[42nd IAEE Annual Conference]

Multi-Criteria Decision Analysis of Electricity Sector Transition in Korea

2019.5.31

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Contents

1. INTRODUCTION

01 Introduction

Policy background (1)

Economic

• Energy planning and dispatch based on economic priority
→ Highly dependent on coal and nuclear power sources

Environmental

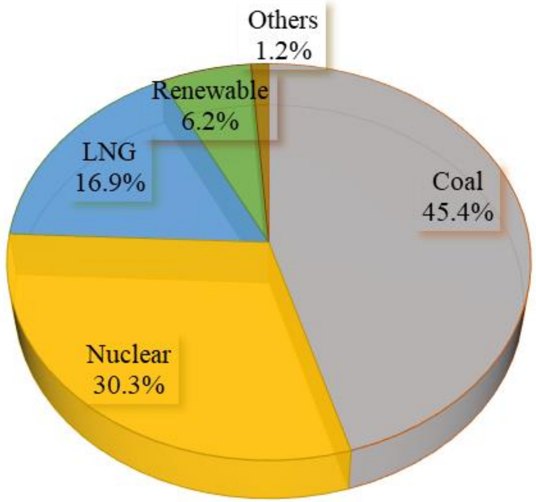
• Stringent emission reduction* to achieve NDC
• Bad air quality due to fine dust
→ Necessity to reduce carbon-intensive coal power generation

Social

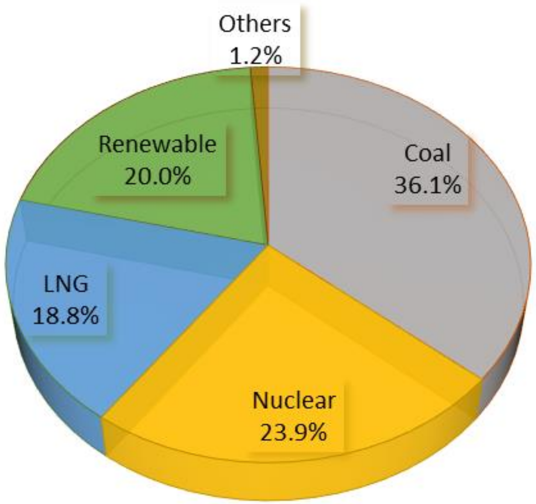
• Fukushima nuclear accident (2011)
• Record-breaking earthquake (2017) near nuclear power plant
→ Low public acceptance of nuclear power plants

* Electricity sector GHG emissions should be reduced from 333Mt (BAU) to 192.7Mt in 2030, which is equivalent to 40.2%

- 8th Basic Plan for Long-term Electricity Supply & Demand (MOTIE*, 2017)
  - Transition toward clean and safe energy system
  - Power generation from coal and nuclear will reduced from 75.7% to 60%
  - Expansion of renewables up to 20% in total generation



Generation Mix as of 2017



Generation Mix in 2030 (Expected)

* Ministry of Trade Industry and Energy

01 Introduction
Policy background (3)

- Major Issues
  - Substantial increase in cost of electricity generation
  - Preferences between moderate and rapid transformation
  - Feasibility of renewable expansion due to limited national territory

- Research objectives
  - Create an MCDM tool that can aid energy policy decision making
  - Assess sustainability of various electricity sector policy and scenarios
  - Identify tradeoffs among sustainability aspects in the electricity sector

2. LITERATURE REVIEW

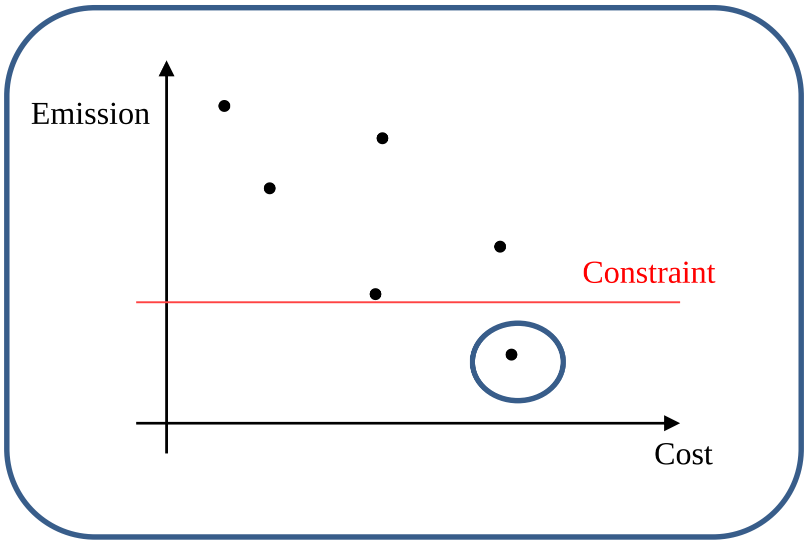
02 Literature Review
MCDM

- MCDM (multi-criteria decision-making)
  - Evaluates multiple conflicting criteria in decision making
  - In energy planning: economic, environmental, and security of supply with increasing inclusion of social aspects (Ribeiro et al. 2013)

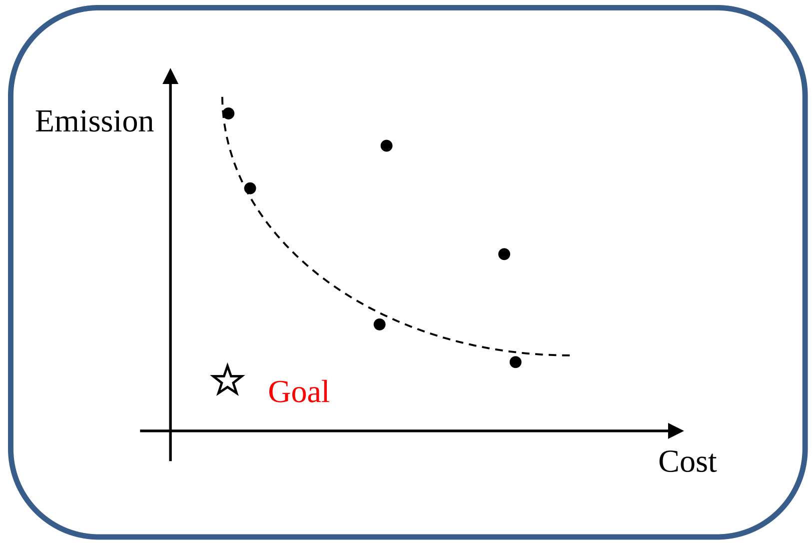
- MCDM in energy sector
  - Sustainability assessment of power generation technologies (Atilgan & Azapagic, 2016)
    ex) Comparing conventional & renewable power generation technologies
  - Sustainability assessment of energy portfolio or energy policy
    ex) Comparing government plan & various scenarios (Santoyo-Castelazo & Azapagic, 2014)

- Energy model – MCDM model linkage
  - Cost minimization with constraints (Streimikiene et al., 2013; Volkart et al. 2017)
  - Cost and other factors in objective functions (Lehtveer et al., 2015; Shmelev et al. 2016)

- Multi-objective optimization
  - Supports DM finding the most preferred Pareto optimal solution and tradeoff
  - Goal programming minimize deviations from goals → Various options take into account



Cost-minimization under emission constraint



Goal Programming (With Cost & Emission)

02 Literature Review

Energy Sector MCDM in Korea

Korea's electricity sector MCDM

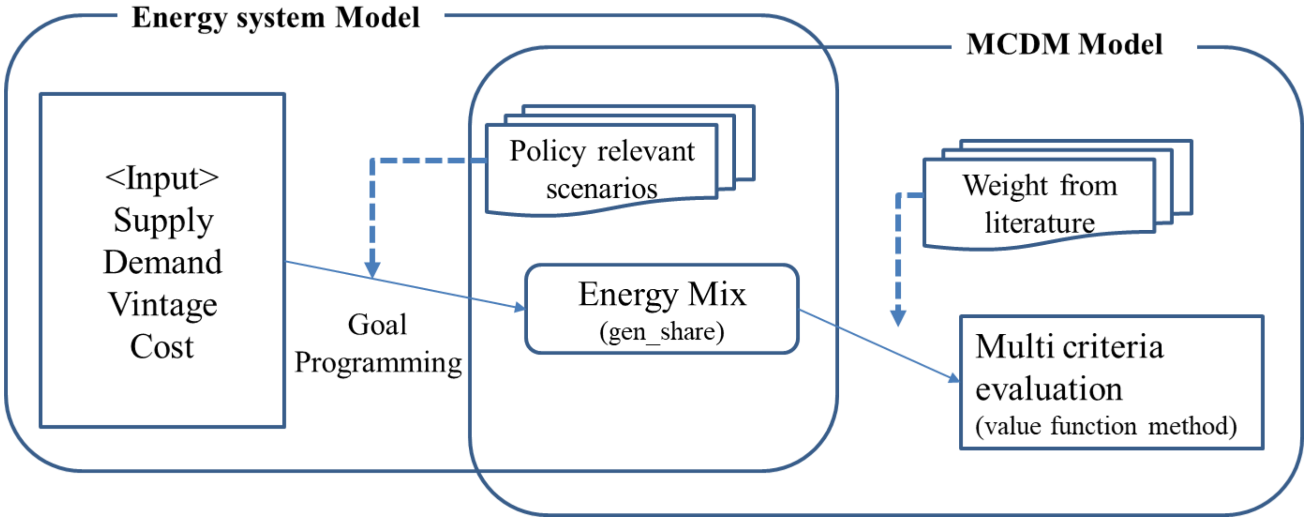
Study	Methodology	Criteria & Weight	Result
Lee & Ahn (2012)	AHP - WASP	- Economic(2), Environmental(3), Social(3) - Weight derived from various stakeholders (215)	
Hong et al. (2014)	Outranking	- Environmental (6), Economic (1), Social (1), Technical (4) - Equal weighting	Nuclear > Coal > Solar = gas > wind
Kim (2017)	Fuzzy – TOPSIS	- Economic(2), Environmental(2), Social(2), Technical(2) - Focus group interview with 7 experts	Solar > Wind > LNG > Nuclear > Coal

- Evaluation of each generation technology & Conflicting outcomes
- In this study,
  - Energy model with multi-objective optimization (Goal Programming)
  - Assess the sustainability of energy portfolio

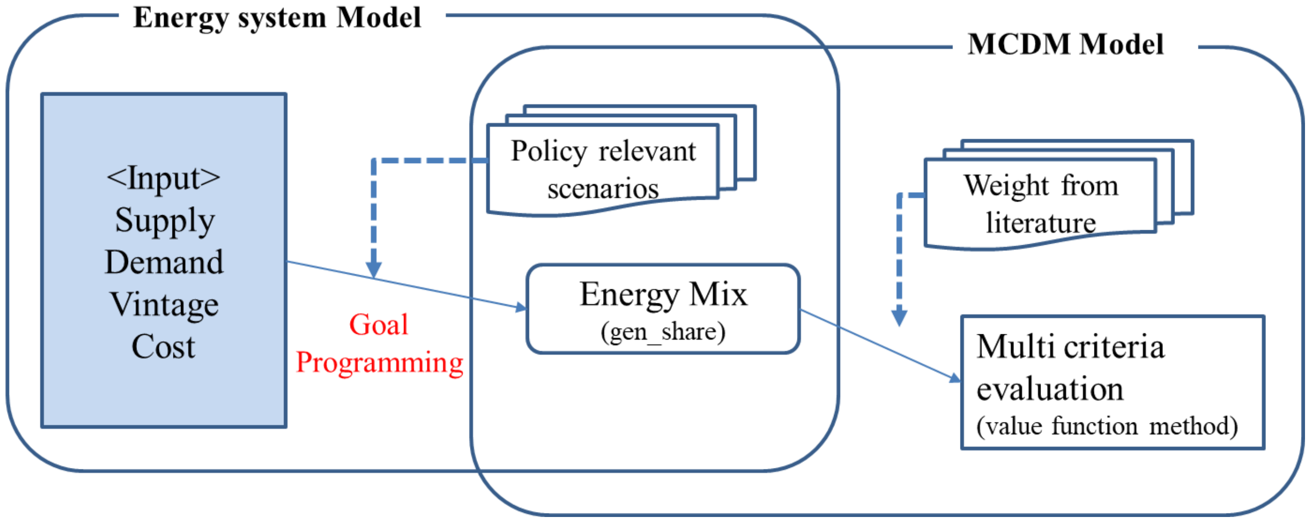
3. METHODOLOGY

03 Methodology

Research Framework

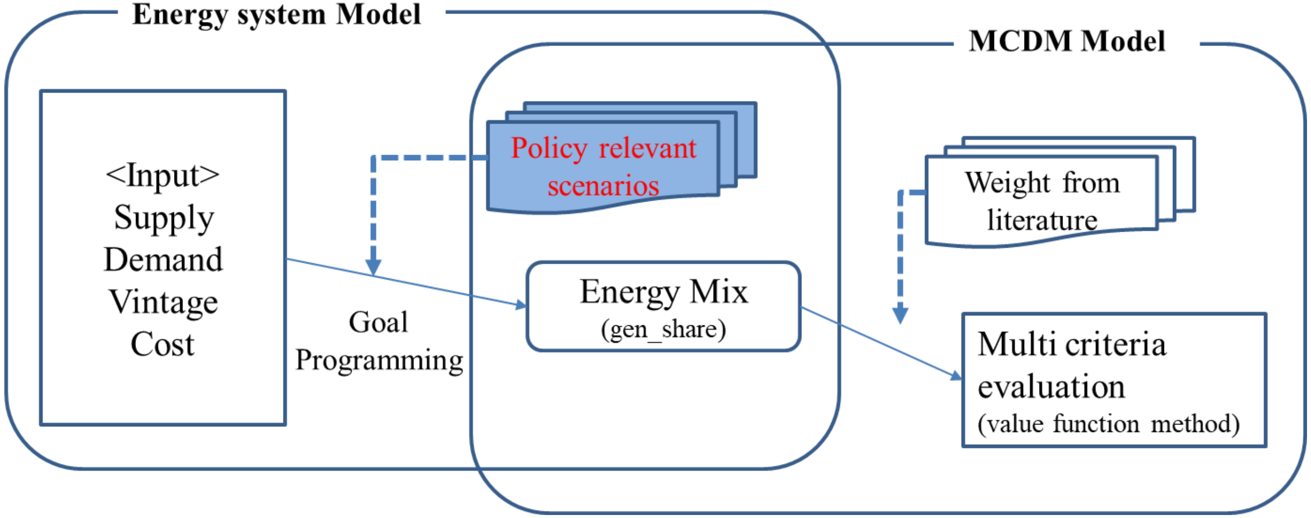


03 Methodology
Energy Model



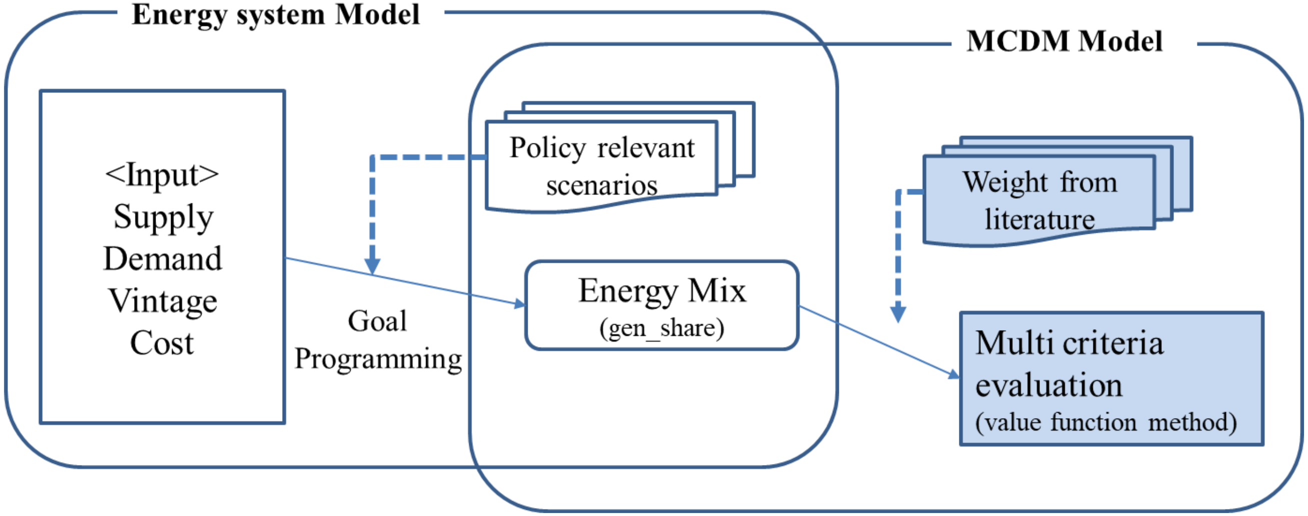
- Goal Programming formulation using percentage deviations (Jones & Mehrdad, 2010)
  - Total deviation = Economic deviation (%) + Emission deviation (%)
  - Economic goal: Total cost of electricity supply under cost minimization in 7th BPLE
  - Emission goal: Electricity sector target emission in 2030 (Ministry of Environment, 2018)
- Model assumptions
  - Electricity demand: Fixed to the 8th BPLE projection
  - Electricity supply: Adopt technology learning for renewable sources

03 Methodology
Scenarios



	Scenario	Explanation
BAU	*7th BPLE*	- Cost minimizing dispatch under 7th BPLE
Government Policy	*8th BPLE – a*	- 8th BPLE by MOTIE (2017)
	8th BPLE – b	- Revised GHG reduction roadmap by Ministry of the Environment (2018)
Coordinated Policy	*Low Coal*	- No new coal after 2022 (7th BPLE + 8th BPLE coal)
	Low Nuclear	- No new nuclear after 2023 (7th BPLE + 8th BPLE nuclear)
Extreme Policy	*No Coal*	- All existing coal phase out by 2030
	No Nuclear	- All existing nuclear phase out by 2030

03 Methodology
MCDM model



Attributes	Weight	Data source	Coal	LNG	Nuclear	Wind	Solar
Efficiency (%)	0.1365	Stein (2013)	39	33	32	35	20
Safety ($/MWh)	0.1753	Hong et al. (2014)	40.4	17.94**	6.94	0.44	0.06
Investment Cost (₩/kWh)	0.1525	Park et al. (2016) Min et al. (2018)	1449	592.9	2378	1272.7	1540
Variable Cost (₩/kWh)	0.1465		37.15	87.58	4.57	0	0
Emission (₩/kWh)	0.1565	Cho & Park (2015)	32.1	14.9	0	0	0
Land Use (m^2/kW)	0.0863	NABO* (2017)	815	192	745	1372.5	15000
Social Acceptance (%)	0.1465	Woo et al. (2017)	4.61	8.27	8.22	36.66	38.95

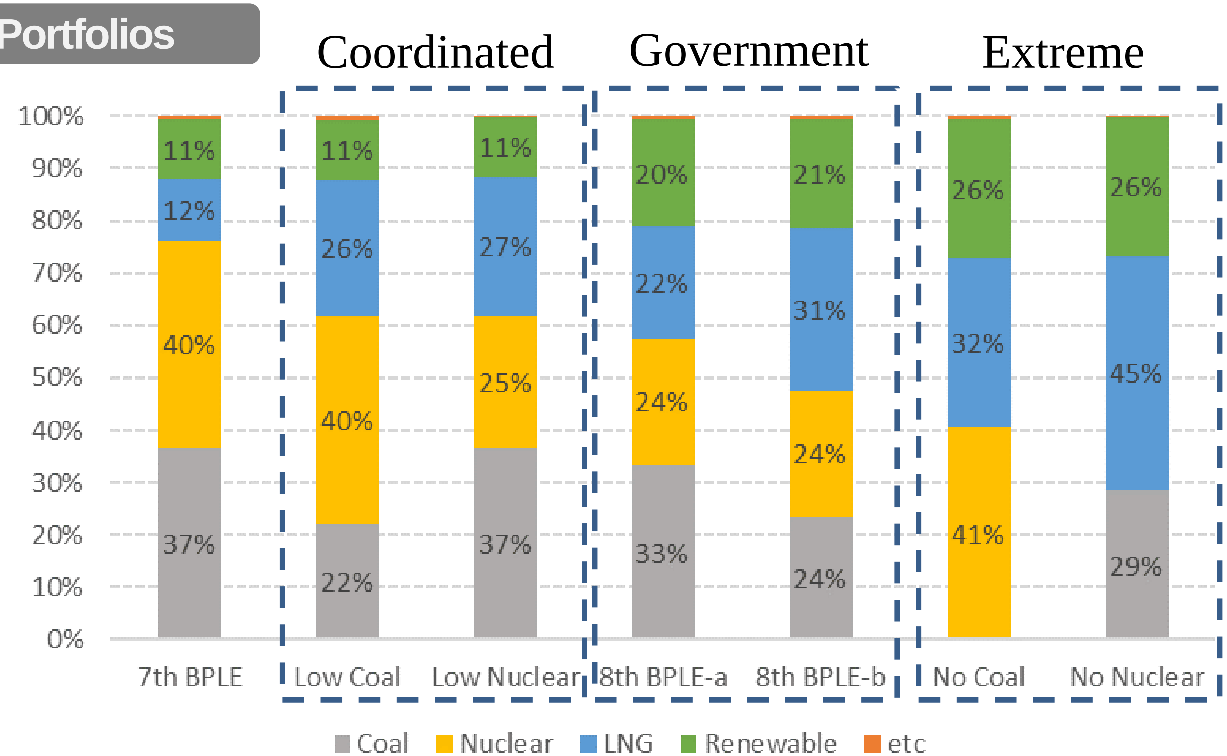
* National Assembly Budget Office

** The safety cost of LNG as estimated by the authors

4. ANALYSIS

04 Analysis
Results (1)

Generation Portfolios

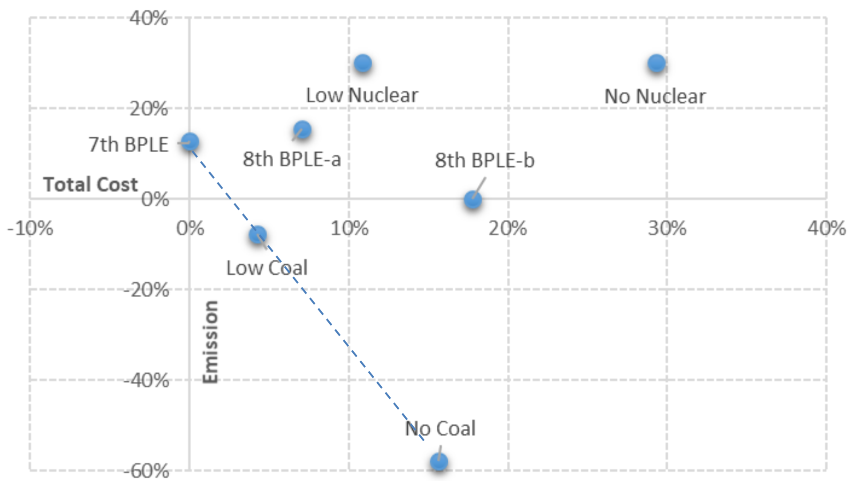


- Coordinated policy, *8th BPLE-b* increase the share of LNG
- *No Coal* depends more on nuclear while *No Nuclear* depend more on LNG

04 Analysis

Results (2) – Model outcomes

Energy Model



MCDM Model

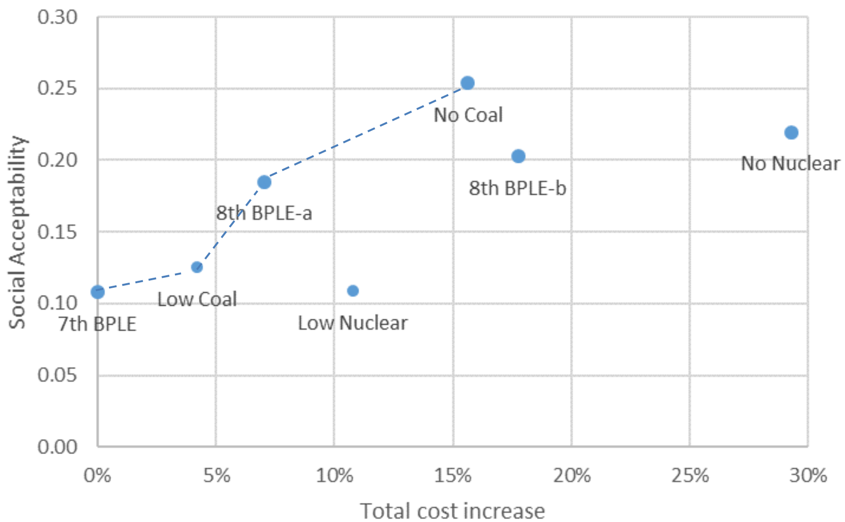
	7^{th} BPLE	*Low Coal*	*Low Nuc*	*8th BPLE-a*	*8th BPLE-b*	*No Coal*	*No Nuc*
Efficiency	0.77	0.72	0.78	0.74	0.71	0.63	0.75
Social acceptability	0.11	0.12	0.11	0.18	0.20	0.25	0.22
Safety	0.47	0.56	0.43	0.48	0.55	0.75	0.45
Investment cost	0.36	0.43	0.52	0.50	0.55	0.50	0.77
Variable cost	0.68	0.59	0.53	0.60	0.54	0.57	0.36
Emission	0.54	0.63	0.47	0.53	0.59	0.81	0.44
Land use	0.89	0.90	0.88	0.75	0.78	0.79	0.76
MCDM Score	0.53	0.55	0.52	0.53	0.54	0.59	0.53

- Energy model: *7^{th} BPLE* (12.87%) < *8^{th} BPLE-b* (17.76%)
- MCDM model: *7^{th} BPLE* (0.53) < *8^{th} BPLE-b* (0.54)
- Coal-reducing scenarios > Nuclear-reducing scenarios
- Extreme policy incur high cost, high MCDM scores

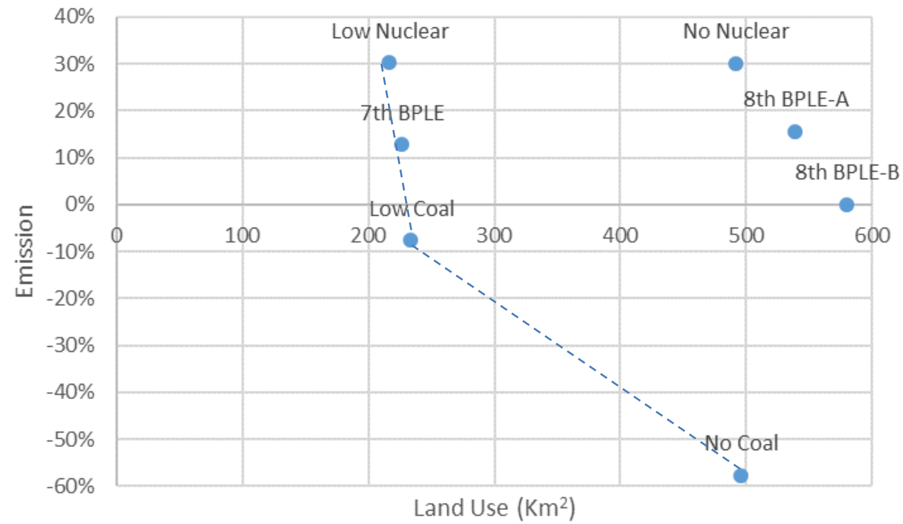
04 Analysis

Results (3) - Tradeoffs

Cost – Social acceptability



Land use – Emission



- ‘Cost – Social acceptability’ shows similar pattern with ‘Cost – Emission’
- *8th BPLE-b* and *No Nuclear* require high cost to achieve high social acceptability
- Land area requirement for *8th BPLE*s much higher than others
- ‘Coordinated policy’ use less territory than ‘Extreme policy’

* We follow the tradeoff analysis in the Shmelev et al. (2016)

04 Analysis

Results (4) - Sensitivity Analysis

Ranking with different priority

	7th BPLE	*Low Coal*	*Low Nuclear*	*8th BPLE-a*	*8th BPLE-b*
No preference	3	1	5	4	2
Technology	3	1	5	4	2
Economic	4	3	5	2	1
Environmental	2	1	4	5	3
Social acceptability	4	3	5	2	1

- Ideal energy policy can vary based on sustainability criteria being emphasized
- 8^{th} BPLEs were preferable when giving priority to economics and social acceptability
- Low ranking of 8^{th} BPLEs in environmental aspect because
  1) Substitution of nuclear with fossil-based power sources
  2) Increased land use with renewables

5. CONCLUSION

05 Conclusions

Korea's energy transition policy (8^{th} BPLE)

- Substantial increase in cost of electricity generation is unavoidable (7.1% ~ 17.8% total cost increase in electricity supply)
- Korea's new energy policy was desirable in the sustainability perspective
  → Assessment of energy policy should not be limited to cost and emission
- Coal-reducing scenarios were preferable than nuclear-reducing scenarios
  → Gov't energy transition should put higher priority in coal reduction
- Rapid deployment of renewables in 8^{th} BPLEs require abundant land area

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Thank you

Acknowledgement: This research is supported by the Ministry of Environment of Korea through its Climate Change Correspondence Program (2014001300002). This views and opinions expressed in this study are those of the authors alone.

Appendix
Energy Model

- Goal Programming formulation using percentage deviations (Jones & Mehrdad, 2010)

$$\text{Min } \frac{(D^+_{econ} + D^-_{econ})}{\text{G}(econ)} + \frac{(D^+_{emis} + D^-_{emis})}{\text{G}(emis)} \quad (1)$$

where D^+_{econ}, D^-_{econ}: economic deviation under-achieved (over-achieved),
D^+_{emis}, D^-_{emis}: emission deviation under-achieved (over-achieved),
$G(econ), G(emis)$: defined economic and emission target in 2030.

- Goal settings

- Economic goal: The cost of electricity supply under cost minimization in 7th BPLE

$$\text{G}(econ) = \sum\{\sum_t \{(1+r)^{-t} \sum_i ANCOST_{i,t}\} - D^+_{econ} + D^-_{econ}\} \quad (2)$$

where $ANCOST_{i,t} = CAP_{i,t} + FC_{i,t} + VC_{i,t} + FUEL_{i,t}$.

- Emission goal: Electricity sector target emission level in 2030*

$$\text{G}(emis) = \{\sum_i co_{2eq}(i) * X_{i,2030} - D^+_{emis} + D^-_{emis}\} \quad (3)$$

* The Ministry of Environment (2018)

Appendix
MCDM Model

MCDM Criteria Definition

Aspect	Attributes	Measurement
Technical	Efficiency	= Btu content of electricity / Heat rate (Btu/kWh) (Renewable: Empirical and theoretical value)
	Safety	= Rare accident probability * Impact of accident
Economic	Investment Cost	= Capital cost + Fixed O&M cost
	Variable Cost	= Fuel cost + Variable O&M cost
Environmental	Emission	= External cost of CO_2, NO_X, SO_X, PM emission
	Land Use	= Unit land use of generation facility (m^2/kW)
Social	Social Acceptance	= Survey result of preference for each generation technology

- Attribute score normalization → Attribute score summation → Scenario score

$$v_{ij}(A_{ij}) = \frac{A_{ij} - min(A_{ij})}{max(A_{ij}) - min(A_{ij})}$$

where $0 \leq v_{ij}(A_{ij}) \leq 1$.

⇨

$$AS_{jk} = \sum_{i=1} w_{ik} v_{ij}(A_{ij}),$$

where $w_{ik} = \frac{x_{ik}}{\sum_i x_{ik}}$ for i = land use,

$w_{ik} = \frac{z_{ik}}{\sum_i z_{ik}}$ for i ≠ land use.

⇨

$$SS_k = \sum_{j=1} r_j \, AS_{jk}$$