicability are selected.

It is assumed that general lighting equipments replacement is done by using LED and replacement of metal halide lighting equipments is done by using one of either LED, HEM or IL.

There are no issues in replacing general lighting equipments with LED but in case of metal halides there is a issue of difficulty in selecting replacement ratio among three different types of high efficient lighting equipments. In order to solve this, AHP detailed methodology from MCDM[10] model have been used for the modelling.

300 companies have been surveyed for the AHP analysis and the replacement ratio have been calculated based on modelling using 100 survey results.

The range of application is intended for the entire industrial and commercial facilities. Households are not included in the range of application because it failed to fulfill its monitoring requirements due to the fact that it is nearly impossible to monitor lighting equipments use time in households.

Data to be used in modelling such as lighting equipments use status in industrial/commercial facilities, energy consumption of lighting, high efficient lighting equipments used in replacement, lighting equipments replacement time and etc have been secured from KOSIS, KEA, Korea lighting industry association and etc.

For the estimation of energy consumption and energy savings, modelling is done by using LEAP model.

Through the energy efficient lighting equipments replacement, potential GHG reduction of 2,548.7KtCO_2eq until 2017, 7,168.9KtCO_2eq until 2020 and 27,911.4KtCO_2eq until 2030 have been calculated.

In addition, sensitivity analysis for the calculation of potential KOC amount is performed according to four carbon price scenarios of 5,000 won, 10,000 won, 30,000 won and 100,000 won.

The potential KOC amount compared to total potential GHG emission reduction is 6.7% at 5,000 won, 12.7% at the carbon price of 10,000 won, over 19.2 at 30,000 won and over 26.2% at 100,000 won which is very low.

10) Sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments(Martin Aruldoss et al., 2013)

Through the analysis, it is confirmed that potential emission reduction and potential KOC amount are different due to the fact that the potential emission reduction amount from energy efficient lighting equipments replacement is high but potential KOC amount from it is only a small part of the total amount.

In addition, the potential KOC amount had varying sensitivity depending on the change in carbon price and administration cost.

The potential KOC amount rose in accordance with rise in carbon price but the potential KOC amount are not the same as potential emission reduction even at the carbon price of 100,000 won. Therefore, it can be said that the carbon price had low sensitivity on the implementation of KOC project.

Potential KOC amount is calculated through the analysis and additional analysis on implications of the result and mutual influence between the K-ETS are performed.

Firstly, supply-demand analysis and market forecast on carbon credits during K-ETS Phase1 have been performed in order to examine implications of calculated potential KOC amount.

Even when the potential KOC supply amount through domestic offset projects are not considered, oversupply of carbon credit ranging from 47,808KtCO_2eq to 110,808KtCO_2eq during the next three years is expected. The current state of the market is under oversupply situation, which is the opposite of what the media and allocated companies have claimed so far.

If there are no such limitations on banking of carbon credits from Phase1 to Phase2 (2018～2020) in the K-ETS, the surplus carbon credits would be sent over to phase2 and would act as a burden on the emission trading scheme design. In EU-ETS, with net ratio higher than +0.6 include the member states for which the evidence of over-allocation in much stronger. In K-ETS, net ratio (+0.35) with KAU only is lower than +0.6. But using net ratio with MSR and EAC, the result (+0.79) is higher than +0.6 include the evidence of over-allocation in much stronger like EU-ETS(A. Denny Ellerman et al., 2006).

The potential KOC amount derived from this study compared to estimated potential oversupply forecast is very low.

To draw a conclusion regarding the interactions between the result of the study and K-ETS, interviews with 522 allocated companies, consulting firms, brokers, traders and other stakeholder are performed to gather their views and opinions about the shortage and oversupply of carbon credits in the carbon market.

In addition, investigation of factors considered in decision making for implementation of KOC projects as well as analysis on the influence of domestic offset credit on other types of carbon credits and the carbon market are performed.

As a result of the analysis, firstly the KAU and KOC showed totally different characteristics. As confirmed in interviews, even if there are plenty of surplus KAU it does not lead to selling of KAU by companies in the market.

However in the case of KOC which is generated outside the 522 allocated companies, most of the generated KOC are being supplied to the market for sale.

In other words, the amount of carbon credit oversupply ranging from 47,808KtCO_2eq to 110,808KtCO_2eq which is estimated through supply-demand analysis are mostly KAU derived from additional allocation regarding early emission reduction performance.

Such oversupply amount would not be released to the market for sale and most of the companies would instead keep their oversupply amount for its use to cope with future risks. Therefore, it is more likely that companies would tend to undergo banking of oversupply carbon credits.

In other words, there is low possibility of carbon credits being released to the market for sale in large amount as long as the companies change their carbon market strategy to selling their KAU.

Despite the fact that it is clearly shown in the data that the current market is under oversupply state, there is still a possibility of carbon credit shortage in the market.

Sufficient liquidity is required for normal operation of the carbon market and continuous price signals through trading should be provided to encourage more active participation of companies in the market.

In this respect, most of KOC from CDM projects (international offset) as well as potential KOC amount based on domestic offset projects are key factors in providing liquidity to the carbon market.

In this case, the truth that actual supply is being provided to the market has greater implications than the amount of supply being provided.

If the market have few KOC selling amount situation like 1st year, it can be regarded that the amount of potential KOC through high efficient lighting equipments replacement itself is small but it even a small amount would have significant impact on the carbon market in terms of providing carbon credits continuously in the market.

In this way, policy support from the support is needed for increasing the potential KOC from replacement of high efficient lighting equipments amount which will have significant affect the soft landing of K-ETS. From a financial perspective, business support on projects must be done through financial support programs designed to invest on GHG reduction projects.

But as mentioned in the result of the study potential GHG emission reduction and potential KOC amount are different. Additional measures regarding administration support are required to increase the potential KOC amount.

Various kinds of support such as simplification of KOC audit process, reduction of verification fees through simplified audit, support on verification fee as well as providing of consulting services can increase the ratio of implementing KOC projects by companies.

5.2 Research limitation and scalability of this study

The first difficulty experienced in this study is gaining access to data on status (types and numbers) of existing lighting equipments in companies.

The search for the status of existing lighting equipments in companies was done by inquiry and direct visit to institutions such as SMBA (Small and Medium Business Administration), KMBA (Korea Minor Business Agency), KOSIS (Korean Statistical Information Service), SMBA statistical information service website as well as other possible sources of information. However, nevertheless of the efforts it was difficult to secure the appropriate data on status of existing lighting equipments in companies.

If it wasn't the survey result from research done by KAPID (Korea Association For Photonics Industry Development), there would have been too much assumptions in drawing a conclusion in this study.

The second difficulty experienced in this study was gaining access to data on number of companies and average energy consumption according to categories based on energy consumption amount in the industrial and commercial sector because there are such limited data present in Korea.

In case of companies and buildings showing energy consumption amount of over 2,000TOE, it was possible to gain relevant data through KOSIS because it was mandatory to submit such data to the government. But for companies and buildings showing energy consumption amount of less than 2,000TOE, it was not mandatory to submit such data and there was no alternative but to put them under assumption. Fortunately the relevant data for industrial sector was secured through support from KEA (Korea Energy Agency) but data for commercial sector was unable to be acquired.

The third difficulty experienced in this study was understanding the changes of systematic interaction between carbon price and the carbon market accurately because there are not enough trading volumes and the carbon price fluctuation was mostly affected by the government's artificial intervention rather than the movement by the market itself.

In addition, it was also difficult to see that the stakeholder in the market are participating normally due to lack of experience and knowledge on the emission trading scheme. And the government intervened market. So this isn't a normal situation.

In order to raise confidence of this study, improvements on the difficulties experienced during the analysis mentioned earlier should be done.

This study includes only the modelling results from one out of 22 methodologies approved by the Ministry of Environment (MOE) in Korea. The supply and demand of KAU as well as potential supply amount of international KOC can already be estimated.

In other words, supply demand balancing of K-ETS can somehow be estimated if potential supply amount of domestic KOC could be calculated.

Of course, it has been confirmed through this study that currently K-ETS is already under oversupply state by small amount and throughout the Phase 1 period oversupply amount of approximately 1 billion tons at maximum is being expected.

If the potential supply amount of 21 approved methodologies could be identified, the possible amount of supply to the K-ETS could be estimated. Such estimated results are expected to be helpful in designing Phase 2 system.

References

Ministry of Trade, Industry and Energy, 5th National Energy usage rationalization plan, 2015

Vatanavongs Ratanavaraha, Sajjakaj Jomnonkwao, Trends in Thailand CO_2 emissions in the transportation sector and Policy mitigation, Transport policy 41 (2015) 136～146

L. Chen, W. Pan, A BIM-integrated Fuzzy Multi-criterial Decision Making Model for selecting low-carbon building measures, Proccedia Engineering 118 (2015) 606～613

Jingzheng Ren, Marie Lützen, Fuzzy multi-criterial decision-making method for technology selection for emissions reduction from shipping under uncertainties, Transpertation Research Part D 40 (2015) 43～60

Sangyoung Park, YoungJi Han, Aram Oh, Wookeun Lee, Development of GHG emissions inventory and evaluation of GHG reduction plans of Kangwon National University, Environmental Engineering (2012) 32～41

Jikyung Jang, Hongbae Kim, A Study on the VAT Taxation after Adoption of Emission Rights Trading, KOREAN INTERNATIONAL ACCOUNTING REVIEW 65 (2016) 69～88

Sunghee Shim, Jiwoong Lee, On Inefficiency Factors in the Korean Emissions Trading Scheme, Korean Energy Economic Review 14 (2015) 177～211

Jaehyung Lee, Hojeong Park, A Study on Liquidity Provider (LP) Systems for the Korea Emission Trading Scheme (K-ETS), Journal of Environmental Policy and Administration 23 (2015) 199~221

Jongmin Yu, The effect of ETS penalizing system on carbon prices, Korea Envirionmental Policy and Administration Society (2016) 49~50

Soonsuk Kim, A Study on the GHG Emission Trading Through the Trust, The Korean Journal of Securities Law (37) (2015) 149~194

Freitas, Carlos J. Pereira, Silva, Patrícia Pereira da, European Union emissions trading scheme impact on the Spanish electricity price during phase II and phase III implementation, RCAAP (2017)

Younmi Park, Myungkoon Lee, Feasibility Analysis on Replacing LED lighting with Incandescent Bulbs in Public Institution, Climate Change Research vol1 no3 (2010) 205~210

Yeongjin Jeong, Kaichao Li, Taeoh Kim, Injo Hwang, Estimation of greenhouse gas emissions (GHG) inventory and reduction plans for low carbon green campus in Daegu University, Environmental Engineering 36 (7) (2014) 506~513

Wathanyu Amatayakul et al, Determining factor for the development of CDM biomass power projects, Energy for sustainable development 16 (2012) 197~203

Seokman Han, Balho Kim, A study on the power expansion planning model using multi-criteria decision making rule, The Transactions of The Korean Institute of Electrical Engineers, Volume 58 3 (2009) 462~466

Iejung Choi, Misuk Lee, Economic Valuation of the Korean Climate Change Mitigation and Adaptation Model, Korean Society for Atmospheric Environment Vol. 30, No. 3 (2014) 270~280

Betul Ozer, Erdem Görgüna, Selahattin İncecikb, The scenario analysis on CO_2 emission mitigation potential in the Turkish electricity sector: 2006～2030, Energy 49 (2013) 395～403

A. Sadri, K. Amirnekooei, General procedure for long-term energy-environmental planning for transportation sector of developing countries with limited data based on LEAP, Energy 77 (2014) 831～843

Seyithan A.Ates, Energy efficiency and CO_2 mitigation potential of the Turkish iron and steel industry using the LEAP, Energy (2015) 1～12

Amit Kumar, Bhattacharya, S.C, Pham, H.L, Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the LEAP model, Energy 28 (2003) 627～654

Wenjia Cai, Ke Wang, Ying Zhang, Jining Chen, Scenario analysis on CO_2 emissions reduction potential in China's electricity sector, Energy Policy 35 (2007) 6445～6456

Nan Zhou, David Fridleya, Michael McNeila, Nina Zhenga, Virginie Letscherta, Jing Kea, Yamina Sahebb, Analysis of potential energy saving and CO_2 emission reduction of home appliances and commercial equipments in China, Energy Policy 39 (2011) 4541～4550

Ali Haji Vahabzadeh, Arash Asiaeib, Suhaiza Zailanic, Green decision making model in reverse logistics using Fuzzy-VIKOR method, Resurces, Conservation and Recycling 103 (2015) 125～138

Nyunbae Park, Sunjin Yunb, Euichan Jeona, An analysis of long term scenarios for the transition to renewable energy in the Korean electricity sector, Energy Policy 52 (2013) 288～296

Jing Li, Navid Sabbaghi, Decision analysis on CDM project investments, Int.J.Production Economics 146 (2013) 269～280

Albayrak, E, Erensal, Y. C. A study bank selection decision in Turkey using the extended fuzzy AHP method. Proceeding of 35th International conference on computers and industrial engineering, Istanbul, Turkey (2005)

Mohammad SaeedZaeri, Amir Sadeghi, Amir Naderi, Application of multi criteria decision making technique to evaluation suppliers in supply chain management, African Journal of Mathematics and Computer Science Research Vol. 4 (3) (2011) 100～106

DoraidDalalah, Mohammed Hayajneh, FarhanBatieha, A fuzzy multi-criteria decision making model for supplier selection, Expert Systems with Applications Vol. 38 (2011) 8384～8391

ErgünEraslan, Yusuf TanselIç, A Multi-Criteria Approach for Determination of Investment Regions: Turkish Case, Industrial Management and Data Systems Vol. 111 (2011)

Martin Aruldoss, T. Miranda Lakshmi, Prasanna Venkatesan, A Survey on Multi Criteria Decision Making Methods and Its Applications, American Journal of Information Systems, 1 (1) (2013) 31～43

Anjali Awasthia, S.S. Chauhanb, S.K. Goyalb, A multi-criteria decision making approach for location planning for urban distribution centers under uncertainty, CIISE, Montreal, Canada (2000)

TuncayOzcan, NumanCelebi, Comparative analysis of multi-criteria decision making methodologies and implementation of a warehouse location selection problem. Vol. 38 (2011) 9773～9779

Mohammad SaeedZaeri, Amir Sadeghi, Amir Naderi, Application of multi criteria decision making technique to evaluation suppliers in supply chain management, African Journal of Mathematics and Computer Science Research Vol. 4 (3) (2011) 100～106

SaharRezaiana, Seyed Ali Joziba, Health Safety and Environmental Risk Assessment of Refineries Using of Multi Criteria Decision Making Method, APCBEE Procedia Vol.3 (2012) 235～238

Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption (2014)

Pallav Purohit, Axel Michaelowa, CDM potential of solar water heating systems in India, Solar energy 82 (2008) 799～811

Xingshu Zhao, Axel Michaelowa, CDM potential for rural transition in Chinan case study: Options in Yinzhou district, Zhejiang province, Energy Policy 34 (2006) 1867～1882

Dewi Restuti, Axel Michaelowa, The economic potential of bagasse cogeneration as CDM projects in Indonesia, Energy Policy 35 (2007) 3952～3966

Alain Cormier, Valentin Bellassen, The risks of CDM projects: How did only 30% of expected credits come through?, Energy Policy 54 (2013) 173～183

Charikleia Karakosta, John Psarras, Understanding CDM potential in the Mediterranean basin: A country assessment of Egypt and Morocco, Energy Policy 60 (2013) 827～839

Ken L. Mok, Seung H. Han, Seokjin Choi, The implementation of CDM in the construction and built environment industry, Energy Policy 65 (2014) 512～523

Kathy Baylis, Nicholas D. Paulson, Potential for carbon offsets from anaerobic digesters in livestock production, Animal Feed Science and Technology 166-167 (2011) 446～456

William C. Wedley, Consistency Prediction for incomplete AHP matrices, Mathl. Comput. modelling Vol. 17, No.4/5 (1993) 151～161

Keun won Song, Young Lee, Re-scaling for Improving the Consistency of the AHP Method, Social Science Research Review, Kyungsung University, Vol.29, No.2, 271～288

A. Denny Ellerman and Barbara Buchner, Over-Allocation or Abatement? A preliminary analysis of the EU emissions trading scheme based on the 2006 emission data (2006)

Jacques Despres, Nouredine Hadjsaid, Patrick Criqui, Isabelle Noirot, Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools, Energy, 80 (2015) 486～496

Appendix

1. Questionnaire form for AHP analysis
2. Annual power sales in commercial and industrial sector
3. Monthly electric consumption in industrial sector
4. Monthly electric consumption in commercial sector
5. Assumed unit price of LED which can be replaced
6. Assumed energy consumption of LED which can be replaced
7. Raw data of LEAP modelling in this study
8. Raw data of AHP survey in this study raw for Criteria
9. Raw data of AHP survey in this study raw for TR
10. Raw data of AHP survey in this study raw for OM
11. Raw data of AHP survey in this study raw for IC
12. Raw data of AHP survey in this study raw for PP
13. Raw data of AHP survey in this study raw for BT
14. UN CDM project status which can use CER in K-ETS

1. Questionnaire form for AHP analysis

설문 목적	☞ 저희 OOO 컨설팅 지원사업에 참여해 주신 고객사를 대상으로, 공장 내 고효율조명교체에 대한 의견을 여쭈고자 하오니 아래 내용을 보신 후 체크하여 회신 (E-mail: yuinsik@ibk.co.kr, fax: 0505-075-0779)주시면 감사하겠습니다. 설문결과는 학술논문 (고효율조명교체의 상쇄배출권 잠재량 추정 방법론 개발) 목적 외 사용되지 않으며, 논문작업 기초자료로 활용 후 폐기처분됩니다. 또한, 기업 및 작성자 정보 역시 공개되지 않으니 부담없이 응답해 주시면 감사하겠습니다.

1) 아래 두 항목 중 고효율조명교체 투자 의사결정에 있어 무엇이 상대적으로 더 중요한지 동그라미 한군데에 체크해주십시오.

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (유지보수 편의성 및 비용) 유지보수가 얼마나 편리하고 관리비용은 얼마나 적은가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	유지보수 편의성 및 비용

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (초기투자비용) 초기투자비용이 얼마나 적은가? 부담스럽지 않은 수준인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	초기투자비용

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (투자회수기간) 단기간에 투자회수가 가능한 매력적인 기술인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	투자회수기간

- (기술신뢰도) 얼마나 기술안정성이 높고 신뢰할만한 기술인가?
- (조도 및 온도) 조도, 온도가 최적인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
기술신뢰도	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	조도 및 온도

- (유지보수 편의성 및 비용) 유지보수가 얼마나 편리하고 관리비용은 얼마나 적은가?
- (초기투자비용) 초기투자비용이 얼마나 적은가? 부담스럽지 않은 수준인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
유지보수 편의성 및 비용	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	초기투자비용

- (유지보수 편의성 및 비용) 유지보수가 얼마나 편리하고 관리비용은 얼마나 적은가?
- (투자회수기간) 단기간에 투자회수가 가능한 매력적인 기술인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
유지보수 편의성 및 비용	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	투자회수기간

- (유지보수 편의성 및 비용) 유지보수가 얼마나 편리하고 관리비용은 얼마나 적은가?
- (조도 및 온도) 조도, 온도가 최적인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
유지보수 편의성 및 비용	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	조도 및 온도

- (초기투자비용) 초기투자비용이 얼마나 적은가? 부담스럽지 않은 수준인가?
- (투자회수기간) 단기간에 투자회수가 가능한 매력적인 기술인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
초기투자비용	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	투자회수기간

- (초기투자비용) 초기투자비용이 얼마나 적은가? 부담스럽지 않은 수준인가?
- (조도 및 온도) 조도, 온도가 최적인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
초기투자비용	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	조도 및 온도

- (투자회수기간) 단기간에 투자회수가 가능한 매력적인 기술인가?
- (조도 및 온도) 조도, 온도가 최적인가?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
투자회수기간	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	조도 및 온도

2) 위와 같은 방법으로 아래 두 항목 중 고효율조명교체 투자 의사결정에 있어 무엇이 상대적으로 더 중요한지 동그라미 한군데에 체크해주십시오.

- (기술신뢰도) 다음 중 기술안정성이 높고 신뢰할만한 기술이라 생각하는 조명은?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	고효율 메탈할라이드

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
고효율 메탈할라이드	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

- (유지보수 편의성 및 비용) 다음 중 유지보수가 편리하고 관리비용은 적다고 생각하는 조명은?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	고효율 메탈할라이드

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
고효율 메탈할라이드	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

- (초기투자비용) 다음 중 초기투자비용이 부담없어 좋다고 생각되는 조명은?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	고효율 메탈할라이드

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
고효율 메탈할라이드	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

- (투자회수기간) 다음 중 투자회수기간이 더 짧거나, 좋다고 생각하는 조명은?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	고효율 메탈할라이드

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
고효율 메탈할라이드	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

- (조도 및 온도) 다음 중 조도, 온도가 더 좋다고 생각하는 조명은?

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	고효율 메탈할라이드

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
LED	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

평가지표	좌측지표가 더 중요 <-- ⑨ ⑧ ⑦ ⑥ ⑤ ④ ③ ②	동등 ①	--> 우측지표가 더 중요 ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨	평가지표
고효율 메탈할라이드	○ ○ ○ ○ ○ ○ ○ ○	○	○ ○ ○ ○ ○ ○ ○ ○	무전극램프

2. Annual power sales in commercial and industrial sector

Year	Commercial sector		Industrial sector	
	Volume of electricity (MWh)	Ratio (%)	Volume of electricity (MWh)	Ratio (%)
2014	150,298,769.70	31.47	264,617,621.06	55.41
2013	154,037,032.00	32.40	256,841,077.00	54.10
2012	153,921,115.04	32.99	249,135,683.56	53.39
2011	151,301,584.11	33.25	242,204,427.61	53.22
2010	149,794,610.36	34.50	223,171,450.54	51.40
2009	139,135,233.15	35.27	197,743,922.62	50.13
2008	134,212,365.54	34.85	194,629,832.77	50.54
2007	128,179,803.50	34.77	186,251,642.70	50.53
2006	121,536,321.00	34.85	174,661,153.00	50.09
2005	114,727,183.00	34.51	166,812,610.00	50.18
2004	105,143,173.00	33.70	158,337,093.00	50.70
2003	98,640,210.00	33.60	150,386,937.00	51.20
2002	91,719,314.00	33.00	144,453,758.00	51.90
2001	82,728,817.00	32.10	135,791,309.00	52.60
2000	70,173,395.00	29.30	132,259,780.00	55.20
1999	58,775,235.00	27.50	120,858,975.00	56.30
1998	51,729,664.00	26.70	108,828,073.00	56.30
1997	51,885,095.00	25.80	116,383,179.00	58.00
1996	45,090,781.00	24.70	106,737,116.00	58.50
1995	38,531,320.00	23.60	96,435,676.00	59.10
1994	33,633,149.00	23.00	86,353,855.00	58.90
1993	27,293,242.00	21.40	76,524,546.00	59.90
1992	22,942,865.00	19.90	70,505,344.00	61.20
1991	19,708,955.00	18.90	65,183,155.00	62.50
1990	17,400,372.00	18.40	59,247,738.00	62.80
1989	14,530,115.00	17.70	52,486,401.00	63.90
1988	12,558,205.00	16.90	48,548,689.00	65.30
1987	10,352,056.00	16.20	42,355,761.00	66.00
1986	9,177,760.00	16.30	36,833,154.00	65.40
1985	8,401,810.00	16.60	32,698,181.00	64.00
1984	7,471,617.00	15.90	30,822,956.00	65.50
1983	6,562,708.00	15.40	28,315,145.00	66.40
1982	5,810,164.00	15.40	25,440,135.00	67.20
1981	5,194,555.00	14.70	24,295,693.00	68.50
1980	4,503,632.00	13.80	22,913,329.00	70.00

Reference: Korean Statistical Information Service (KOSIS), 2016

3. Monthly electric consumption in industrial sector

(Unit : 1,000 TOE ; 2014)

Month	Total	Coal	Oil	Natural gas	City gas	Electricity	Renewable Energy
01	11,669	2,857	5,208	33	929	1,954	688
02	10,744	2,675	4,770	35	830	1,801	634
03	11,623	2,929	5,164	38	846	1,957	689
04	11,292	3,043	4,924	8	739	1,906	672
05	11,350	2,920	5,181	9	711	1,870	659
06	11,076	2,909	4,927	21	692	1,869	658
07	11,301	2,862	5,029	38	724	1,958	690
08	11,540	2,896	5,449	44	643	1,855	653
09	10,945	2,770	5,018	49	638	1,826	643
10	11,324	2,891	5,130	10	714	1,908	672
11	11,196	2,900	5,001	25	726	1,882	663
12	11,940	2,984	5,389	43	859	1,971	694
Total	136,000	34,636	61,190	353	9,051	22,757	8,015

Reference: Korean Statistical Information Service (KOSIS), 2016

4. Monthly electric consumption in commercial sector

(Unit : 1,000 TOE ; 2014)

Month	Electric consumption
01	1,073
02	1,023
03	890
04	818
05	736
06	760
07	825
08	880
09	800
10	737
11	798
12	975
Total	10,315

Reference: Korean Statistical Information Service (KOSIS), 2016

5. Assumed unit price of LED which can be replaced

(Unit : won)

Type of lighting instruments	Electric consumption (W)	Assumed product price of LED					
		‘15	‘16	‘17	‘18	‘19	‘20
Incandescent lamp	15	3,375	2,531	1,898	1,424	1,068	801
	20	4,500	3,375	2,531	1,898	1,424	1,068
	60	8,438	6,328	4,746	3,560	2,670	2,002
Halogen lamp	15	4,500	3,375	2,531	1,898	1,424	1,068
	20	5,625	4,219	3,164	2,373	1,780	1,335
	50	8,438	6,328	4,746	3,560	2,670	2,002
	75	16,875	12,656	9,492	7,119	5,339	4,005
Compact Fluorescent lamp	11	5,625	4,219	3,164	2,373	1,780	1,335
	13	7,875	5,906	4,430	3,322	2,492	1,869
	15	8,438	6,328	4,746	3,560	2,670	2,002
	18	10,125	7,594	5,695	4,271	3,204	2,403
	20	12,375	9,281	6,961	5,221	3,916	2,937
	30	45,000	33,750	25,313	18,984	14,238	10,679
	36	56,250	42,188	31,641	23,730	17,798	13,348
Tubular Fluorescent lamp	28	27,000	20,250	15,188	11,391	8,543	6,407
	32	28,125	21,094	15,820	11,865	8,899	6,674
	36	30,938	23,203	17,402	13,052	9,789	7,342
Metal halide lamp	60	298,125	223,594	167,695	125,771	94,329	70,746
	70	337,500	253,125	189,844	142,383	106,787	80,090
	75	337,500	253,125	189,844	142,383	106,787	80,090
	100	393,750	295,313	221,484	166,113	124,585	93,439
	150	506,250	379,688	284,766	213,574	160,181	n.a

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014

6. Assumed energy consumption of LED which can be replaced

Type of lighting instruments	Electric consumption (W)	Efficiency (%)	Installation ratio (%)	Assumed energy consumption of LED(W)						
				‘15	‘16	‘17	‘18	‘19	‘20	‘30*
Incandescent lamp	15	10	0.1	1.6	1.5	1.3	1.3	1.2	1.1	0.6
	20	10	0.3	2.1	2.0	1.8	1.7	1.6	1.4	0.7
	60	12	5.0	7.7	7.0	6.5	6.0	5.6	5.2	2.6
Halogen lamp	15	16	0.2	2.3	2.1	1.9	1.8	1.6	1.5	0.8
	20	16	0.5	3.4	3.1	2.9	2.7	2.5	2.3	1.2
	50	16	2.9	9.6	8.8	8.1	7.5	7.0	6.5	3.3
	75	16	2.0	14.5	13.2	12.1	11.3	10.5	9.8	4.9
Compact Fluorescent lamp	11	65	1.4	6.5	6.2	5.8	5.5	5.2	4.9	2.5
	13	65	1.7	7.7	7.3	6.9	6.5	6.1	5.8	2.9
	15	65	1.5	8.9	8.4	7.9	7.5	7.1	6.7	3.4
	18	65	3.4	10.7	10.1	9.5	9.0	8.5	8.1	4.1
	20	65	9.8	11.9	11.2	10.6	10.0	9.5	9.0	4.5
	30	65	3.2	19.1	18.0	17.0	16.0	15.0	14.4	7.2
	36	65	20.2	23.0	21.6	20.4	19.3	18.2	17.3	8.7
Tubular Fluorescent lamp	28	90	2.9	19.1	18.0	17.0	16.1	15.3	14.6	7.3
	32	90	12.1	21.8	20.6	19.4	18.4	17.5	16.7	8.4
	36	90	24.7	24.5	23.1	21.9	20.7	19.7	18.7	9.4
Metal halide lamp	60	65	0.3	35.6	33.6	31.7	30.0	28.4	26.9	13.5
	70	65	0.4	41.6	39.2	37.0	34.9	33.1	31.4	15.7
	75	65	3.7	44.5	41.9	39.6	37.4	35.5	33.7	16.9
	100	65	0.4	59.4	55.9	52.8	49.9	47.3	44.9	22.5
	150	65	3.5	89.1	83.9	79.2	74.9	71.0	67.4	33.7
	250	65		148.5	139.8	132.0	124.8	118.3	112.3	56.2
	400	65		237.6	223.7	211.2	199.7	189.3	179.7	89.9

Reference: Korea Association for photonics industry development, Survey on the utilization of lighting apparatus and study on saving lighting power consumption, 2014
* predicted data in this study

7. Raw data of LEAP modelling in this study

1) Baseline scenario

1.1) Energy demand

(Unit : GWh/year)

Energy Demand Final Units: Reference Scenario, All Fuels

Branches	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Industry	43,873.5	44,999.5	46,199.6	47,257.2	48,314.3	49,371.1	50,427.6	51,483.7	52,539.5	53,595.0	54,650.3	55,705.2	56,759.9
Incandescent lamp	296.7	304.5	312.8	320.0	327.3	334.5	341.8	349.1	356.3	363.6	370.8	378.1	385.4
Halogen lamp	339.1	347.9	357.3	365.6	373.9	382.2	390.5	398.7	407.0	415.3	423.6	431.9	440.2
Compact Fluorescent lamp	15,768.0	16,178.0	16,614.8	17,000.5	17,386.2	17,771.9	18,157.6	18,543.3	18,929.0	19,314.7	19,700.3	20,086.0	20,471.7
Tubular Fluorescent lamp	20,937.4	21,481.8	22,061.8	22,573.9	23,086.1	23,598.2	24,110.3	24,622.5	25,134.6	25,646.7	26,158.9	26,671.0	27,183.1
Metal Halide	5,811.7	5,962.8	6,123.8	6,266.0	6,408.2	6,550.3	6,692.5	6,834.6	6,976.8	7,118.9	7,261.1	7,403.3	7,545.4
Existing LED	720.5	724.4	729.1	731.1	732.7	734.0	734.9	735.5	735.8	735.8	735.5	734.9	734.0
Commercial	21,586.1	22,128.2	22,706.1	23,245.4	23,784.1	24,322.4	24,860.1	25,397.4	25,934.1	26,470.5	27,006.4	27,541.9	28,077.0
Incandescent lamp	1,285.6	1,319.3	1,354.9	1,388.3	1,421.6	1,455.0	1,488.3	1,521.7	1,555.0	1,588.4	1,621.7	1,655.1	1,688.4
Halogen lamp	1,880.8	1,929.7	1,981.8	2,030.5	2,079.3	2,128.1	2,176.9	2,225.7	2,274.4	2,323.2	2,372.0	2,420.8	2,469.6
Compact Fluorescent lamp	13,831.8	14,191.4	14,574.6	14,933.3	15,292.1	15,650.9	16,009.6	16,368.4	16,727.1	17,085.9	17,444.7	17,803.4	18,162.2
Tubular Fluorescent lamp	1,568.2	1,609.0	1,652.4	1,693.1	1,733.8	1,774.5	1,815.1	1,855.8	1,896.5	1,937.2	1,977.8	2,018.5	2,059.2
Metal Halide	2,073.2	2,127.1	2,184.5	2,238.3	2,292.0	2,345.8	2,399.6	2,453.4	2,507.1	2,560.9	2,614.7	2,668.5	2,722.2
Existing LED	946.6	951.8	957.9	961.9	965.3	968.2	970.6	972.5	973.9	974.9	975.4	975.6	975.4
Total	65,459.5	67,127.7	68,905.7	70,502.6	72,098.5	73,693.5	75,287.7	76,881.1	78,473.7	80,065.5	81,656.6	83,247.1	84,836.8

1.2) GHG emission amount

(Unit : $KtCO_2eq$/year)

Energy Demand Final Units: Reference Scenario, All Fuels

Branches	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Industry	20,682.8	20,981.0	21,540.6	22,033.7	22,526.6	23,019.3	23,511.9	24,004.3	24,496.6	24,988.7	25,480.7	25,972.6	26,464.3	26,955.9	27,447.4	27,938.8
Incandescent lamp	139.9	142.0	145.8	149.2	152.6	156.0	159.4	162.7	166.1	169.5	172.9	176.3	179.7	183.1	186.4	189.8
PC_15W	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.2	3.3	3.4	3.4	3.5
PC_20W	7.8	7.9	8.1	8.3	8.5	8.7	8.9	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.5
PC_60W	129.5	131.5	135.0	138.2	141.3	144.4	147.6	150.7	153.8	157.0	160.1	163.3	166.4	169.5	172.7	175.8
Halogen lamp	159.8	162.2	166.6	170.4	174.3	178.2	182.0	185.9	189.8	193.6	197.5	201.4	205.2	209.1	213.0	216.8
PC_15W	5.7	5.8	5.9	6.1	6.2	6.4	6.5	6.6	6.8	6.9	7.1	7.2	7.3	7.5	7.6	7.7
PC_20W	14.3	14.5	14.9	15.2	15.6	15.9	16.3	16.6	16.9	17.3	17.6	18.0	18.3	18.7	19.0	19.4
PC_50W	82.8	84.0	86.3	88.3	90.3	92.3	94.3	96.3	98.3	100.3	102.3	104.3	106.3	108.3	110.3	112.3
PC_75W	57.1	57.9	59.5	60.9	62.3	63.6	65.0	66.4	67.8	69.2	70.5	71.9	73.3	74.7	76.1	77.4
Compact Fluorescent lamp	7,433.4	7,543.0	7,746.7	7,926.5	8,106.3	8,286.2	8,466.0	8,645.8	8,825.6	9,005.5	9,185.3	9,365.1	9,544.9	9,724.8	9,904.6	10,084.4
PC_11W	252.6	256.3	263.2	269.3	275.5	281.6	287.7	293.8	299.9	306.0	312.1	318.2	324.3	330.5	336.6	342.7
PC_13W	306.7	311.2	319.6	327.1	334.5	341.9	349.3	356.7	364.2	371.6	379.0	386.4	393.8	401.3	408.7	416.1
PC_15W	270.6	274.6	282.0	288.6	295.1	301.7	308.2	314.8	321.3	327.9	334.4	341.0	347.5	354.1	360.6	367.2
PC_18W	613.4	622.5	639.3	654.1	669.0	683.8	698.6	713.5	728.3	743.2	758.0	772.8	787.7	802.5	817.4	832.2
PC_20W	1,768.1	1,794.2	1,842.7	1,885.4	1,928.2	1,971.0	2,013.8	2,056.5	2,099.3	2,142.1	2,184.8	2,227.6	2,270.4	2,313.2	2,355.9	2,398.7
PC_30W	577.4	585.9	601.7	615.7	629.6	643.6	657.6	671.5	685.5	699.5	713.4	727.4	741.4	755.3	769.3	783.3
PC_36W	3,644.5	3,698.3	3,798.1	3,886.3	3,974.5	4,062.6	4,150.8	4,239.0	4,327.1	4,415.3	4,503.5	4,591.6	4,679.8	4,768.0	4,856.1	4,944.3
Tubular Fluorescent lamp	9,870.3	10,015.9	10,286.3	10,525.1	10,763.9	11,002.7	11,241.5	11,480.2	11,719.0	11,957.8	12,196.6	12,435.4	12,674.2	12,912.9	13,151.7	13,390.5
PC_28W	721.0	731.6	751.4	768.8	786.3	803.7	821.2	838.6	856.1	873.5	890.9	908.4	925.8	943.3	960.7	978.1
PC_32W	3,008.3	3,052.7	3,135.1	3,207.9	3,280.7	3,353.5	3,426.2	3,499.0	3,571.8	3,644.6	3,717.4	3,790.1	3,862.9	3,935.7	4,008.5	4,081.2
PC_36W	6,141.0	6,231.6	6,399.8	6,548.4	6,696.9	6,845.5	6,994.1	7,142.6	7,291.2	7,439.7	7,588.3	7,736.9	7,885.4	8,034.0	8,182.6	8,331.1
Metal Halide	2,739.8	2,780.2	2,855.2	2,921.5	2,987.8	3,054.1	3,120.4	3,186.6	3,252.9	3,319.2	3,385.5	3,451.8	3,518.1	3,584.3	3,650.6	3,716.9
PC_60W	18.8	19.1	19.6	20.0	20.5	20.9	21.4	21.8	22.3	22.7	23.2	23.7	24.1	24.6	25.0	25.5
PC_70W	25.0	25.4	26.1	26.7	27.3	27.9	28.5	29.1	29.7	30.3	30.9	31.5	32.2	32.8	33.4	34.0
PC_75W	231.6	235.0	241.4	247.0	252.6	258.2	263.8	269.4	275.0	280.6	286.2	291.8	297.4	303.0	308.6	314.2
PC_100W	25.0	25.4	26.1	26.7	27.3	27.9	28.5	29.1	29.7	30.3	30.9	31.5	32.1	32.8	33.4	34.0
PC_150W	219.1	222.3	228.3	233.6	238.9	244.2	249.5	254.8	260.1	265.4	270.7	276.0	281.3	286.6	291.9	297.2
PC_250W	1,110.1	1,126.5	1,156.9	1,183.8	1,210.6	1,237.5	1,264.3	1,291.2	1,318.0	1,344.9	1,371.8	1,398.6	1,425.5	1,452.3	1,479.2	1,506.0
PC_400W	1,110.1	1,126.5	1,156.9	1,183.8	1,210.6	1,237.5	1,264.3	1,291.2	1,318.0	1,344.9	1,371.8	1,398.6	1,425.5	1,452.3	1,479.2	1,506.0
Existing LED	339.6	337.8	339.9	340.9	341.6	342.2	342.7	342.9	343.1	343.1	342.9	342.6	342.2	341.7	341.1	340.3
Existing	339.6	337.8	339.9	340.9	341.6	342.2	342.7	342.9	343.1	343.1	342.9	342.6	342.2	341.7	341.1	340.3

Energy Demand Final Units: Reference Scenario, All Fuels

Branches	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Commercial	10,176.1	10,317.3	10,586.7	10,838.2	11,089.4	11,340.3	11,591.0	11,841.5	12,091.8	12,341.9	12,591.7	12,841.4	13,090.9	13,340.2	13,589.3	13,838.3
Incandescent lamp	606.0	615.1	631.7	647.3	662.8	678.4	693.9	709.5	725.0	740.6	756.1	771.7	787.2	802.8	818.3	833.9
PC_15W	11.2	11.3	11.6	11.9	12.2	12.5	12.8	13.0	13.3	13.6	13.9	14.2	14.5	14.8	15.0	15.3
PC_20W	33.7	34.2	35.1	36.0	36.8	37.7	38.5	39.4	40.3	41.1	42.0	42.9	43.7	44.6	45.5	46.3
PC_60W	561.2	569.6	585.0	599.4	613.8	628.2	642.6	657.0	671.4	685.8	700.2	714.6	729.0	743.4	757.8	772.2
Halogen lamp	886.6	899.7	924.0	946.7	969.5	992.2	1,015.0	1,037.7	1,060.5	1,083.2	1,105.9	1,128.7	1,151.4	1,174.2	1,196.9	1,219.7
PC_15W	31.7	32.1	33.0	33.8	34.6	35.4	36.2	37.1	37.9	38.7	39.5	40.3	41.1	41.9	42.7	43.6
PC_20W	79.2	80.3	82.5	84.5	86.6	88.6	90.6	92.7	94.7	96.7	98.7	100.8	102.8	104.8	106.9	108.9
PC_50W	459.1	465.9	478.5	490.3	502.1	513.8	525.6	537.4	549.2	560.9	572.7	584.5	596.3	608.1	619.8	631.6
PC_75W	316.7	321.3	330.0	338.1	346.2	354.4	362.5	370.6	378.7	386.9	395.0	403.1	411.2	419.4	427.5	435.6
Compact Fluorescent lamp	6,520.6	6,616.8	6,795.4	6,962.7	7,130.0	7,297.2	7,464.5	7,631.8	7,799.0	7,966.3	8,133.6	8,300.9	8,468.1	8,635.4	8,802.7	8,969.9
PC_11W	221.6	224.8	230.9	236.6	242.3	248.0	253.6	259.3	265.0	270.7	276.4	282.1	287.8	293.4	299.1	304.8
PC_13W	269.1	273.0	280.4	287.3	294.2	301.1	308.0	314.9	321.8	328.7	335.6	342.5	349.4	356.3	363.2	370.1
PC_15W	237.4	240.9	247.4	253.5	259.6	265.7	271.8	277.9	283.9	290.0	296.1	302.2	308.3	314.4	320.5	326.6
PC_18W	538.1	546.0	560.8	574.6	588.4	602.2	616.0	629.8	643.6	657.4	671.2	685.0	698.8	712.6	726.4	740.2
PC_20W	1,551.0	1,573.9	1,616.4	1,656.2	1,696.0	1,735.7	1,775.5	1,815.3	1,855.1	1,894.9	1,934.7	1,974.5	2,014.3	2,054.0	2,093.8	2,133.6
PC_30W	506.5	513.9	527.8	540.8	553.8	566.8	579.8	592.8	605.8	618.7	631.7	644.7	657.7	670.7	683.7	696.7
PC_36W	3,197.0	3,244.1	3,331.7	3,413.7	3,495.8	3,577.8	3,659.8	3,741.8	3,823.8	3,905.8	3,987.8	4,069.8	4,151.8	4,233.9	4,315.9	4,397.9
Tubular Fluorescent lamp	739.3	750.2	770.4	789.4	808.4	827.3	846.3	865.3	884.2	903.2	922.2	941.1	960.1	979.1	998.0	1,017.0
PC_28W	54.0	54.8	56.3	57.7	59.1	60.4	61.8	63.2	64.6	66.0	67.4	68.7	70.1	71.5	72.9	74.3
PC_32W	225.3	228.6	234.8	240.6	246.4	252.2	257.9	263.7	269.5	275.3	281.1	286.8	292.6	298.4	304.2	310.0
PC_36W	460.0	466.7	479.3	491.1	502.9	514.7	526.5	538.3	550.1	561.9	573.7	585.5	597.3	609.1	620.9	632.7
Metal Halide	977.3	991.7	1,018.5	1,043.6	1,068.7	1,093.7	1,118.8	1,143.9	1,169.0	1,194.0	1,219.1	1,244.2	1,269.2	1,294.3	1,319.4	1,344.5
PC_60W	6.7	6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.4	8.5	8.7	8.9	9.0	9.2
PC_70W	8.9	9.1	9.3	9.5	9.8	10.0	10.2	10.5	10.7	10.9	11.1	11.4	11.6	11.8	12.1	12.3
PC_75W	82.6	83.8	86.1	88.2	90.3	92.5	94.6	96.7	98.8	100.9	103.1	105.2	107.3	109.4	111.5	113.7
PC_100W	8.9	9.1	9.3	9.5	9.8	10.0	10.2	10.5	10.7	10.9	11.1	11.4	11.6	11.8	12.1	12.3
PC_150W	78.2	79.3	81.4	83.4	85.5	87.5	89.5	91.5	93.5	95.5	97.5	99.5	101.5	103.5	105.5	107.5
PC_250W	396.0	401.8	412.7	422.9	433.0	443.2	453.3	463.5	473.6	483.8	494.0	504.1	514.3	524.4	534.6	544.8
PC_400W	396.0	401.8	412.7	422.9	433.0	443.2	453.3	463.5	473.6	483.8	494.0	504.1	514.3	524.4	534.6	544.8
Existing LED	446.2	443.8	446.6	448.5	450.1	451.4	452.5	453.4	454.1	454.5	454.8	454.9	454.8	454.5	454.0	453.4
Existing	446.2	443.8	446.6	448.5	450.1	451.4	452.5	453.4	454.1	454.5	454.8	454.9	454.8	454.5	454.0	453.4
Total	30,858.9	31,298.3	32,127.3	32,871.8	33,615.9	34,359.6	35,102.9	35,845.8	36,588.4	37,330.6	38,072.4	38,814.0	39,555.2	40,296.1	41,036.8	41,777.1

2) Abatement scenario

2.1) Energy demand

(Unit : GWh/year)

Energy Demand Final Units: Reference Scenario, All Fuels

Branches	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Industry	43,873.5	43,892.2	43,742.1	43,224.6	42,492.4	41,553.1	40,396.1	39,049.7	37,487.5	35,694.1	33,638.7	31,311.9	28,704.4	25,981.4	23,285.2	21,593.9
Incandescent lamp	296.7	260.1	220.6	177.4	131.3	82.4	31.2	26.9	26.0	24.9	23.8	22.7	21.5	20.2	18.9	17.5
Halogen lamp	339.1	309.3	276.6	240.1	200.5	158.6	114.3	67.3	44.4	42.6	40.7	38.8	36.7	34.5	32.2	29.9
Compact Fluerescent lamp	15,768.0	15,762.6	15,695.0	15,494.3	15,217.0	14,865.9	14,440.4	13,930.4	13,332.9	12,644.4	11,861.7	10,981.6	10,000.7	9,090.6	8,399.4	7,645.6
Tubular Flueorescnet lamp	20,937.4	20,990.2	20,955.3	20,737.7	20,410.8	19,979.2	19,432.4	18,762.0	17,962.8	17,029.8	15,957.7	14,741.5	13,376.1	11,856.4	10,177.2	9,599.4
Metal Halide	5,811.7	5,845.6	5,865.5	5,844.1	5,800.0	5,733.0	5,642.9	5,527.4	5,385.7	5,216.6	5,019.2	4,792.4	4,535.3	4,246.8	3,925.9	3,571.7
Existing LED	720.5	724.4	729.1	731.1	732.7	734.0	734.9	735.5	735.8	735.8	735.5	734.9	734.0	732.9	731.5	729.9
Commercial	21,586.1	21,275.3	20,870.4	20,279.1	19,574.9	18,764.6	17,849.5	17,030.3	16,262.8	15,513.2	14,659.7	13,698.8	12,626.9	11,593.6	10,728.4	9,878.4
Incandescent lamp	1,285.6	1,127.0	955.7	768.4	568.8	356.9	135.1	116.7	112.5	108.0	103.3	98.3	93.1	87.5	81.7	75.7
Halogen lamp	1,880.8	1,715.4	1,534.3	1,331.6	1,112.1	879.5	633.9	373.4	246.0	236.3	226.0	215.1	203.6	191.5	178.9	165.6
Compact Fluerescent lamp	13,831.8	13,827.0	13,767.7	13,591.6	13,348.4	13,040.5	12,667.1	12,219.8	11,695.6	11,091.7	10,405.2	9,633.1	8,772.7	7,974.3	7,368.0	6,706.8
Tubular Flueorescnet lamp	1,568.2	1,572.2	1,569.5	1,553.2	1,528.8	1,496.4	1,455.5	1,405.3	1,345.4	1,275.5	1,195.2	1,104.1	1,001.9	888.0	762.3	719.0
Metal Halide	2,073.2	2,082.0	2,085.3	2,073.7	2,054.2	2,026.9	1,992.2	1,948.8	1,896.5	1,834.9	1,763.7	1,682.6	1,591.3	1,489.3	1,376.5	1,252.4
Existing LED	946.6	951.8	957.9	960.6	962.7	964.4	965.6	966.4	966.8	966.7	966.3	965.5	964.4	962.9	961.1	959.0
Total	65,459.5	65,167.5	64,612.5	63,503.7	62,067.3	60,317.7	58,245.6	56,080.0	53,750.3	51,207.3	48,298.4	45,010.7	41,331.3	37,575.0	34,013.6	31,472.3

2.2) GHG emission amount

(Unit : $KtCO_2eq$/year)

Branches	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Industry	20,682.8	20,464.7	20,394.8	20,153.5	19,812.1	19,374.2	18,834.7	18,206.9	17,478.6	16,642.4	15,684.0	14,599.2	13,383.4	12,113.8	10,856.7	10,068.2
Incandescent lamp	139.9	121.3	102.9	82.7	61.2	38.4	14.5	12.6	12.1	11.6	11.1	10.6	10.0	9.4	8.8	8.1
PC_15W	2.6	2.3	2.0	1.7	1.3	1.0	0.6	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
PC_20W	7.8	6.9	6.0	5.0	4.0	2.9	1.8	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
PC_60W	129.5	112.1	94.9	76.0	55.9	34.5	12.2	11.8	11.3	10.9	10.4	9.9	9.4	8.8	8.2	7.6
Halogen lamp	159.8	144.2	129.0	111.9	93.5	73.9	53.3	31.4	20.7	19.9	19.0	18.1	17.1	16.1	15.0	13.9
PC_15W	5.7	5.2	4.6	4.1	3.4	2.8	2.1	1.4	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4
PC_20W	14.3	13.0	11.7	10.3	8.8	7.1	5.4	3.6	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.1
PC_50W	82.8	74.1	65.6	56.1	45.8	35.0	23.5	11.3	10.9	10.5	10.0	9.5	9.0	8.5	7.9	7.3
PC_75W	57.1	52.0	47.0	41.5	35.5	29.0	22.3	15.1	7.5	7.2	6.9	6.6	6.2	5.9	5.5	5.1
Compact Fluerescent lamp	7,433.4	7,349.3	7,317.8	7,224.2	7,094.9	6,931.3	6,732.8	6,495.1	6,216.5	5,895.5	5,530.5	5,120.2	4,662.9	4,238.5	3,916.2	3,564.8
PC_11W	252.6	247.9	244.6	238.9	231.9	223.3	213.3	201.7	188.4	173.4	156.6	138.0	117.4	112.9	108.3	103.3
PC_13W	306.7	301.8	298.8	293.2	285.8	277.0	266.4	254.1	239.9	223.7	205.6	185.3	162.9	138.2	132.5	126.5
PC_15W	270.6	265.5	262.0	256.0	248.4	239.3	228.7	216.3	202.1	186.0	168.0	148.1	126.0	121.2	116.2	110.9
PC_18W	613.4	601.9	594.0	580.4	563.3	542.5	518.4	490.3	458.2	421.9	381.2	335.9	286.0	275.3	263.9	251.9
PC_20W	1,768.1	1,739.4	1,722.1	1,689.1	1,646.6	1,595.3	1,534.3	1,462.9	1,380.7	1,287.1	1,182.0	1,064.8	935.1	792.6	759.6	724.9
PC_30W	577.4	573.4	573.8	569.9	563.3	554.4	543.2	529.2	512.4	492.7	470.0	444.1	415.0	382.6	346.6	307.2
PC_36W	3,644.5	3,619.5	3,622.4	3,596.7	3,555.7	3,499.5	3,428.5	3,340.5	3,234.7	3,110.5	2,967.1	2,804.0	2,620.4	2,415.7	2,189.1	1,940.1
Tubular Flueorescnet lamp	9,870.3	9,786.7	9,770.4	9,668.9	9,516.5	9,315.3	9,060.4	8,747.8	8,375.2	7,940.1	7,440.3	6,873.2	6,236.6	5,528.1	4,745.1	4,475.7
PC_28W	721.0	716.0	716.0	710.2	700.8	688.1	671.7	651.4	627.0	598.2	565.1	527.3	484.8	437.3	384.8	326.9
PC_32W	3,008.3	2,982.5	2,977.1	2,945.7	2,898.6	2,836.7	2,758.2	2,662.1	2,547.6	2,414.0	2,260.6	2,086.6	1,891.2	1,673.9	1,433.7	1,364.1
PC_36W	6,141.0	6,088.3	6,077.3	6,013.0	5,917.1	5,790.5	5,630.4	5,434.3	5,200.6	4,927.8	4,614.6	4,259.4	3,860.6	3,416.9	2,926.7	2,784.6
Metal Halide	2,739.8	2,725.5	2,734.8	2,724.8	2,704.3	2,673.0	2,631.0	2,577.2	2,511.1	2,432.2	2,340.2	2,234.5	2,114.6	1,980.1	1,830.5	1,665.3
PC_60W	18.8	18.7	18.8	18.8	18.8	18.6	18.4	18.2	17.9	17.5	17.0	16.5	15.9	15.2	14.5	13.6
PC_70W	25.0	25.0	25.1	25.1	25.0	24.8	24.6	24.3	23.8	23.3	22.7	22.0	21.2	20.3	19.3	18.2
PC_75W	231.6	230.9	232.2	232.1	231.3	229.7	227.5	224.4	220.6	215.9	210.3	203.8	196.3	187.9	178.5	168.0
PC_100W	25.0	25.0	25.1	25.1	25.0	24.8	24.6	24.3	23.8	23.3	22.7	22.0	21.2	20.3	19.3	18.2
PC_150W	219.1	218.5	220.0	220.1	219.5	218.2	216.2	213.4	209.8	205.4	200.1	193.9	186.8	178.8	169.7	159.6
PC_250W	1,110.1	1,105.1	1,109.9	1,106.9	1,099.8	1,088.5	1,072.8	1,052.6	1,027.5	997.3	961.9	921.2	874.8	822.7	764.6	700.3
PC_400W	1,110.1	1,102.3	1,103.7	1,096.7	1,084.9	1,068.4	1,046.9	1,020.0	987.7	949.5	905.4	855.0	798.3	734.9	664.6	587.3
Existing LED	339.6	337.8	339.9	340.9	341.6	342.2	342.7	342.9	343.1	343.1	342.9	342.6	342.2	341.7	341.1	340.3
Existing	339.6	337.8	339.9	340.9	341.6	342.2	342.7	342.9	343.1	343.1	342.9	342.6	342.2	341.7	341.1	340.3

Energy Demand Final Units: Reference Scenario, All Fuels

Branches	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Commercial	10,176.1	9,919.6	9,730.8	9,455.1	9,126.8	8,749.0	8,322.3	7,940.4	7,582.5	7,233.0	6,835.1	6,387.1	5,887.3	5,405.5	5,002.1	4,605.8
Incandescent lamp	606.0	525.5	445.6	358.3	265.2	166.4	63.0	54.4	52.4	50.4	48.2	45.8	43.4	40.8	38.1	35.3
PC_15W	11.2	9.9	8.6	7.2	5.7	4.2	2.6	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6
PC_20W	33.7	29.8	26.0	21.8	17.4	12.7	7.7	2.6	2.5	2.4	2.3	2.2	2.1	1.9	1.8	1.7
PC_60W	561.2	485.8	411.0	329.2	242.1	149.5	52.7	51.0	49.2	47.2	45.1	43.0	40.6	38.2	35.7	33.0
Halogen lamp	886.6	799.8	715.4	620.9	518.5	410.0	295.6	174.1	114.7	110.2	105.4	100.3	94.9	89.3	83.4	77.2
PC_15W	31.7	28.7	25.8	22.6	19.1	15.5	11.6	7.6	3.3	3.1	3.0	2.9	2.7	2.5	2.4	2.2
PC_20W	79.2	71.9	64.8	57.0	48.5	39.5	30.0	20.0	9.3	9.0	8.6	8.2	7.7	7.3	6.8	6.3
PC_50W	459.1	411.1	363.9	311.3	254.1	193.9	130.2	62.7	60.4	58.0	55.5	52.8	50.0	47.0	43.9	40.6
PC_75W	316.7	288.2	260.8	230.0	196.7	161.1	123.7	83.9	41.7	40.0	38.3	36.5	34.5	32.5	30.3	28.1
Compact Fluerescent lamp	6,520.6	6,446.8	6,419.2	6,337.1	6,223.7	6,080.1	5,906.1	5,697.5	5,453.1	5,171.5	4,851.4	4,491.4	4,090.3	3,718.0	3,435.3	3,127.0
PC_11W	221.6	217.4	214.5	209.6	203.4	195.8	187.1	176.9	165.3	152.1	137.4	121.0	103.0	99.1	95.0	90.6
PC_13W	269.1	264.7	262.1	257.2	250.7	243.0	233.7	222.9	210.4	196.3	180.3	162.5	142.9	121.2	116.2	111.0
PC_15W	237.4	232.9	229.9	224.6	217.9	209.9	200.6	189.7	177.3	163.2	147.4	129.9	110.5	106.3	101.9	97.3
PC_18W	538.1	528.0	521.1	509.2	494.1	475.9	454.7	430.1	401.9	370.1	334.4	294.7	250.9	241.5	231.5	221.0
PC_20W	1,551.0	1,525.8	1,510.6	1,481.7	1,444.4	1,399.4	1,345.9	1,283.3	1,211.1	1,129.1	1,036.8	934.0	820.3	695.2	666.3	635.9
PC_30W	506.5	503.0	503.4	499.9	494.1	486.3	476.5	464.2	449.5	432.2	412.3	389.6	364.1	335.6	304.1	269.4
PC_36W	3,197.0	3,175.0	3,177.6	3,155.0	3,119.1	3,069.8	3,007.5	2,930.3	2,837.5	2,728.5	2,602.8	2,459.7	2,298.6	2,119.0	1,920.3	1,701.9
Tubular Flueorescnet lamp	739.3	733.0	731.8	724.2	712.8	697.7	678.6	655.2	627.3	594.7	557.3	514.8	467.1	414.1	355.4	335.2
PC_28W	54.0	53.6	53.6	53.2	52.5	51.5	50.3	48.8	47.0	44.8	42.3	39.5	36.3	32.8	28.8	24.5
PC_32W	225.3	223.4	223.0	220.6	217.1	212.5	206.6	199.4	190.8	180.8	169.3	156.3	141.7	125.4	107.4	102.2
PC_36W	460.0	456.0	455.2	450.4	443.2	433.7	421.7	407.0	389.5	369.1	345.6	319.0	289.2	255.9	219.2	208.6
Metal Halide	977.3	970.7	972.3	966.8	957.8	945.1	928.9	908.6	884.2	855.5	822.3	784.5	741.9	694.4	641.8	583.9
PC_60W	6.7	6.7	6.7	6.7	6.7	6.6	6.6	6.5	6.4	6.2	6.1	5.9	5.7	5.4	5.2	4.9
PC_70W	8.9	8.9	9.0	9.0	8.9	8.9	8.8	8.7	8.5	8.3	8.1	7.9	7.6	7.2	6.9	6.5
PC_75W	82.6	82.4	82.8	82.8	82.5	81.9	81.1	80.1	78.7	77.0	75.0	72.7	70.0	67.0	63.7	59.9
PC_100W	8.9	8.9	9.0	9.0	8.9	8.9	8.8	8.7	8.5	8.3	8.1	7.9	7.6	7.2	6.9	6.5
PC_150W	78.2	77.9	78.4	78.3	78.0	77.5	76.8	75.7	74.4	72.8	70.9	68.8	66.2	63.4	60.2	56.7
PC_250W	396.0	393.6	394.5	392.7	389.4	384.7	378.6	370.9	361.6	350.6	337.9	323.3	306.8	288.4	268.0	245.6
PC_400W	396.0	392.4	391.9	388.4	383.3	376.6	368.2	358.1	346.1	332.2	316.2	298.2	278.0	255.6	230.9	203.9
Existing LED	446.2	443.8	446.6	447.9	448.9	449.6	450.2	450.6	450.7	450.7	450.5	450.2	449.6	449.0	448.1	447.1
Existing	446.2	443.8	446.6	447.9	448.9	449.6	450.2	450.6	450.7	450.7	450.5	450.2	449.6	449.0	448.1	447.1
Total	30,858.9	30,384.4	30,125.6	29,608.6	28,938.9	28,123.2	27,157.0	26,147.3	25,061.1	23,875.4	22,519.2	20,986.3	19,270.7	17,519.4	15,858.9	14,674.0

3) GHG emission reduction

(Unit: $KtCO_2eq$/year)

	abatement					baseline				reduction			
	2017	2020	2025	2030	%1)	2017	2020	2025	2030	2017	2020	2025	2030
industrial sector	20,176.80	19,072.00	15,453.20	10,024.90	49.7	21,310.40	22,660.30	25,105.70	27,818.90	1,363.80	3,947.30	10,027.50	17,913.90
- Incandescent lamp	101.8	37.8	11	8.1	8	144.3	153.5	170.4	189	44	118.2	161.9	181.7
- Halogen lamp	127.6	72.8	18.7	13.9	10.9	164.8	175.4	194.6	215.9	39	105.4	178.8	202.9
- Compact Fluorescent lamp	7,239.60	6,823.10	5,449.20	3,549.50	49	7,663.90	8,156.90	8,864.00	10,041.10	507.1	1,463.10	3,736.10	6,534.90
- Tubular Fluorescent	9,666.00	9,170.00	7,330.80	4,456.50	46.1	10,176.40	10,390.10	11,769.90	13,333.00	620.3	1,832.70	4,865.80	8,934.00
- Metal Halide	2,705.60	2,631.30	2,305.70	1,658.10	61.2	2,824.70	3,006.50	3,267.10	3,700.90	149.6	422.8	1,079.80	2,058.80
- Existing LED	336.3	336.9	337.9	338.9	100	336.5	336.9	337.7	338.9	3.6	5.3	5	1.4
Commercial sector	9,401.90	8,118.20	5,983.60	3,840.80	40.9	10,228.80	10,481.40	10,919.70	11,380.40	1,184.80	3,222.10	6,608.10	9,997.50
- Incandescent lamp	430.5	154.4	42.2	29.4	6.8	610.4	627	655.7	685.8	201.2	524	713.9	804.5
- Halogen lamp	691.2	380.5	92.2	64.4	9.3	892.8	917.1	959.1	1,003.00	232.8	611.7	1,013.70	1,155.30
- Compact Fluorescent lamp	6,202.20	5,641.70	4,247.00	2,607.60	42	6,565.70	6,744.50	7,053.60	7,376.70	593.2	1,655.50	3,886.60	6,362.30
- Tubular Fluorescent	707.1	647.4	487.8	279.5	39.5	744.4	764.7	799.7	836.4	63.3	179.9	434.4	737.5
- Metal Halide	939.4	876.9	719.9	486.9	51.8	984.1	1,010.90	1,057.20	1,105.70	79.1	216.8	499.2	857.6
- Existing LED	431.5	417.2	394.4	372.9	86.4	431.5	417.2	394.4	372.9	15.1	34.2	60.4	80.5
Total	29,578.60	27,190.70	21,436.80	13,865.70	46.9	31,539.20	33,141.70	36,025.50	39,199.30	2,548.70	7,168.90	16,635.60	27,911.40

8. Raw data of AHP survey in this study raw for Criteria

Survey number	TR	OM	IC	PP	BT	Consistency Index	CR
Avg	0.294	0.175	0.135	0.186	0.210		
81	0.077	0.077	0.077	0.077	0.692	0.0000	0.0000
70	0.644	0.090	0.090	0.090	0.087	0.0005	0.0007
91	0.380	0.073	0.076	0.076	0.395	0.0010	0.0012
94	0.645	0.065	0.070	0.070	0.150	0.0062	0.0075
60	0.087	0.152	0.258	0.415	0.087	0.0091	0.0111
66	0.068	0.131	0.274	0.121	0.407	0.0120	0.0146
93	0.414	0.078	0.059	0.070	0.379	0.0176	0.0215
56	0.089	0.158	0.246	0.404	0.104	0.0180	0.0220
34	0.365	0.107	0.180	0.241	0.107	0.0181	0.0220
92	0.377	0.085	0.066	0.075	0.396	0.0182	0.0222
46	0.101	0.153	0.258	0.413	0.076	0.0237	0.0289
42	0.468	0.144	0.069	0.091	0.228	0.0288	0.0351
64	0.051	0.127	0.273	0.425	0.123	0.0308	0.0376
51	0.617	0.113	0.050	0.050	0.169	0.0314	0.0383
82	0.114	0.066	0.081	0.081	0.659	0.0332	0.0405
43	0.541	0.086	0.075	0.048	0.249	0.0332	0.0405
38	0.121	0.091	0.183	0.183	0.423	0.0341	0.0415
59	0.549	0.110	0.083	0.110	0.148	0.0341	0.0416
39	0.327	0.249	0.119	0.119	0.185	0.0344	0.0419
57	0.167	0.123	0.080	0.080	0.550	0.0345	0.0420
62	0.083	0.135	0.257	0.452	0.072	0.0361	0.0440
86	0.130	0.634	0.082	0.049	0.105	0.0408	0.0497
9	0.126	0.182	0.242	0.346	0.104	0.0482	0.0587
5	0.248	0.186	0.138	0.324	0.105	0.0489	0.0596
54	0.105	0.186	0.324	0.248	0.138	0.0489	0.0596
63	0.138	0.186	0.248	0.324	0.105	0.0489	0.0596
14	0.419	0.213	0.118	0.159	0.090	0.0489	0.0596
58	0.213	0.419	0.090	0.118	0.159	0.0489	0.0596
67	0.491	0.187	0.104	0.140	0.079	0.0489	0.0597
96	0.107	0.678	0.089	0.057	0.069	0.0515	0.0629
45	0.548	0.138	0.064	0.083	0.167	0.0528	0.0644
84	0.117	0.681	0.087	0.064	0.051	0.0546	0.0665
12	0.157	0.217	0.115	0.445	0.065	0.0555	0.0677
29	0.060	0.145	0.226	0.489	0.080	0.0573	0.0698
1	0.085	0.221	0.360	0.278	0.057	0.0617	0.0752
100	0.507	0.225	0.030	0.031	0.207	0.0634	0.0773
85	0.117	0.657	0.095	0.043	0.088	0.0644	0.0785
97	0.102	0.066	0.079	0.100	0.653	0.0717	0.0875
36	0.078	0.186	0.261	0.407	0.067	0.0770	0.0939
18	0.074	0.099	0.513	0.232	0.082	0.0790	0.0963

* TR; Technical Reliability, OM; Operation and Maintenance, IC; Initial Cost, PP; Payback Period, BT; Brightness and Temperature

(Continued)

Survey number	TR	OM	IC	PP	BT	Consistency Index	CR
20	0.132	0.157	0.266	0.345	0.101	0.0794	0.0968
44	0.558	0.072	0.101	0.071	0.198	0.0837	0.1021
37	0.070	0.128	0.257	0.462	0.083	0.0841	0.1025
4	0.085	0.115	0.101	0.488	0.211	0.0883	0.1077
22	0.049	0.108	0.246	0.536	0.061	0.0891	0.1087
72	0.496	0.228	0.034	0.028	0.214	0.0898	0.1095
88	0.204	0.438	0.051	0.051	0.255	0.0903	0.1101
89	0.438	0.204	0.051	0.051	0.255	0.0903	0.1101
23	0.482	0.076	0.182	0.182	0.078	0.0938	0.1144
27	0.114	0.177	0.282	0.359	0.069	0.0953	0.1162
52	0.141	0.273	0.190	0.254	0.141	0.0957	0.1167
15	0.085	0.169	0.217	0.468	0.060	0.0967	0.1179
55	0.485	0.094	0.096	0.153	0.173	0.0968	0.1181
48	0.326	0.046	0.064	0.106	0.458	0.0987	0.1204
41	0.451	0.136	0.038	0.051	0.324	0.1001	0.1221
25	0.401	0.268	0.103	0.139	0.088	0.1008	0.1229
95	0.427	0.102	0.060	0.055	0.356	0.1008	0.1230
2	0.508	0.154	0.043	0.262	0.032	0.1013	0.1236
73	0.488	0.191	0.031	0.031	0.259	0.1083	0.1320
78	0.208	0.148	0.035	0.035	0.574	0.1110	0.1353
49	0.539	0.108	0.069	0.069	0.215	0.1123	0.1370
99	0.418	0.248	0.037	0.029	0.268	0.1173	0.1431
76	0.201	0.155	0.035	0.035	0.574	0.1193	0.1455
71	0.576	0.186	0.026	0.026	0.186	0.1203	0.1467
40	0.667	0.114	0.044	0.066	0.108	0.1220	0.1488
77	0.205	0.154	0.035	0.034	0.572	0.1255	0.1530
75	0.588	0.124	0.037	0.024	0.228	0.1256	0.1532
7	0.527	0.212	0.051	0.078	0.132	0.1275	0.1555
32	0.195	0.158	0.190	0.190	0.267	0.1288	0.1571
31	0.552	0.118	0.048	0.057	0.225	0.1294	0.1578
74	0.610	0.125	0.031	0.026	0.208	0.1321	0.1611
35	0.525	0.209	0.077	0.126	0.063	0.1333	0.1626
30	0.044	0.155	0.442	0.298	0.062	0.1362	0.1661
65	0.359	0.105	0.155	0.261	0.120	0.1369	0.1670
80	0.220	0.131	0.032	0.035	0.583	0.1372	0.1673
19	0.043	0.119	0.233	0.580	0.025	0.1393	0.1699
68	0.104	0.142	0.337	0.286	0.131	0.1445	0.1763
33	0.049	0.331	0.250	0.261	0.108	0.1450	0.1768
11	0.216	0.134	0.066	0.309	0.275	0.1471	0.1794
16	0.638	0.043	0.089	0.197	0.032	0.1471	0.1794
50	0.467	0.095	0.132	0.211	0.095	0.1474	0.1797

* TR; Technical Reliability, OM; Operation and Maintenance, IC; Initial Cost, PP; Payback Period, BT; Brightness and Temperature

(Continued)

Survey number	TR	OM	IC	PP	BT	Consistency Index	CR
21	0.072	0.161	0.286	0.434	0.047	0.1505	0.1835
98	0.236	0.136	0.031	0.036	0.561	0.1514	0.1846
47	0.631	0.084	0.133	0.134	0.019	0.1522	0.1856
83	0.104	0.089	0.066	0.116	0.625	0.1568	0.1912
79	0.206	0.161	0.032	0.036	0.565	0.1575	0.1920
53	0.405	0.108	0.148	0.199	0.140	0.1593	0.1942
28	0.575	0.190	0.077	0.121	0.037	0.1608	0.1961
8	0.272	0.177	0.106	0.362	0.084	0.1920	0.2341
90	0.095	0.071	0.180	0.081	0.574	0.1983	0.2418
61	0.434	0.034	0.137	0.229	0.166	0.2015	0.2457
10	0.337	0.150	0.064	0.384	0.064	0.2099	0.2560
3	0.114	0.594	0.046	0.216	0.031	0.2138	0.2608
69	0.115	0.140	0.325	0.220	0.200	0.2160	0.2634
13	0.236	0.110	0.127	0.426	0.101	0.2262	0.2758
6	0.047	0.081	0.206	0.572	0.095	0.2378	0.2900
24	0.126	0.193	0.207	0.375	0.100	0.2728	0.3327
87	0.369	0.184	0.028	0.028	0.391	0.3587	0.4375
17	0.227	0.118	0.083	0.414	0.158	0.4301	0.5245
26	0.478	0.052	0.112	0.287	0.072	0.5018	0.6120

* TR; Technical Reliability, OM; Operation and Maintenance, IC; Initial Cost, PP; Payback Period, BT; Brightness and Temperature

9. Raw data of AHP survey in this study raw for TR

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
Avg	0.601	0.197	0.202		
11	0.143	0.571	0.286	0.0000	0.0000
15	0.333	0.333	0.333	0.0000	0.0000
22	0.714	0.143	0.143	0.0000	0.0000
84	0.582	0.140	0.278	0.0000	0.0000
79	0.719	0.146	0.136	0.0006	0.0008
94	0.780	0.114	0.106	0.0006	0.0008
82	0.802	0.102	0.095	0.0006	0.0008
92	0.820	0.093	0.087	0.0006	0.0008
89	0.508	0.059	0.434	0.0014	0.0017
87	0.655	0.120	0.225	0.0022	0.0026
96	0.812	0.096	0.093	0.0027	0.0033
100	0.812	0.096	0.093	0.0027	0.0033
75	0.755	0.086	0.159	0.0030	0.0036
86	0.792	0.105	0.103	0.0031	0.0038
98	0.792	0.105	0.103	0.0031	0.0038
39	0.634	0.192	0.174	0.0046	0.0056
20	0.540	0.297	0.163	0.0046	0.0056
4	0.126	0.416	0.458	0.0046	0.0056
59	0.697	0.151	0.152	0.0058	0.0071
99	0.802	0.098	0.100	0.0069	0.0085
5	0.626	0.238	0.136	0.0092	0.0112
64	0.321	0.561	0.118	0.0096	0.0117
80	0.663	0.093	0.244	0.0100	0.0122
97	0.797	0.074	0.129	0.0111	0.0135
78	0.796	0.131	0.073	0.0139	0.0170
93	0.809	0.072	0.119	0.0186	0.0227
83	0.763	0.150	0.086	0.0199	0.0242
74	0.788	0.134	0.077	0.0213	0.0259
1	0.194	0.496	0.310	0.0269	0.0328
3	0.597	0.155	0.248	0.0269	0.0328
6	0.248	0.597	0.155	0.0269	0.0328
66	0.606	0.151	0.242	0.0269	0.0328
12	0.137	0.531	0.332	0.0270	0.0329
53	0.752	0.095	0.152	0.0270	0.0329
10	0.695	0.216	0.089	0.0270	0.0330
21	0.695	0.089	0.216	0.0270	0.0330
69	0.699	0.214	0.086	0.0308	0.0375
54	0.193	0.504	0.303	0.0313	0.0381

* TR; Technical Reliability

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
49	0.509	0.306	0.184	0.0313	0.0381
58	0.509	0.306	0.184	0.0313	0.0381
63	0.606	0.246	0.148	0.0313	0.0382
50	0.717	0.177	0.106	0.0314	0.0383
81	0.751	0.060	0.189	0.0371	0.0453
26	0.791	0.146	0.063	0.0407	0.0497
7	0.680	0.223	0.097	0.0434	0.0529
95	0.546	0.086	0.367	0.0451	0.0550
43	0.699	0.121	0.180	0.0469	0.0572
28	0.694	0.123	0.183	0.0474	0.0578
33	0.694	0.123	0.183	0.0474	0.0578
44	0.639	0.273	0.087	0.0479	0.0585
25	0.284	0.074	0.641	0.0480	0.0585
27	0.641	0.074	0.284	0.0480	0.0585
48	0.645	0.144	0.211	0.0534	0.0651
14	0.638	0.147	0.215	0.0544	0.0663
19	0.147	0.215	0.638	0.0544	0.0663
31	0.638	0.215	0.147	0.0544	0.0663
76	0.240	0.052	0.708	0.0578	0.0704
57	0.645	0.214	0.141	0.0596	0.0727
77	0.747	0.054	0.200	0.0615	0.0750
60	0.567	0.180	0.253	0.0661	0.0806
67	0.567	0.180	0.253	0.0661	0.0806
9	0.556	0.259	0.185	0.0683	0.0832
18	0.556	0.259	0.185	0.0683	0.0832
41	0.556	0.259	0.185	0.0683	0.0832
32	0.556	0.185	0.259	0.0683	0.0832
34	0.717	0.165	0.118	0.0687	0.0838
23	0.108	0.662	0.230	0.0690	0.0841
35	0.662	0.230	0.108	0.0690	0.0841
45	0.567	0.257	0.176	0.0730	0.0890
51	0.819	0.125	0.057	0.0743	0.0906
56	0.769	0.076	0.155	0.0904	0.1102
91	0.567	0.099	0.334	0.0975	0.1189
17	0.694	0.102	0.204	0.1010	0.1232
40	0.694	0.102	0.204	0.1010	0.1232
2	0.256	0.419	0.326	0.1089	0.1329
37	0.598	0.178	0.224	0.1099	0.1341
85	0.740	0.044	0.215	0.1123	0.1370
47	0.646	0.237	0.118	0.1158	0.1412
88	0.262	0.041	0.697	0.1189	0.1450

* TR; Technical Reliability

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
90	0.262	0.041	0.697	0.1189	0.1450
24	0.556	0.290	0.154	0.1306	0.1593
52	0.813	0.052	0.135	0.1343	0.1638
68	0.813	0.052	0.135	0.1343	0.1638
73	0.225	0.041	0.734	0.1389	0.1694
65	0.678	0.114	0.208	0.1489	0.1816
36	0.672	0.117	0.211	0.1516	0.1849
46	0.061	0.194	0.745	0.1562	0.1905
8	0.815	0.140	0.044	0.1571	0.1916
71	0.782	0.045	0.173	0.1693	0.2065
70	0.495	0.238	0.266	0.1707	0.2082
62	0.612	0.248	0.140	0.1909	0.2328
29	0.043	0.160	0.796	0.1999	0.2438
42	0.036	0.150	0.814	0.2429	0.2962
30	0.722	0.073	0.205	0.2518	0.3071
13	0.605	0.269	0.126	0.2609	0.3181
61	0.761	0.055	0.184	0.2877	0.3508
38	0.705	0.212	0.083	0.3346	0.4080
16	0.747	0.192	0.062	0.3592	0.4380
55	0.180	0.754	0.066	0.5095	0.6214
72	0.816	0.030	0.155	0.3268	0.3986

* TR; Technical Reliability

10. Raw data of AHP survey in this study raw for OM

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
Avg	0.712	0.127	0.162		
72	0.818	0.091	0.091	0.0000	0.0000
74	0.692	0.077	0.231	0.0000	0.0000
77	0.818	0.091	0.091	0.0000	0.0000
88	0.818	0.091	0.091	0.0000	0.0000
97	0.714	0.143	0.143	0.0000	0.0000
85	0.800	0.100	0.100	0.0000	0.0000
17	0.582	0.140	0.278	0.0000	0.0000
25	0.357	0.333	0.310	0.0006	0.0008
23	0.513	0.252	0.235	0.0006	0.0008
41	0.609	0.203	0.189	0.0006	0.0008
4	0.673	0.169	0.158	0.0006	0.0008
14	0.673	0.169	0.158	0.0006	0.0008
26	0.753	0.128	0.119	0.0006	0.0008
56	0.780	0.114	0.106	0.0006	0.0008
95	0.761	0.082	0.158	0.0006	0.0008
80	0.809	0.093	0.097	0.0008	0.0009
86	0.809	0.093	0.097	0.0008	0.0009
90	0.809	0.097	0.093	0.0008	0.0009
99	0.809	0.097	0.093	0.0008	0.0009
75	0.789	0.103	0.108	0.0010	0.0012
81	0.789	0.103	0.108	0.0010	0.0012
91	0.764	0.115	0.121	0.0013	0.0016
98	0.764	0.115	0.121	0.0013	0.0016
96	0.751	0.087	0.162	0.0028	0.0034
47	0.755	0.086	0.159	0.0030	0.0036
67	0.540	0.163	0.297	0.0046	0.0056
82	0.779	0.078	0.143	0.0046	0.0056
93	0.779	0.078	0.143	0.0046	0.0056
83	0.695	0.095	0.210	0.0046	0.0056
57	0.552	0.160	0.289	0.0052	0.0063
34	0.643	0.177	0.181	0.0082	0.0100
7	0.780	0.109	0.111	0.0084	0.0103
62	0.626	0.136	0.238	0.0092	0.0112
92	0.770	0.083	0.146	0.0092	0.0112
20	0.570	0.119	0.311	0.0104	0.0127
28	0.732	0.099	0.169	0.0148	0.0180
51	0.690	0.199	0.111	0.0157	0.0191
48	0.732	0.171	0.097	0.0181	0.0221

* OM; Operation and Maintenance

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
78	0.807	0.121	0.073	0.0185	0.0226
89	0.807	0.073	0.121	0.0185	0.0226
100	0.807	0.073	0.121	0.0185	0.0226
19	0.809	0.072	0.119	0.0186	0.0227
58	0.788	0.134	0.077	0.0213	0.0259
55	0.646	0.254	0.100	0.0229	0.0279
63	0.496	0.194	0.310	0.0269	0.0328
37	0.510	0.189	0.302	0.0269	0.0328
54	0.510	0.189	0.302	0.0269	0.0328
10	0.606	0.151	0.242	0.0269	0.0328
73	0.799	0.077	0.124	0.0270	0.0329
94	0.799	0.124	0.077	0.0270	0.0329
9	0.801	0.076	0.122	0.0270	0.0329
3	0.819	0.069	0.111	0.0270	0.0329
60	0.695	0.216	0.089	0.0270	0.0330
13	0.655	0.082	0.264	0.0285	0.0348
8	0.671	0.206	0.124	0.0314	0.0383
11	0.801	0.124	0.075	0.0315	0.0384
45	0.813	0.074	0.114	0.0370	0.0451
70	0.620	0.114	0.266	0.0371	0.0452
59	0.766	0.141	0.093	0.0405	0.0494
35	0.769	0.163	0.068	0.0412	0.0502
43	0.663	0.279	0.058	0.0415	0.0506
22	0.739	0.104	0.157	0.0429	0.0523
33	0.739	0.104	0.157	0.0429	0.0523
30	0.686	0.096	0.219	0.0440	0.0536
79	0.500	0.131	0.369	0.0475	0.0580
76	0.805	0.061	0.135	0.0549	0.0670
6	0.645	0.214	0.141	0.0596	0.0727
24	0.735	0.067	0.198	0.0642	0.0783
52	0.701	0.064	0.235	0.0651	0.0794
12	0.567	0.180	0.253	0.0661	0.0806
38	0.757	0.146	0.098	0.0661	0.0807
50	0.751	0.079	0.170	0.0692	0.0844
1	0.819	0.058	0.124	0.0694	0.0846
71	0.540	0.081	0.379	0.0699	0.0852
42	0.722	0.165	0.113	0.0746	0.0910
21	0.790	0.156	0.053	0.0790	0.0963
66	0.721	0.073	0.206	0.0841	0.1025

* OM; Operation and Maintenance

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
31	0.793	0.068	0.139	0.0875	0.1067
36	0.769	0.076	0.155	0.0904	0.1102
64	0.728	0.061	0.211	0.0952	0.1161
29	0.542	0.382	0.076	0.0988	0.1205
40	0.646	0.120	0.235	0.1096	0.1337
68	0.709	0.079	0.212	0.1126	0.1374
46	0.818	0.050	0.132	0.1134	0.1383
84	0.561	0.092	0.347	0.1341	0.1636
87	0.410	0.067	0.523	0.1369	0.1670
15	0.678	0.114	0.208	0.1489	0.1816
5	0.712	0.069	0.219	0.1558	0.1900
44	0.748	0.060	0.191	0.1563	0.1906
2	0.807	0.056	0.138	0.1603	0.1955
61	0.783	0.063	0.154	0.1683	0.2053
49	0.781	0.041	0.178	0.2075	0.2530
18	0.807	0.049	0.144	0.2135	0.2604
39	0.807	0.049	0.144	0.2135	0.2604
53	0.812	0.041	0.146	0.2296	0.2800
69	0.796	0.039	0.165	0.2424	0.2956
16	0.816	0.035	0.148	0.2429	0.2963
65	0.776	0.035	0.189	0.2821	0.3440
27	0.793	0.166	0.041	0.2851	0.3477
32	0.816	0.030	0.155	0.3268	0.3986

* OM; Operation and Maintenance

11. Raw data of AHP survey in this study raw for IC

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
Avg	0.308	0.424	0.258		
4	0.333	0.333	0.333	0.0000	0.0000
8	0.091	0.455	0.455	0.0000	0.0000
19	0.111	0.444	0.444	0.0000	0.0000
21	0.571	0.286	0.143	0.0000	0.0000
24	0.250	0.500	0.250	0.0000	0.0000
40	0.143	0.571	0.286	0.0000	0.0000
44	0.067	0.467	0.467	0.0000	0.0000
55	0.143	0.429	0.429	0.0000	0.0000
57	0.143	0.571	0.286	0.0000	0.0000
66	0.143	0.429	0.429	0.0000	0.0000
69	0.333	0.333	0.333	0.0000	0.0000
76	0.750	0.125	0.125	0.0000	0.0000
85	0.714	0.143	0.143	0.0000	0.0000
91	0.250	0.500	0.250	0.0000	0.0000
95	0.750	0.125	0.125	0.0000	0.0000
11	0.200	0.400	0.400	0.0000	0.0000
34	0.200	0.400	0.400	0.0000	0.0000
72	0.800	0.100	0.100	0.0000	0.0000
87	0.800	0.100	0.100	0.0000	0.0000
99	0.800	0.100	0.100	0.0000	0.0000
60	0.122	0.649	0.230	0.0018	0.0023
71	0.649	0.230	0.122	0.0018	0.0023
100	0.649	0.230	0.122	0.0018	0.0023
54	0.109	0.582	0.309	0.0018	0.0023
64	0.109	0.582	0.309	0.0018	0.0023
70	0.088	0.670	0.242	0.0035	0.0043
1	0.192	0.634	0.174	0.0046	0.0056
74	0.297	0.540	0.163	0.0046	0.0056
97	0.297	0.540	0.163	0.0046	0.0056
17	0.163	0.540	0.297	0.0046	0.0056
36	0.163	0.540	0.297	0.0046	0.0056
79	0.776	0.106	0.117	0.0046	0.0056
75	0.741	0.166	0.093	0.0071	0.0086
96	0.741	0.166	0.093	0.0071	0.0086
42	0.209	0.551	0.240	0.0092	0.0112

* IC; Initial Cost

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
22	0.136	0.626	0.238	0.0092	0.0112
29	0.136	0.626	0.238	0.0092	0.0112
50	0.136	0.626	0.238	0.0092	0.0112
52	0.136	0.626	0.238	0.0092	0.0112
62	0.136	0.626	0.238	0.0092	0.0112
15	0.559	0.319	0.121	0.0092	0.0112
18	0.559	0.319	0.121	0.0092	0.0112
88	0.728	0.171	0.101	0.0146	0.0178
27	0.257	0.640	0.103	0.0194	0.0236
77	0.511	0.421	0.067	0.0195	0.0237
94	0.511	0.421	0.067	0.0195	0.0237
61	0.194	0.310	0.496	0.0269	0.0328
10	0.194	0.496	0.310	0.0269	0.0328
39	0.310	0.496	0.194	0.0269	0.0328
48	0.310	0.496	0.194	0.0269	0.0328
12	0.597	0.248	0.155	0.0269	0.0328
46	0.248	0.597	0.155	0.0269	0.0328
56	0.155	0.248	0.597	0.0269	0.0328
20	0.129	0.665	0.206	0.0269	0.0329
35	0.206	0.665	0.129	0.0269	0.0329
41	0.129	0.206	0.665	0.0269	0.0329
5	0.137	0.531	0.332	0.0270	0.0329
33	0.089	0.695	0.216	0.0270	0.0330
63	0.073	0.571	0.357	0.0272	0.0331
23	0.097	0.223	0.680	0.0434	0.0529
59	0.097	0.223	0.680	0.0434	0.0529
14	0.0474	0.0474	0.0474	0.0474	0.0578
86	0.694	0.123	0.183	0.0474	0.0578
73	0.500	0.131	0.369	0.0475	0.0580
80	0.500	0.369	0.131	0.0475	0.0580
98	0.500	0.131	0.369	0.0475	0.0580
81	0.529	0.384	0.087	0.0552	0.0673
31	0.065	0.696	0.239	0.0636	0.0776
68	0.065	0.239	0.696	0.0636	0.0776
7	0.129	0.594	0.277	0.0688	0.0838
6	0.230	0.662	0.108	0.0690	0.0841
9	0.230	0.662	0.108	0.0690	0.0841
16	0.197	0.711	0.092	0.0691	0.0843

* IC; Initial Cost

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
30	0.080	0.172	0.747	0.0692	0.0844
49	0.669	0.141	0.190	0.0826	0.1008
38	0.180	0.755	0.065	0.0884	0.1078
67	0.157	0.766	0.077	0.0908	0.1107
92	0.302	0.088	0.610	0.1022	0.1246
47	0.054	0.186	0.760	0.1032	0.1258
89	0.256	0.326	0.419	0.1089	0.1329
58	0.166	0.786	0.048	0.1094	0.1334
83	0.500	0.188	0.313	0.1097	0.1338
37	0.140	0.486	0.374	0.1109	0.1352
2	0.122	0.638	0.239	0.1111	0.1354
65	0.247	0.660	0.093	0.1123	0.1369
78	0.550	0.351	0.099	0.1126	0.1373
93	0.550	0.351	0.099	0.1126	0.1373
26	0.212	0.709	0.079	0.1126	0.1374
82	0.392	0.095	0.513	0.1129	0.1377
25	0.046	0.764	0.190	0.1150	0.1402
43	0.046	0.764	0.190	0.1150	0.1402
51	0.084	0.161	0.755	0.1202	0.1466
53	0.084	0.161	0.755	0.1202	0.1466
45	0.057	0.190	0.753	0.1263	0.1540
3	0.183	0.720	0.097	0.1322	0.1612
90	0.394	0.482	0.124	0.1524	0.1858
28	0.483	0.309	0.208	0.2845	0.3469
84	0.598	0.168	0.233	0.4274	0.5212
32	0.398	0.245	0.357	0.6217	0.7582
13	0.132	0.250	0.618	0.8696	1.0605

* IC; Initial Cost

12. Raw data of AHP survey in this study raw for PP

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
Avg	0.302	0.385	0.313		
5	0.250	0.500	0.250	0.0000	0.0000
12	0.143	0.571	0.286	0.0000	0.0000
16	0.067	0.467	0.467	0.0000	0.0000
27	0.143	0.429	0.429	0.0000	0.0000
29	0.143	0.571	0.286	0.0000	0.0000
38	0.500	0.250	0.250	0.0000	0.0000
44	0.714	0.143	0.143	0.0000	0.0000
45	0.222	0.111	0.667	0.0000	0.0000
67	0.500	0.250	0.250	0.0000	0.0000
92	0.444	0.444	0.111	0.0000	0.0000
98	0.333	0.333	0.333	0.0000	0.0000
34	0.200	0.400	0.400	0.0000	0.0000
40	0.600	0.200	0.200	0.0000	0.0000
69	0.200	0.600	0.200	0.0000	0.0000
73	0.761	0.158	0.082	0.0006	0.0008
90	0.715	0.187	0.098	0.0010	0.0012
74	0.764	0.121	0.115	0.0013	0.0016
32	0.122	0.649	0.230	0.0018	0.0023
59	0.122	0.649	0.230	0.0018	0.0023
61	0.122	0.649	0.230	0.0018	0.0023
26	0.109	0.582	0.309	0.0018	0.0023
35	0.109	0.582	0.309	0.0018	0.0023
54	0.109	0.309	0.582	0.0018	0.0023
60	0.109	0.309	0.582	0.0018	0.0023
63	0.109	0.582	0.309	0.0018	0.0023
52	0.309	0.582	0.109	0.0018	0.0023
86	0.691	0.149	0.160	0.0028	0.0034
57	0.174	0.634	0.192	0.0046	0.0056
41	0.540	0.297	0.163	0.0046	0.0056
33	0.163	0.540	0.297	0.0046	0.0056
81	0.727	0.200	0.073	0.0046	0.0056
14	0.209	0.551	0.240	0.0092	0.0112
80	0.209	0.551	0.240	0.0092	0.0112
3	0.136	0.626	0.238	0.0092	0.0112
10	0.136	0.626	0.238	0.0092	0.0112
22	0.136	0.626	0.238	0.0092	0.0112
24	0.136	0.626	0.238	0.0092	0.0112

* PP; Payback Period

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
46	0.238	0.626	0.136	0.0092	0.0112
96	0.656	0.249	0.095	0.0092	0.0112
100	0.794	0.131	0.075	0.0109	0.0133
55	0.155	0.661	0.184	0.0146	0.0178
85	0.728	0.101	0.171	0.0146	0.0178
68	0.348	0.068	0.584	0.0163	0.0199
84	0.807	0.121	0.073	0.0185	0.0226
8	0.257	0.640	0.103	0.0194	0.0236
49	0.257	0.103	0.640	0.0194	0.0236
53	0.103	0.640	0.257	0.0194	0.0236
20	0.310	0.496	0.194	0.0269	0.0328
18	0.248	0.597	0.155	0.0269	0.0328
28	0.155	0.248	0.597	0.0269	0.0328
13	0.129	0.206	0.665	0.0269	0.0329
70	0.129	0.206	0.665	0.0269	0.0329
65	0.216	0.695	0.089	0.0270	0.0330
62	0.344	0.106	0.550	0.0270	0.0330
97	0.774	0.160	0.066	0.0271	0.0330
91	0.351	0.562	0.086	0.0271	0.0331
50	0.073	0.357	0.571	0.0272	0.0331
87	0.524	0.402	0.073	0.0375	0.0457
89	0.791	0.146	0.063	0.0407	0.0497
4	0.097	0.223	0.680	0.0434	0.0529
31	0.097	0.223	0.680	0.0434	0.0529
36	0.097	0.223	0.680	0.0434	0.0529
47	0.097	0.223	0.680	0.0434	0.0529
58	0.097	0.223	0.680	0.0434	0.0529
64	0.097	0.223	0.680	0.0434	0.0529
39	0.090	0.633	0.277	0.0435	0.0531
1	0.147	0.638	0.215	0.0544	0.0663
88	0.347	0.491	0.162	0.0685	0.0835
79	0.347	0.162	0.491	0.0685	0.0835
56	0.118	0.165	0.717	0.0687	0.0838
11	0.080	0.172	0.747	0.0692	0.0844
94	0.378	0.536	0.086	0.0697	0.0851
82	0.540	0.379	0.081	0.0699	0.0852
21	0.669	0.141	0.190	0.0826	0.1008
93	0.736	0.114	0.150	0.0900	0.1097
76	0.781	0.095	0.124	0.0944	0.1151

* PP; Payback Period

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
51	0.088	0.177	0.735	0.0949	0.1157
19	0.054	0.186	0.760	0.1032	0.1258
71	0.256	0.326	0.419	0.1089	0.1329
30	0.166	0.786	0.048	0.1094	0.1334
7	0.212	0.709	0.079	0.1126	0.1374
42	0.079	0.212	0.709	0.1126	0.1374
6	0.046	0.764	0.190	0.1150	0.1402
15	0.046	0.764	0.190	0.1150	0.1402
23	0.084	0.161	0.755	0.1202	0.1466
25	0.084	0.161	0.755	0.1202	0.1466
17	0.057	0.190	0.753	0.1263	0.1540
43	0.556	0.290	0.154	0.1306	0.1593
75	0.714	0.131	0.155	0.1377	0.1679
83	0.266	0.691	0.043	0.1390	0.1695
66	0.672	0.211	0.117	0.1516	0.1849
95	0.271	0.677	0.052	0.1739	0.2120
72	0.368	0.418	0.214	0.1854	0.2261
48	0.132	0.312	0.555	0.1898	0.2315
78	0.424	0.502	0.074	0.1990	0.2426
2	0.269	0.605	0.126	0.2609	0.3181
9	0.483	0.309	0.208	0.2845	0.3469
77	0.552	0.240	0.208	0.3152	0.3844
99	0.294	0.608	0.099	0.3948	0.4815
37	0.242	0.422	0.336	0.4627	0.5643

* PP; Payback Period

13. Raw data of AHP survey in this study raw for BT

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
Avg	0.616	0.094	0.289		
7	0.474	0.053	0.474	0.0000	0.0000
17	0.467	0.067	0.467	0.0000	0.0000
36	0.600	0.100	0.300	0.0000	0.0000
45	0.571	0.143	0.286	0.0000	0.0000
51	0.571	0.143	0.286	0.0000	0.0000
53	0.615	0.077	0.308	0.0000	0.0000
69	0.474	0.053	0.474	0.0000	0.0000
71	0.818	0.091	0.091	0.0000	0.0000
74	0.778	0.111	0.111	0.0000	0.0000
76	0.761	0.082	0.158	0.0006	0.0008
80	0.761	0.082	0.158	0.0006	0.0008
97	0.761	0.082	0.158	0.0006	0.0008
73	0.809	0.093	0.097	0.0008	0.0009
93	0.682	0.082	0.236	0.0008	0.0009
78	0.789	0.103	0.108	0.0010	0.0012
99	0.789	0.103	0.108	0.0010	0.0012
75	0.764	0.121	0.115	0.0013	0.0016
62	0.649	0.122	0.230	0.0018	0.0023
9	0.444	0.083	0.472	0.0018	0.0023
68	0.596	0.128	0.276	0.0028	0.0034
55	0.751	0.087	0.162	0.0028	0.0034
88	0.799	0.096	0.105	0.0035	0.0043
92	0.799	0.096	0.105	0.0035	0.0043
96	0.799	0.096	0.105	0.0035	0.0043
58	0.490	0.059	0.451	0.0035	0.0043
63	0.540	0.163	0.297	0.0046	0.0056
24	0.702	0.106	0.193	0.0046	0.0056
43	0.702	0.193	0.106	0.0046	0.0056
65	0.682	0.068	0.250	0.0046	0.0056
3	0.741	0.166	0.093	0.0071	0.0086
26	0.770	0.146	0.083	0.0092	0.0112
39	0.656	0.095	0.249	0.0092	0.0112
11	0.340	0.064	0.596	0.0092	0.0112
42	0.596	0.064	0.340	0.0092	0.0112
48	0.794	0.075	0.131	0.0109	0.0133
77	0.794	0.075	0.131	0.0109	0.0133
100	0.794	0.075	0.131	0.0109	0.0133

* BT; Brightness and Temperature

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
79	0.753	0.069	0.177	0.0146	0.0178
98	0.753	0.069	0.177	0.0146	0.0178
23	0.673	0.062	0.265	0.0146	0.0179
6	0.786	0.134	0.080	0.0175	0.0214
20	0.786	0.080	0.134	0.0175	0.0214
95	0.786	0.080	0.134	0.0175	0.0214
72	0.807	0.121	0.073	0.0185	0.0226
90	0.807	0.121	0.073	0.0185	0.0226
12	0.640	0.103	0.257	0.0194	0.0236
18	0.640	0.103	0.257	0.0194	0.0236
15	0.745	0.074	0.182	0.0222	0.0271
46	0.496	0.194	0.310	0.0269	0.0328
70	0.496	0.194	0.310	0.0269	0.0328
21	0.713	0.110	0.177	0.0270	0.0329
49	0.713	0.110	0.177	0.0270	0.0329
25	0.799	0.077	0.124	0.0270	0.0329
89	0.818	0.070	0.112	0.0270	0.0329
4	0.695	0.089	0.216	0.0270	0.0330
60	0.351	0.086	0.562	0.0271	0.0331
41	0.357	0.073	0.571	0.0272	0.0331
66	0.735	0.186	0.079	0.0328	0.0400
47	0.748	0.061	0.192	0.0362	0.0442
30	0.283	0.060	0.657	0.0375	0.0457
35	0.371	0.058	0.570	0.0391	0.0477
64	0.371	0.058	0.570	0.0391	0.0477
59	0.791	0.146	0.063	0.0407	0.0497
1	0.660	0.052	0.287	0.0412	0.0502
2	0.287	0.052	0.660	0.0412	0.0502
10	0.633	0.277	0.090	0.0435	0.0531
91	0.500	0.131	0.369	0.0475	0.0580
38	0.705	0.061	0.234	0.0481	0.0587
67	0.770	0.058	0.173	0.0552	0.0673
19	0.743	0.054	0.203	0.0603	0.0735
16	0.201	0.068	0.731	0.0634	0.0773
44	0.731	0.068	0.201	0.0634	0.0773
40	0.347	0.162	0.491	0.0685	0.0835
56	0.277	0.129	0.594	0.0688	0.0838
52	0.817	0.058	0.125	0.0694	0.0846
94	0.540	0.081	0.379	0.0699	0.0852
54	0.304	0.045	0.651	0.0710	0.0865

* BT; Brightness and Temperature

(Continued)

Survey number	LED	High efficiency Metal Halide	Induction Lamp	Consistency Index	C.R
13	0.248	0.048	0.704	0.0756	0.0922
87	0.399	0.062	0.539	0.0975	0.1188
34	0.316	0.050	0.634	0.1097	0.1337
29	0.316	0.057	0.628	0.1154	0.1407
14	0.261	0.041	0.697	0.1166	0.1422
31	0.261	0.041	0.697	0.1166	0.1422
37	0.290	0.154	0.556	0.1306	0.1593
5	0.762	0.042	0.196	0.1451	0.1770
50	0.230	0.038	0.732	0.1616	0.1970
8	0.683	0.045	0.271	0.1671	0.2038
22	0.182	0.036	0.782	0.2131	0.2599
57	0.329	0.117	0.555	0.2462	0.3002
28	0.781	0.033	0.186	0.2473	0.3015
33	0.345	0.073	0.582	0.2756	0.3360
86	0.444	0.085	0.471	0.3082	0.3759
61	0.248	0.048	0.704	0.3214	0.3920
32	0.302	0.089	0.609	0.4583	0.5589
27	0.304	0.438	0.258	1.2162	1.4831
81	0.563	0.218	0.219	1.3291	1.6209
83	0.363	0.387	0.250	1.7145	2.0909
85	0.388	0.316	0.296	2.0652	2.5186
82	0.341	0.305	0.353	2.2405	2.7323
84	0.316	0.301	0.383	3.2120	3.9171

* BT; Brightness and Temperature

14. UN CDM project status which can use CER in K-ETS

Title	Type	Expected CER ($KtCO_2eq$)				
		2016	2017	2018	2019	2020
HFC Decomposition Project in Ulsan	HFCs	1,400	1,400	1,400	1,400	1,400
N2O Emission Reduction in Onsan, Republic of Korea	N2O	9,150	9,150	9,150	9,150	9,150
Gangwon Wind Park Project	Wind	150	150	150	150	150
Sihwa Tidal Power Plant CDM Project	Tidal	315	315	315	315	315
Youngduk Wind Park Project	Wind	60	60	60	60	60
Korea Water Resources Corporation (KOWACO) small-scale hydroelectric power plants project	Hydro	10	10	10	10	10
Switching of fuel from Low Sulphur Waxy Residue fuel oil to natural gas at Gangnam branch Korea District Heating Corporation Project	Fossil fuel switch	35	35	35	35	35
1MW Donghae PV (photovoltaic) Power Plant	Solar	1	1	1	1	1
Catalytic N2O destruction project in the tail gas of three Nitric Acid Plants at Hu-Chems Fine Chemical Corp.	N2O	1,268	1,268	1,268	1,268	1,268
Korea Water Resources Corporation (Kwater) small-scale hydroelectric power plants project II	Hydro	9	9	9	9	9
Yangyang Renewable Energy Project (3MW Wind Power + 1.4MW Small Hydroelectric Power)	Mixed renewables	9	9	9	9	9
Sudokwon Landfill Gas Electricity Generation Project (50MW)	Landfill gas	1,210	1,210	1,210	1,210	1,210
Korea South-East Power Co. (KOSEP) small scale hydroelectric power plants project (The Samchonpo Thermal Power Plant and Younghung Thermal Power plant small scale hydroelectric power plants construction project)	Hydro	21	21	21	21	21
K water Wind Power Plant Project in Bang-a muri	Wind	4	4	4	4	4
Catalytic N2O Abatement Project in the Tail Gas of the Nitric Acid Plant of the Hanwha Corporation (HWC) in Ulsan, Republic of Korea	N2O	281	281	281	281	281
Sungsan Wind Power Project	Wind	35	35	35	35	35
Hangyeong second phase SS-wind power Project	Wind	29	29	29	29	29

(Continued)

Title	Type	Expected CER ($KtCO_2eq$)				
		2016	2017	2018	2019	2020
Project for the catalytic reduction of N2O emissions with a secondary catalyst inside the ammonia reactor of the nitric acid plant at Dongbu Hannong Chemicals Ltd., Ulsan, Korea ("Dongbu").	N2O	241	241	241	241	241
Daegu Bangcheon-Ri Landfill Gas CDM Project	Landfill gas	405	405	405	405	405
Small Hydroelectric Steelworks of POSCO Co., Ltd. (Gwangyang Steelworks)	Hydro	3	3	3	3	3
New Energy and Hongik Energy and Research small-scale hydroelectric power plants project	Hydro	6	6	6	6	6
Korea Land Corporation Pyeongtaek Sosabul-district new and renewable energy model city (Photovoltaic system + solar water heating system)	Solar	5	5	5	5	5
Yeong Yang 61.5MW Wind Farm Project	Wind	113	113	113	113	113
DAEGU and SINANJEUNGDO PV (PHOTOVOLTAIC) POWER PLANT PROJECT	Solar	1	1	1	1	1
Korea East-West Power Dangjin small hydro power plant project (5MW)	Hydro	15	15	15	15	15
Korea Midland Power Co., LTD. (KOMIPO) Boryeong Small Hydroelectric Power Plant Project	Hydro	14	14	14	14	14
1 MW Hwaseong PV (photovoltaic) Power Plant	Solar	1	1	1	1	1
Samryangjin PV (photovoltaic) Power Plant	Solar	2	2	2	2	2
Taegisan Wind Power Project	Wind	60	60	60	60	60
The Korea Hydro and Nuclear Power Co. Renewable Energy Project (3MW Yonggwang Photovoltaic Power + 0.75MW Kori Wind Power, Bundling Project)	Mixed renewables	3	3	3	3	3
South West Solar Power Plant Project	Solar	1	1	1	1	1
Samdal Wind Power Project	Wind	54	54	54	54	54
LG Solar Energy Taean Photovoltaic Power Plant Project	Solar	12	12	12	12	12

(Continued)

Title	Type	Expected CER ($KtCO_2eq$)				
		2016	2017	2018	2019	2020
8.85MW SECHAN POWER PV (photovoltaic) power plant (a bundling project which consists of 7different PV power plants)	Solar	8	8	8	8	8
LG Chem Naju plant fuel switching project	Fossil fuel switch	20	20	20	20	20
K-water 0.96MW bundle small-scale hydroelectric power plants project	Hydro	3	3	3	3	3
Gimcheon PV Power Plant Site 2 CDM Project	Solar	8	8	8	8	8
Gimcheon PV Power Plant Site 1 CDM Project	Solar	8	8	8	8	8
Taean Solar Farm PV (photovoltaic) power plant project	Solar	1	1	1	1	1
3MW Shinan Wind power project	Wind	4	4	4	4	4
Mokpo Landfill Gas Recovery Project for Electricity Generation	Landfill gas	26	26	26	26	26
Gochang Solapark 14.98MW Photovoltaic Power Plant Project	Solar	14	14	14	14	14
24MW DONG YANG ENERGY PV (photovoltaic) power plant	Solar	22	22	22	22	22
Korea Hydro and Nuclear Power Co. (KHNP) Cheongpyeong Hydro Power Plant Unit 4 Project	Hydro	21	21	21	21	21
KDHC Daegu Biomass Cogeneration Project	Biomass energy	21	21	21	21	21
SK EandS fuel switching CDM bundling project	Fossil fuel switch	30	30	30	30	30
Gimhae PV (photovoltaic) Power Plant Project	Solar	1	1	1	1	1
Bundled fossil fuel switching to NG (natural gas) project in Gyeonggi-do, Republic of Korea	Fossil fuel switch	6	6	6	6	6
14MW MIRAE ASSET PV (photovoltaic) power plant bundling project	Solar	13	13	13	13	13
Point of Use Abatement Device to Reduce SF6 emissions in LCD Manufacturing Operations in the Republic of Korea (South Korea)	PFCs and SF6	1,298	1,298	1,298	1,298	1,298

(Continued)

Title	Type	Expected CER ($KtCO_2eq$)				
		2016	2017	2018	2019	2020
SF6 recovery and reclamation project, South Korea	PFCs and SF6	165	165	165	165	165
Bundled Hadong-Busan photovoltaic Power Project of The Korea Southern Power Corporation (1MW Hadong Photovoltaic Power + 0.39MW Busan Photovoltaic Power, Bundling Project)	Solar	1	1	1	1	1
8.053MW CHUNILPV (photovoltaic) power plant bundling CDM Project	Solar	8	8	8	8	8
12 MW Bundled Photovoltaic power plant in Jeollanam-Do	Solar	9	9	9	9	9
1.728 MW, Bundled Photovoltaic power plant in KOMIPO	Solar	1	1	1	1	1
Samsung Electronics SF6 abatement project	PFCs and SF6	768	768	768	768	768
4.85 MW Korea Rural Community Corporation (KRC) PV Power Plants bundling Project	Solar	4	4	4	4	4
K-water small hydroelectric power plant project (IV)	Hydro	3	3	3	3	3
Jeju special self-governing province Wind Power Project	Wind	24	24	24	24	24
KWPCO SMALL HYDROELECTRIC CDM PROJECT IN TAEAN	Hydro	4	4	4	4	4
N2O Abatement Project of Capro Corporation	N2O	661	661	661	661	661
Gwangju metropolitan city sanitary landfill LFG power plant CDM project	Landfill gas	31	31	31	31	31
KSEPA 2.6MW PV power plants bundle CDM project	Solar	2	2	2	2	2
SF6 Emission Reduction in LCD Manufacturing Operation in Tangjung, South Korea	PFCs and SF6	726	726	726	726	726
SF6 Emission Reduction in LCD Manufacturing Operation in Cheonan, South Korea	PFCs and SF6	498	498	498	498	498
Korea Land and Housing Corporation (LH Corporation)'s National Rental House PV power plant bundling	Solar	2	2	2	2	2
Gangwon+Inje+Ansan Renewable Energy Bundling Project	Wind	11	11	11	11	11

(Continued)

Title	Type	Expected CER ($KtCO_2eq$)				
		2016	2017	2018	2019	2020
SF6 emission reductions in distribution part of Korea Electric Power Corporation	PFCs and SF6	136	136	136	136	136
K-water Water Pumping System Energy Efficiency Project	EE service	7	7	7	7	7
Himaxen/Hudigm/IK bundled Photovoltaic Power Plant Project	Solar	2	2	2	2	2
K-water small hydro power plant project (V)	Hydro	3	3	3	3	3
Korea South-East Power Co. Renewable Energy Bundling Project	Solar	13	13	13	13	13
Korea South-East Power Co. Yeongheung Wind Farm Project 22MW	Wind	28	28	28	28	28
Public buildings CDM bundling project in MAC	Geothermal	5	5	5	5	5
Jeju Special Self-Governing Province's 4.1 MW bundled CDM project	Mixed renewables	4	4	4	4	4
„Reduction of N2O emissions from the new nitric acid plant #5 of Hu-Chems Fine Chemical Corp.“	N2O	339	339	339	339	339
Biogas based power generation project at Jeongeup-si	Methane avoidance	2	2	2	2	2
K-water hydropower VII	Hydro	38	38	38	38	38
K-water hydropower VIII	Hydro	39	39	39	39	39
K-water hydropower VI	Hydro	51	51	51	51	51
K-water hydropower IX	Hydro	53	53	53	53	53
5.5MW Bundled Photovoltaic power generation project in KOWEPO	Solar	5	5	5	5	5
Jinju Landfill Gas Recovery and Power Generation CDM Project	Landfill gas	37	37	37	37	37
Korea Midland Power Co. Photovoltaic power generation Bundling Project	Solar	6	6	6	6	6
Seoul PV (photovoltaic) Power Plant Project	Solar	1	1	1	1	1
Taebaek Wind Park (Hasami Samcheok) CDM Project	Wind	30	30	30	30	30
Bundled Yeonggwang (II)-Yecheon PV (Photovoltaic) Power Plant Project in KHNP	Solar	11	11	11	11	11

(Continued)

Title	Type	Expected CER ($KtCO_2eq$)				
		2016	2017	2018	2019	2020
Reforestation of Abandoned Dairy Cattle Grazing Grasslands in Korea	Reforestation	1	1	1	1	1
Gumi City Gupo Landfill Gas Electricity Generation project	Landfill gas	6	6	6	6	6
Yeongam F1 Circuit Photovoltaic Power Plant CDM project	Solar	12	12	12	12	12
Lotte World Tower CDM Project (Photovoltaic and Wind Power)	Mixed renewables	0	0	0	0	0
Lotte World Tower CDM Project (Solar Thermal Water Heater and Geothermal and Han River Water Thermal)	Mixed renewables	1	1	1	1	1
Changwon Water Supply Sewerage Control Office-Kyungnam Power bundling PV power plant project	Solar	2	2	2	2	2

Acknowledgements

This is the best opportunity I've ever had to thank so many people I feel grateful to. So, I'm afraid this is going to be a large section. It is, in any case, the most important one of this paper.

First, I want to thank Professor Euichan Jeon. He gave invaluable help in finding and correcting problems, he also advised and encouraged for this paper and life. If this paper is useful for somebody, It will be, in many aspects, thanks to him.

And I greatly appreciate Professor Wisup Bae, Professor Jungin Kim, Doctor Sungwook Lee and Doctor Sungwoo Kim for their critical review of my work and helpful comments.

If there are persons I must thank most, they are, Cheonchae Jung, Changsuk Lee, Youngjin Park, Sungheum Jo, Seungmun Kwon and Taekyung Lee. I always got throughly and friendly responses and help from them.

Next, I'm talking about people who are Jihong Kim and Jaehyung Lee. They altruistically provided part of their time and/or resources to help me. And I would like to extend a heart-felt thanks to Bongyoung Lee, Hyeonjung Kim, Jihun Kim, Wanjae Lee, Heeju Kim, Dongwook Yang and Hyungman Park. I feel particularly lucky with seniors and friends like them.

Finally, I would like to express my gratitude and special thanks to my parents, parents-in-law and family too. They always tried to make the best opportunities available for me. And I would like to express the most thanks to my wife, my daughter and son.

Many thanks for all. I'm sure to forget someone here. Sorry. I'm certain they know I'm grateful to them too, so if they tell me, everybody will know it.