PRIVATE, GOVERNMENT AND SOCIAL COST OF SMALL-SCALE SOLAR FEED-IN-TARIFF AS AN ALTERNATIVE TO STAND- ALONE RENEWABLE PORTFOLIO STANDARD -USING LINEAR PROGRAMMING

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Abstract- South Korea adopted Feed-in-tariff (FIT) policy in 2002 but discontinued it by the end of 2011 on the grounds of excessive government budget spending. It switched to Renewable Portfolio Standard (RPS) in 2012. However that change has been devastating to small energy developers who could not participate in auction market due to high development and transaction cost. As a result, the Green Party, Korean Solar Energy Association and Korean media argued for introduction of FIT, at least for the small-scale solar developers. This paper analyzes the optimal renewable energy portfolio composition in South Korea each year from 2016 to 2024 (the period of mandatory renewable energy supply) and policy costs both under stand-alone RPS policy and the proposed RPS system with the small-scale solar (under 100 kw) FIT using two market structure scenarios.

Index Terms- RPS, Solar Energy, FIT, Linear Programming, Policy Cost.

I. INTRODUCTION

South Korea has implemented various renewable energy schemes for over a decade. Since 2002 enactment of “the guideline on SMP price for alternative energy’s use” until 2011 Korean government has supported FIT as the main renewable energy facilitating policy. However, government officials and academic papers have reported unbearable financial burdens of FIT support scheme, the projected cumulative spending of which will add up to around ₩300 billion(₩1100=$1) (Kim, 2008). That led the Korean government to adopt RPS policy instead in 2012. Since then, Korean RPS market has issued 4types of Renewable Energy Certificates (RECs) operated in the following submarkets: auction market, where price is freely determined by market forces; contract market, where renewable energy obligator enters into a 12-year contract with renewable energy developer to obtain RECs at a predetermined price; government RECs market, whose price is entirely left up to the government discretion; and self-production RECs where the renewable energy obligator satisfies by producing renewable energy at its owned premises. Since it is virtually impossible to predict the price of government-owned RECs and the focus of this paper is on the RECs decided in the market, this paper will assume that yearly government RECs are satisfied at the price declared by Ministry of Trade, Industry and Energy (MOTIE) in 2014.

Despite the elaborate structure, RPS has also proved to be full of considerable drawbacks. First, MOTIE reported the rising collected penalty from the 13 designated renewable energy obligator companies (renewable obligators), increasing from around ₩254 billion in 2012 to ₩498 billion in 2013. Second, renewable obligators avoid contracts with small-scale energy producers in favor of large-scale energy developers. Third, RPS makes it hard to have a transition from highly concentrated hard energy system to decentralized soft energy system undermining South Korea’s energy security (Shin, 2011). Naturally, this paper aims to solve these problems by suggesting cost-effective solution to fulfill South Korea’s 10% renewable energy commitment by 2024. (Korea Energy Agency, Renewable Energy Center)[1]

The structure of this paper is as follows. Section II presents the literature review on comparative economic studies of RPS and FIT in Korea. Next, section III introduces the model and data source. Section IV interprets the optimization outcome from GAMS linear programming under two predicted market structure scenarios (without restriction and 2014 market structure restriction) by comparing stand-alone RPS social costs with those of the proposed mixed FIT structure. Whereas the government argues that FIT and RPS are just different means to the same outcome, section V of this paper will elucidate the essential differences in cost-bearing under South Korea’s law and will provide cost-effective solution to cover FIT spending. Finally, section VI will summarize our findings and suggest related issues to be analyzed in future papers.
This research is the first quantitative evaluation of small-scale solar support scheme as an adjustment to the current RPS policy. It sets out elaborate scenarios

[1] KEA (2010).“RPS Policy” Retrieved from http://www.knrec.or.kr/knrec/12/KNREC120700_02.asp on August 1st, 2015.

that are most close to the reality to maximize policy application. This paper is also the first to incorporate "compensation for RPS commitment expense" in the analysis and point out 'holes' in renewable Korea's energy support scheme.

II. LITERATURE REVIEW

The comparative quantitative study of RPS and FIT in South Korea is limited, partially due to a short history of RPS in the country. However, there have been some meaningful academic contributions.

Lee (2011) presented a comparative study of RPS and FIT abroad, arguing that South Korean renewable energy market needs expansion of FIT or at least a separate quota for solar renewable energy. South Korea has, in fact, required renewable obligators to satisfy the separate solar energy quota until the end of 2015. However, this quota will be abolished from 2016, effectively signifying the integration of RPS market (Choi, 2014). Kim et al. (2012) suggested FIT support scheme for small-scale solar developers on the grounds of volatility of auction REC price and hence the high interest loan rate on borrowings for small-scale solar developers. Their paper concluded that renewable energy developers' cost-benefit ratio will be improved with the introduction of small-scale solar FIT.

Lee (2010) used GAMS linear programming to analyze the optimal RPS portfolio by 2022, before solar market integration was announced. The use of projected data by credible research institutions, incorporation of energy sales benefit from self-produced REC in calculations and comparison of social cost in case of small-scale solar FIT as well as incorporation of "state compensation for commitment expense" is the additional contribution of our paper.

III. THE MODEL

This paper analyzes the private, government and social costs required to achieve yearly renewable energy targets through stand-alone RPS and RPS with small-scale solar FIT. It uses optimization software GAMS suitable for analyzing problems in engineering and social sciences, among others. This paper found linear optimization suitable since the objective function and all constraints are in linear form.

i) Problem Statement

i-i) Objective Function

$$\text{Min } C = \sum_{i=1}^{13} P_{i1} * Qs_{i1} - \sum_{i=1}^{13} SMP * Qs_{i1} + \sum_{i=1}^{13} Pc * Qc_{i2} + \sum_{i=1}^{13} Pa * Qa_{i3}$$

where

i: renewable source (organized in <Table 2>)

1: self production, 2: contract market, 3: auction market

C: total cost of energy obligators

Ps: cost of generation of electric power

Qs: self produced amount

SMP: Systems Marginal Price

Pc: contract market REC price

Qc: contract market purchased amount

Pa: auction market REC price

Qa: auction market purchased amount

In essence, energy obligators will have to minimize their costs to comply with the yearly renewable requirement (organized in <table 2>). We subtract the benefits that can be earned by the sales of renewable energy due to self production.

<Table 1> Yearly Renewable Energy Target

Year	Renewable Energy Target (%)	Calculated Renewable Target (kWh)
2016	3.5	17593397000
2017	4	20997504000
2018	4.5	24634989000
2019	5	28355125000
2020	6	34842171000
2021	7	41471304000
2022	8	48207852000
2023	9	55031558000
2024	10	61958610000

Source: calculated based on KEA (2010) & MOTIE's "7th basic plan for long-term electricity supply and demand"

In accordance with the "New and Renewable Energy Development, Use and Dissemination Promotion Decree" article 73, statute 18, when a company receives FIT, it has the obligation to submit REC equivalent to the subsidized renewable energy to the government. This becomes government-owned REC. Although FIT was abolished in 2012, facilities that have signed FIT contract with the government still continue to receive FIT support. This paper accounted for such facilities to make the model as realistic as possible. Government REC is sold at a low price to help the renewable energy obligators satisfy their quota. The precise government REC price is state secret; however Energy Times revealed that the price is approximately 1/3 of the market price.[2] This paper will analyze the interactions of self-produced, auction and contract markets, while setting government REC price to be ₩40/kwh, the price calculated from MOTIE (2014) plan for government RECs (which set out the plan to release 1.61 million REC yearly at the price of ₩40 thousand/REC). The cost function was adjusted to account for this expense on the part of renewable obligators.

[2] Kim (2014.10.21) "Government REC to Sell at 32% of the Market Price". Energy Times. Retrieved from http://www.energytimes.kr/news/articleView.html?idxno=27534 on August 4th 2015.

i-ii) Constraints

1) $X022 \leq$ Yearly Target Supply of the Given Renewable
2) $X031 \leq$ Yearly Target Supply of the Given Renewable
3) $X041 + X042 + X043 \leq$ Yearly Target Supply of the Given Renewable
4) $X051 \leq$ Yearly Target Supply of the Given Renewable
5) $X062 + X063 \leq$ Yearly Target Supply of the Given Renewable
6) $X072 + X073 \leq$ Yearly Target Supply of the Given Renewable
7) $X082 + X083 \leq$ Yearly Target Supply of the Given Renewable
8) $X091 \leq$ Yearly Target Supply of the Given Renewable
9) $X102 + X103 \leq$ Yearly Target Supply of the Given Renewable
10) $X131 \leq$ Yearly Target Supply of the Given Renewable
11) $X121 \leq$ Yearly Target Supply of the Given Renewable
12) $X131 + X132 + X133 \leq$ Yearly Target Supply of the Given Renewable
13) $8760 \sum_{i=1}^{k} X_{i1} * U_i \geq$ Cumulative Self – Produced Renewable Energy by the Given Year
14) $8760 \sum_{i=1}^{k} X_{i2} * U_i \geq$ Cumulative Contract Market Produced Renewable Energy by the Given Year
15) $8760 \sum_{i=1}^{k} X_{i1} * U_i \geq$ Cumulative Auction Market Renewable Energy by the Given Year
16) Positive Variables:

X013, X022, X031, X041, X042, X043, X051, X062, X063, X072, X073, X082, X083, X091, X102, X103, X111, X121, X131, X132, X133

Where
i: renewable source (organized in <Table 2>)
1: self production, 2: 12 –year contract market, 3: auction market
8760: total number of hours in a year
U_i: use rate (organized in <table 2>)

Rather than using the natural reserves constraints, we used official target supply data published in the most recent "7th base power supply plan" by Ministry of Trade, Industry and Energy (MOTIE) since the purpose of this analysis is to find the most economical and socially acceptable way to achieve the government plan for the supply of renewable energy. This rationale is also directly linked to the assumption that in case the production of certain renewable energy goes beyond governmentally acceptable level, the government will not give permission for this kind of energy production.

We used constraints 12)~16) to assert that the amount of production units that were installed in previous years do not disappear in the next year. Also production cannot be negative.

ii) Variables & Constraints

<Table 2> Analyzed Energy Sources and Markets

Name of source	Source Code	Capacity factor (%)	REC Weight	Self Production Code	Contract Market Code	Auction Market Code
small-scale solar	X01	15	1	X011	X012	X013
middle-scale solar	X02	15	1	X021	X022	X023
large-scale solar	X03	15	1	X031	X032	X033
Wind	X04	20	1	X041	X042	X043
IGCC	X05	85	0.25	X051	X052	X053
RDF waste	X06	87	1	X061	X062	X063
landfill gas	X07	57	0.5	X071	X072	X073
small-scale hydro	X08	36	1	X081	X082	X083
large-scale hydro	X09	25	1	X091	X092	X093
non-woody biomass	X10	57	1	X101	X102	X103
Tidal	X11	2`	1	X111	X112	X113
woody biomass	X12	37	1.5	X121	X122	X123
fuel cell	X13	85	2	X131	X132	X133

Source: Partially used from Lee (2010)

The red color is used to designate renewable sources that cannot participate in the relevant market. We valued marked in red are placed in zero. The inability of certain renewable energy sources to participate in certain markets lies in government-set constraint, economic incentives and technological requirements of certain energy sources. Specifically, solar energy constraint was set by analyzing Solar Energy Developers Association (2015) and Lee (2014). IGCC and tidal energy is prohibited for sale in contract and auction market. [3] Woody biomass requires coal thermoelectric plant, making it impossible to produce through means other than self-production.

iii) Price Projection

<Table 3> Cost Per Energy Source [456](unit:₩/kwh)

#	Name of source	LCOE
①	IGCC	64.7
②	RDF waste	103.2
③	landfill gas	62.61
④	small-scale hydro	81.22
⑤	large-scale hydro	51.46
⑥	non-woody biomass	92.58

Source ①~⑥: Lee et al. (2014), Lee et al. (2012)

3KEA (2010)."The law concerning the issue and trade of RECs" Retrieved from http://www.knrec.or.kr/knrec/14/KNREC140110.asp?idx=480&page=2&num=56&Search2=&Search=&SearchString= on August 1st, 2015.

[4]Tidal source :Kim (2007.06.25) . "West Sea, South Korean Renewable Energy Rising". Korean Economy. Retrieved from http://www.hankyung.com/news/app/newsview.php?aid=2007062437841 on July 30th , 2015

[5] Biomass source :Kang (2015.03.03). "Woody Pellet Market Trend and Supply Status" . Today Energy. Retrieved from http://www.todayenergy.kr/news/articleView.html?idxno=101186 on July 30th , 2015

[6] Fuel cell source :Park (2013.09.18). "[Special Issue] Fuel Cell, Balancing RPS for Profit". Energy& Environment News. Retrieved from http://www.e2news.com/news/articleView.html?idxno=72174 on July 30th , 2015

The sources in table 3 represent technologies in a mature stage, whose costs are assumed to be rather stable in the future.

Levelized Cost of Energy (LCOE), which includes fixed and variable costs, is calculated in the following manner: $\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Lifetime Energy Production}}$

Source: KEEI (2013)

<Table 4> Solar generation cost (LCOE)[7](unit:₩/kwh)

year	large-scale solar generation cost	middle-scale solar generation cost	wind[11] generation cost
2016	178.493	206.239	216.181
2017	170.864	197.453	216.181
2018	163.234	188.667	216.181
2019	155.604	179.881	216.181
2020	147.974	171.095	216.181
2021	143.581	166.239	212.944
2022	139.188	161.384	209.707
2023	134.795	156.529	206.47
2024	130.402	151.673	203.233

Source: Lee et al. (2014)[8]

Due to unavailability of electricity generation cost for middle-scale solar developers, we used same solar projected generation cost for middle-scale and large-scale solar developers. Both solar and wind take a substantial amount of renewable energy development, so their costs reported in dollars have been adjusted for the average daily exchange rate in 2013 (₩1156.05=$1) for the precision. SMP was used from Korea Power Exchange (2011) projections.

<Table 5> REC Price Projection (unit:₩/kwh)

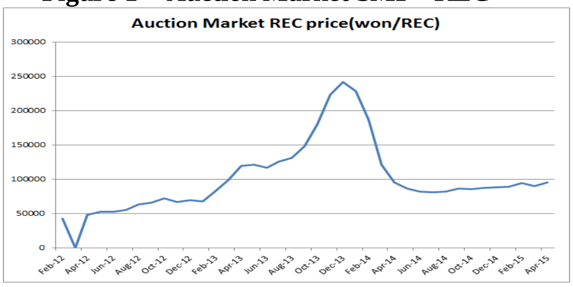
year	Auction REC price	Contract REC price
2016	105.3	70.3
2017	110.2	75.2
2018	112.5	77.5
2019	115.3	80.3
2020	118.7	83.7
2021	126.5	91.5
2022	131.3	96.3
2023	134.4	99.4
2024	138.2	103.2

Source: Korea Power Exchange (2012)

Since it has just the 4th year that South Korea has adopted RPS system, predicting auction REC price econometrically is not advisable. As a result, we had to look into the actual change of price and extrapolate the trend during the period when market was stable, i.e. when government eliminated the incentive to purchase cheap government certificates proportional to the amount of purchased auction market certificates. As can be observed from picture 1, the price of auction market REC + SMP price has been very volatile until in 2014 the government abolished preferential treatment of RECs bought in auction market. Therefore, this paper assumed that the market will sustain the same stability further on. Adjusted for SMP price in 2014, auction market REC was ₩258.4/kwh. Assuming the same profit margin as in 2014, we predicted the future REC price at 258.4(₩/kwh) + SMP price. The outcome can be found in <table5>

Similarly, while the contract REC price is not as readily available as auction market REC, we could find 2014 contract SMP+REC data on Korea Power Exchange database. The same profit margin assumption was used for contract market and the average contract market price was 223.4 (₩/kwh). The projected outcome is organized in the right-hand column of <table 5>

<Figure 1 > Auction Market SMP+ REC



Source: Korea Power Exchange (2012)

IV. SCENARIO AND OUTPUT INTERPRETATION

i) Scenario

Scenario 1: Stand-alone RPS portfolio optimization without the market structure restriction.

Scenario 2: Stand-alone RPS portfolio optimization with the assumption market follows 2014 structure.

Scenario 3: Portfolio optimization with small-scale solar FIT & RPS for the remaining sources without the market structure restriction.

Scenario 4: Portfolio optimization with small-scale solar FIT & RPS for the remaining sources with the assumption market follows 2014 structure.

Assumptions:

(1) Scenario1, scenario2 represent time period from 2016 to 2024, since RPS requires state compensation for commitment expense every year.(2) Scenario3, Scenario 4 represent period from 2016 to 2022, since small-scale solar will be smaller than SMP from year 2022 and does not require FIT.(3) 2014 market structure was 70% self- produced REC, 25%

[7] We used simple average of off-shore and on-shore wind generation cost to get wind generation cost.

[8] Some of the year's data was missing, so we used linear interpolation add-in tool for excel to complete the data set. Retrieved from http://www.digdb.com/download/ on August1, 2015.

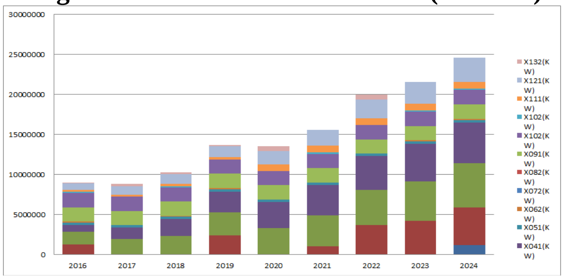
contract market REC and 5% auction market REC.

ii) Output

(ii-i) Comparing Scenario 1 and 3

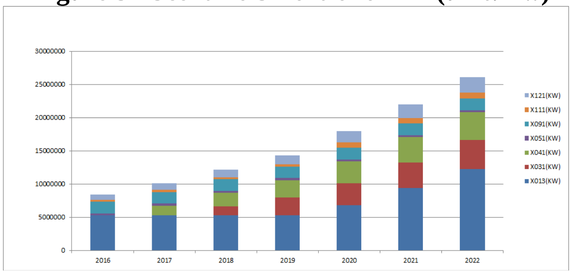
The portfolio mix showed significant difference under scenario 1 and scenario 3 assumptions.

<Figure 2>Scenario 1 Portfolio Mix (unit: kw)



Under scenario 1, without market structure assumptions and FIT support, large-scale solar, wind and large-scale hydro dominate the portfolio mix, all of which are self-produced. Yet, from 2021, the increased renewable energy requirement resulted in increased supply of contract market- produced sources, especially cheap small-scale hydro-power. On the other hand, Small-scale solar market does not start to operate until 2024 when only 5% of the renewable energy is produced from this source. Therefore, under this scenario small-scale solar industry could effectively die without the FIT support policy.

<Figure 3> Scenario 3 Portfolio Mix (unit: kw)



Under scenario 3, on the other hand, we can observe the dominance of small-scale solar, which varied from 37% to 62% of the renewable energy throughout the projected years. These two sources are followed by large-scale solar and wind, since their competitive advantage other renewable energy sources remains.

<Table 6> Scenario 1 and Scenario 3 Cost (unit: ₩trillion)

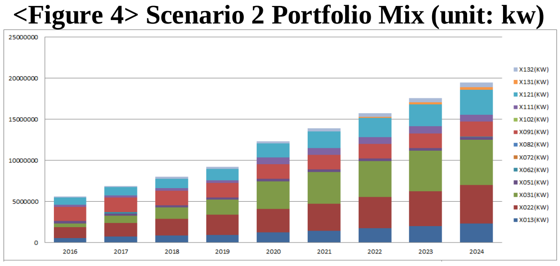
	2016	2017	2018	2019	2020	2021	2022
RPS	0.393	0.488	0.563	0.628	0.78	1.143	1.49
RPS + FIT	0.494	0.514	0.539	0.518	0.493	0.55	0.53
Budget savings	-0.101	-0.026	0.024	0.11	0.287	0.594	0.96

The difference among the budget spending in case of the two policies is organized in <table 6>. Except for the first two years, government budget spent on renewable energy promotion is larger for stand-alone RPS case. In case the government implements RPS policy along with the support for the small-scale FIT, it will save the budget organized in the last row, which mounts to almost ₩1 trillion ($1 billion) one year before small-scale solar grid parity in 2023 .Yet, this outcome should be interpreted with case since the huge savings are based on the rapid expansion of small-scale solar producers and does not account for the historical market structure.

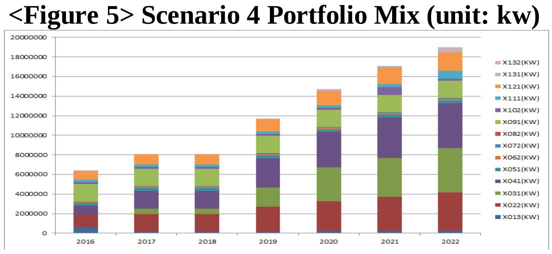
(ii-ii) Comparing Scenario 2 and 4

Scenario 2 and 4 suggested the proportion of self-production to auction market to contract market will stay the same as in 2014. Since it was assumed that small-scale solar cannot participate in self-production market in the first place, its cap was automatically reduced to 30%, of which rather cheap middle-scale solar occupies over 20% (figure 5).

<Figure 4> Scenario 2 Portfolio Mix (unit: kw)



<Figure 5> Scenario 4 Portfolio Mix (unit: kw)



Scenario 2 included 8~9% of small-scale renewable energy. The result above should also be interpreted with care since optimization program does not differentiate the sources with the same price. Since REC within auction market and contract market respectively are assumed to be same, GAMs chooses to optimize from the first source in the code.

<Table 7> Scenario 2 and Scenario 4 Cost (unit:₩ trillion)

	2016	2017	2018	2019	2020	2021	2022
RPS	0.457	0.588	0.686	0.766	0.925	1.236	1.616
RPS+ FIT	0.454	0.533	0.622	0.693	0.831	1.227	1.53
Budget savings	0.003	0.055	0.064	0.072	0.095	0.009	0.086

With the introduction of solar FIT, every year government can save budget while attaining the same renewable energy goal (table 7). The savings start from ₩3.0 billion in 2016 and increase to 86 billion in 2024.

V. SOLUTION TO FIT SPENDING

We considered “state compensation for commitment expense” to be government’s expense on RPS.

According to "New and Renewable Energy Development and Utilization and Dissemination Promotion Decree 11", Article 18, government has the duty to compensate commitment expense, i.e. the money that renewable obligators spend on satisfying their quota requirements. However, according to mandatory renewable energy supply system for management and operating instructions Article 11 Section 2, RECs obtained from large scale hydroelectric, tidal, or IGCC are excluded from compensation payment. In addition, according to an expert opinion,[9] biomass co-firing power generation will be excluded from compensation payments too. Therefore on our model, we excluded cost and benefits of IGCC, large scale hydro, biomass co-firing, tidal from total cost to get governmental expense. The budget that government has to spend on the renewable obligators is expressed as formula below.

$$B = \sum_{i=1}^{13} P_{i1} * Qt_{i1} - \sum_{i=1}^{13} SMP * Qt_{i1} + \sum_{i=1}^{13} Pc * Qc_{i2} + \sum_{i=1}^{13} Pa * Qa_{i3}$$

Ps: cost of generation of electric power
Qt: self-produced amount from covered power plant
SMP: Systems Marginal Price
Pc: contract market REC price
Qc: contract market purchased amount
Pa: auction market REC price
Qa: auction market purchased amount

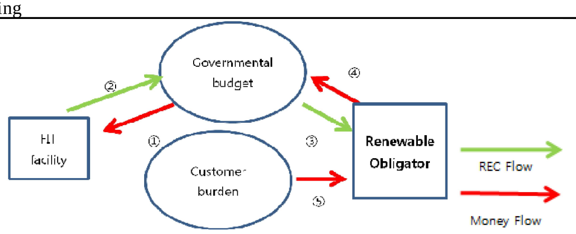
Eventually a state compensation for commitment expense slightly rises wholesale electricity price. For example table below shows wholesale power price and additional settlement price for renewable obligators with the same period January-July 2014

<Table 8> Wholesale Electricity Payment (unit: ₩million)

	january	february	march	april	may	june	july	total
RPS payment	13577	8834	19265	8535	667	314766	18502	384149
Whole sale payment	4211261	3744138	4160292	3415640	3326519	3489647	3945370	26292869
Ratio	0.32%	0.23%	0.46%	0.25%	0.02%	9.02%	0.47%	1.46%

Source: KPX (2015)

January-July 2014 electricity wholesale prices rose by about 1.46% on average. According to Korea Power Exchange, rise in the wholesale power price leads to the rise in the retail price of electricity. The final burden of the RPS are passed to the consumers. In this case, operating budget becomes very much depending on market conditions and demand for electricity. On the other hand, FIT system is operating under separate government budget. Budget source of FIT system is electric power industry-based fund, which must submit an annual budget and operating plan to the National Assembly.



FIT cost recovery through the sale of the government-owned REC can be a solution for these problems if the government sells the government-owned RECs to renewable obligator to secure the budget for FIT operating system. The flow chart of the budget recovery scheme is presented above. Selling government-owned REC will increase state compensation for commitment expense but budget for it is a lot more flexible. Based on the current state of government-owned REC operation I will evaluate the reality of this scenario. Considering that information about price or volume of government-owned REC is to operate in secret by Industry and Energy Notice No. 2015-155 Article 17 paragraph 4, government-owned REC is assumed to be sold at ₩40/kwh (the price suggested by MOTIE).

In scenario 3 (unrestricted market structure, RPS+FIT) produced results with extremely large amount of RECs which makes it hard for government to cover its expenses under the proposed model

<Table 9> Suggested Scheme under Scenario 3

	2016	2017	2018	2019	2020	2021	2022
# of REC	6930 824	6930 824	6930 824	6930 824	8930 824	1238 1165	1606 7198
Required REC Price (₩/kwh)	61.9	60.1 4	57.0 3	52.8 5	45.5 5	40.0 8	35.2 5

However, if the market will sustain the structure similar to 2014, then the proposed model has a promising outcome to cover the government expenses. In this case the government can obtain the following amount of REC and if it sets the price organized in the last table, it will be able to break even.

<Table 10> Suggested Scheme under Scenario 4

	2016	2017	2018	2019	2020	2021	2022
# of REC	7989 25	9691 27	1139 330	1325 340	1629 688	1981 144	2317 975
Required REC Price (₩/kwh)	61.9	60.1 4	57.0 3	52.8 5	45.5 5	40.0 8	35.2 5

Considering the growing demand for REC in the market, the upper-proposed price is not entirely impossible and is still much lower than the projected auction REC or contract REC prices.

CONCLUSION

This paper provided the quantitative analysis of stand-alone RPS and a mixed FIT policy. Contrary to the popular belief, the social cost of stand-alone RPS

[9] Lee (2014)."New and Renewable Energy RECs' Weight Improvement Study". KERI, policy announcement

was found to be actually higher than that of the mixed structure. This is due to the state compensation for commitment expense, the specific characteristic of South Korean RPS structure aimed to provide incentives to renewable obligators. High stand-alone RPS cost is directly transferred to citizens with higher energy costs. We also pointed out that small-scale solar would be pushed out of business completely under certain scenarios. Finally, we explained how government can recover the policy cost spend as a feed-in-tariff. If the RECs market remains the same as under 2014 case, government could use the RECs that it obtained from FIT and sell it in the market for the suggested price. That way it could save the small-scale solar developers, contribute to the energy dispersion and thereby improve energy security of the country.

More transparent data about government REC would improve the simulation credibility and application of the paper's results.

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