Papers Review

2024 the 7th International Conference on Energy, Electrical and Power Engineering

Incentivizing EVs to Participate in V2B Interactions using the Stackelberg Game

Zixuan Wei
Tsinghua-Berkeley Shenzhen Institute, Tsinghua Shenzhen International Graduate School, Tsinghua University
Shenzhen, China
weizx21@mails.tsinghua.edu.cn

Chan, Wai Kin (Victor)*
Tsinghua-Berkeley Shenzhen Institute, Tsinghua Shenzhen International Graduate School, Tsinghua University
Shenzhen, China
ORCID: 0000-0002-7202-1922
*Corresponding author

Yi Zhang
Institute of Future Human Habitats, Tsinghua Shenzhen International Graduate School, Tsinghua University
Shenzhen, China
zy1214@sz.tsinghua.edu.cn

Yinliang Xu
Tsinghua-Berkeley Shenzhen Institute, Tsinghua Shenzhen International Graduate School, Tsinghua University
Shenzhen, China
xu.yinliang@sz.tsinghua.edu.cn

Linwei Sang
Tsinghua-Berkeley Shenzhen Institute, Tsinghua Shenzhen International Graduate School, Tsinghua University
Shenzhen, China
sanglw21@mails.tsinghua.edu.cn

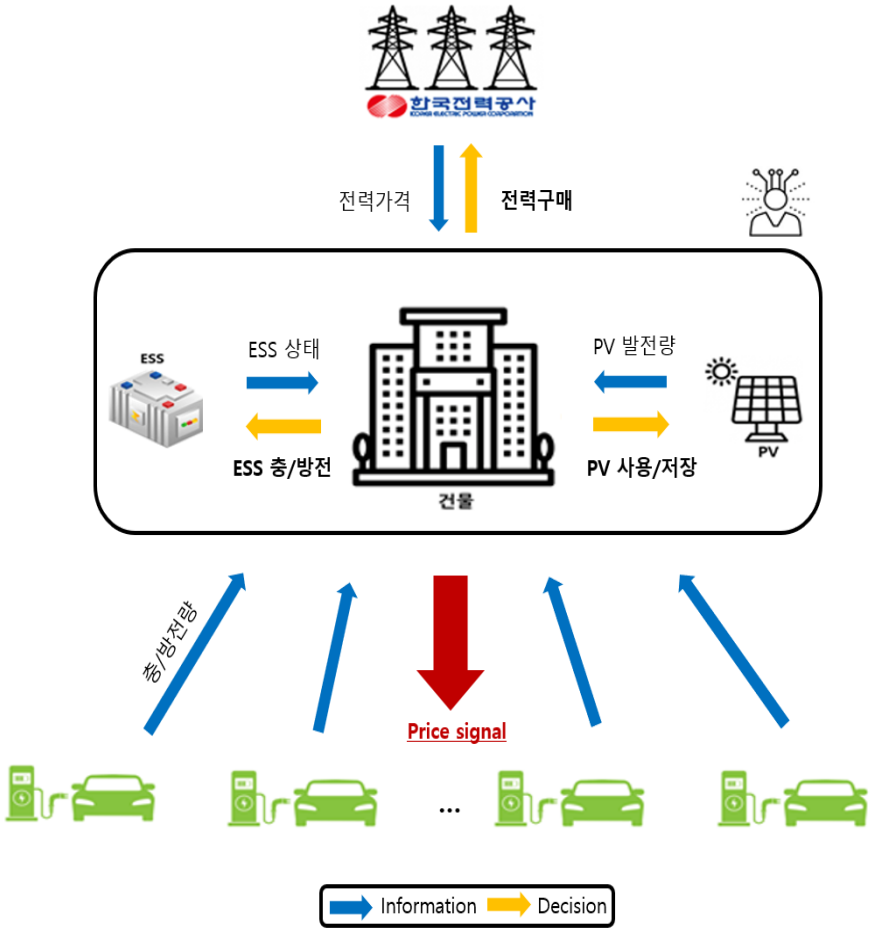
Rongtao Ye
Tsinghua-Berkeley Shenzhen Institute, Tsinghua Shenzhen International Graduate School, Tsinghua University
Shenzhen, China
yrt21@mails.tsinghua.edu.cn

김상훈

shkim@ds.seoultech.ac.kr

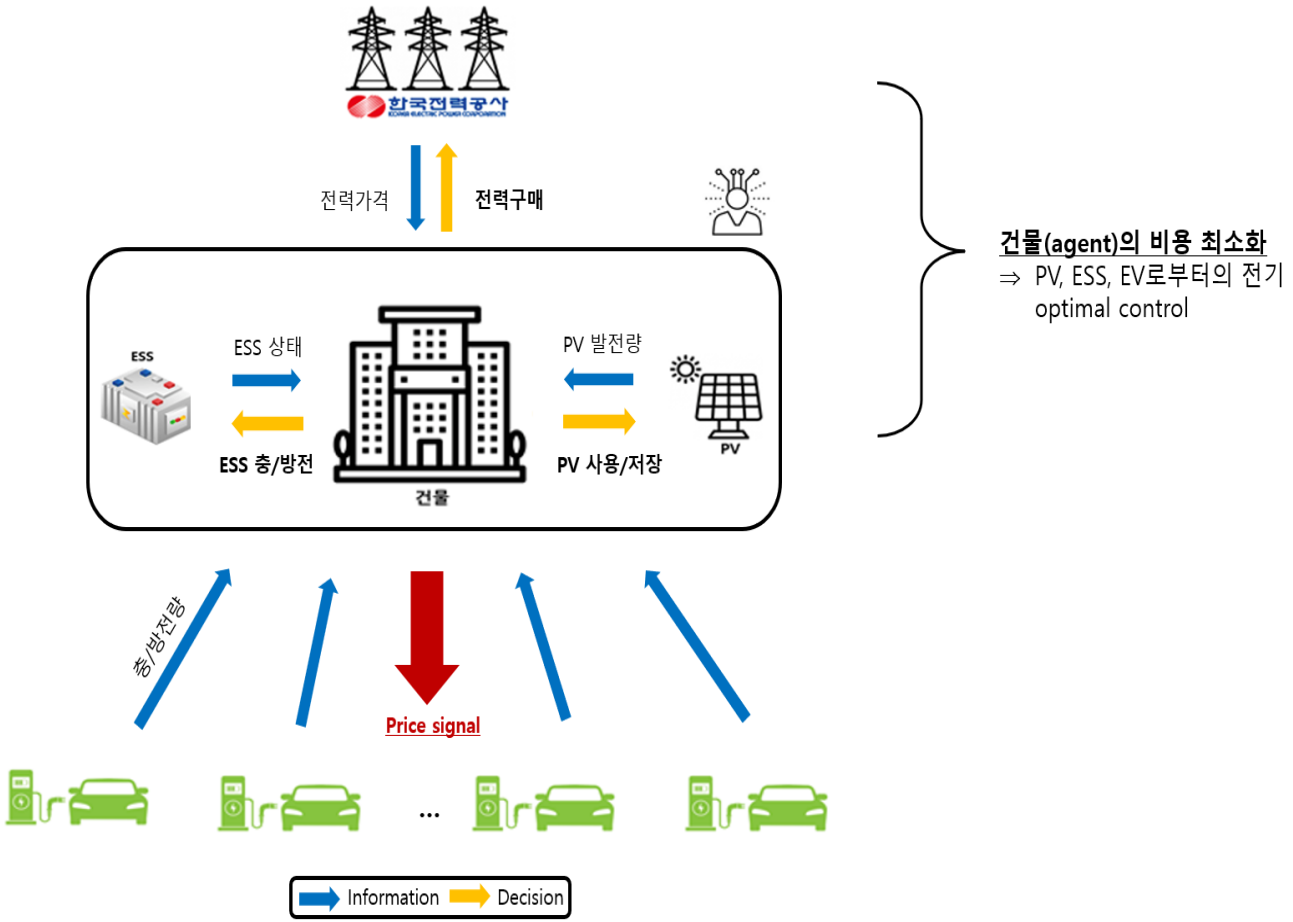
서울과학기술대학교 데이터사이언스학과

Proposal_revised



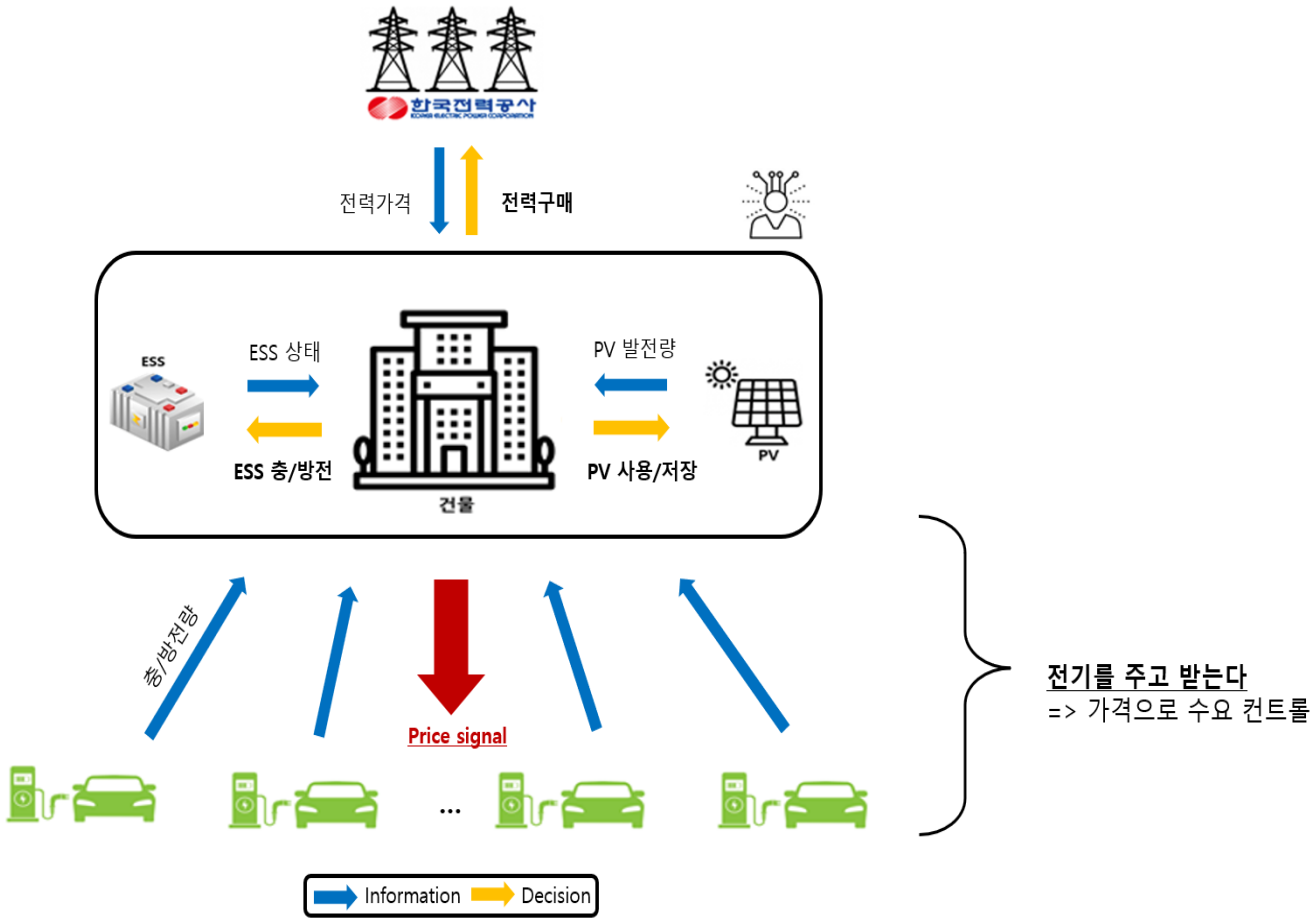
- (기존) 개별 EV들이 에이전트로서, 각각의 decision을 통해 충/방전량을 제공한다
- (수정) 건물이 가격으로 EV 반응 조정

Problem_high level



- 건물이 PV, ESS, EV 로부터의 전기를 control하여 비용을 최소화한다

Problem_low level

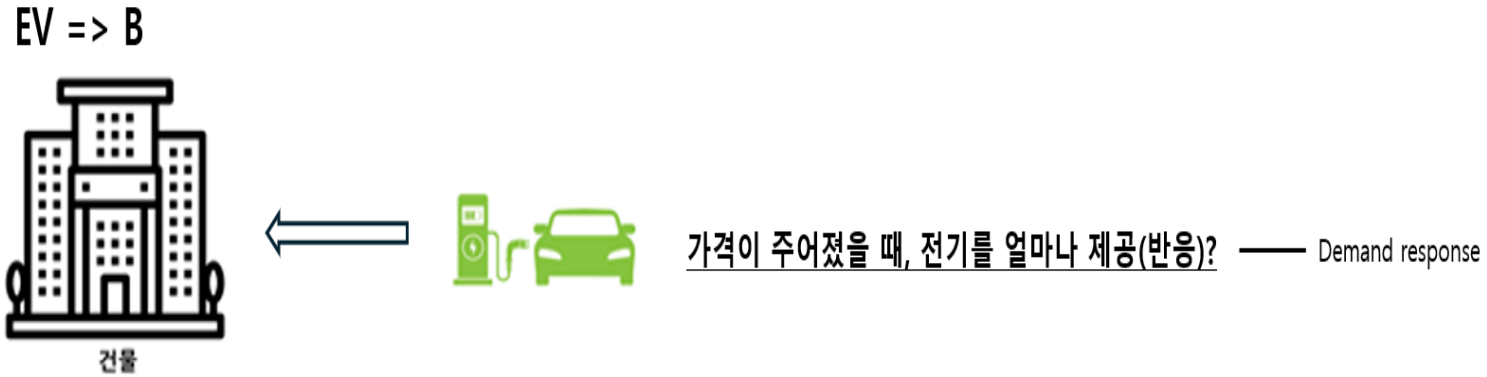


- 건물과 EV는 전기를 주고 받는다
- 건물은 충/방전 가격으로 EV로부터의 수요를 조정한다

Questions_B2V

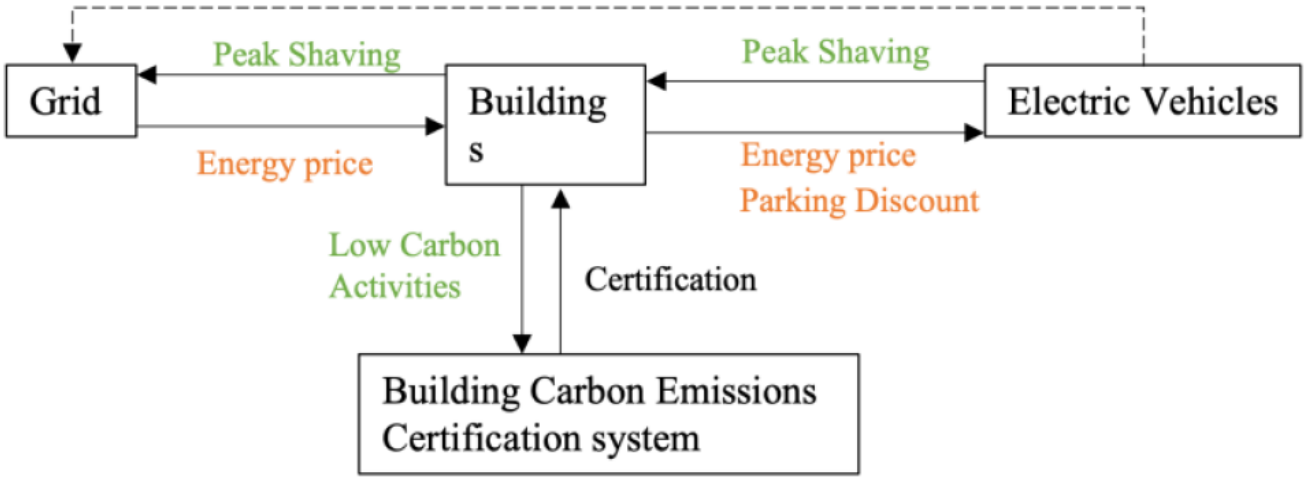
- 건물이 방전 가격을 어떻게 제시할 것인가?
  - Dynamic (real-time) : peak shaving 등의 목적을 고려해, optimal 한 가격을 제시
  - Fix : ToU처럼 시간대별로 고정된 가격을 제시

Questions_V2B



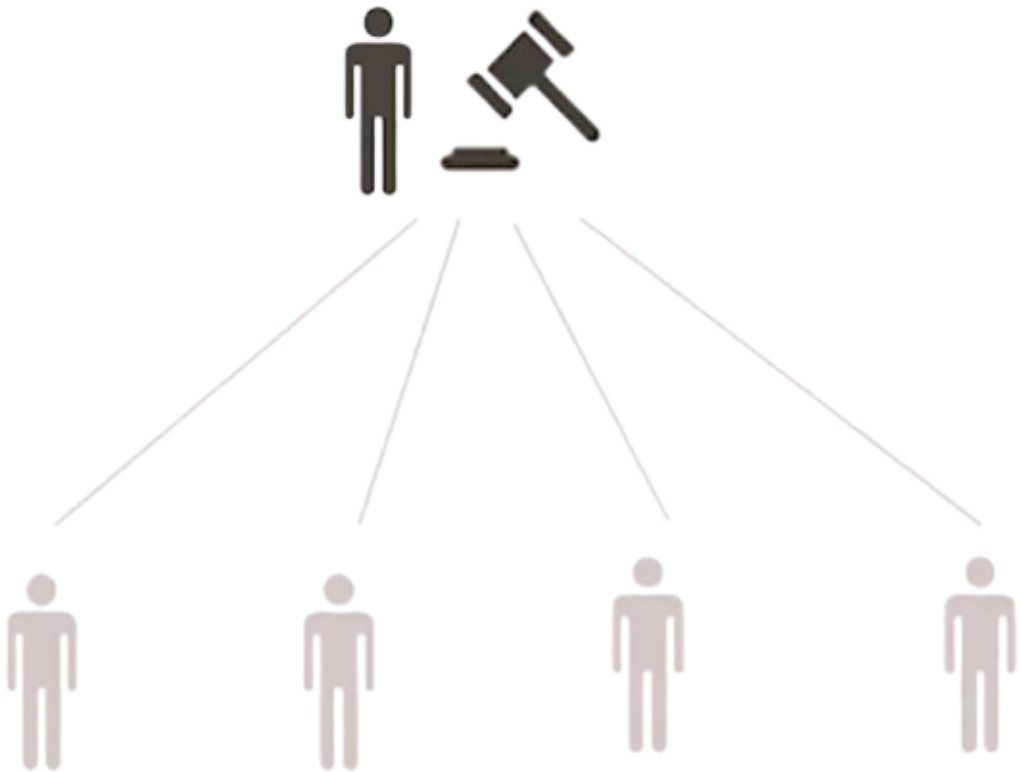
- 제시된 가격에 대해, EV들이 어떻게 반응할 것인가?
  - **충/방전 비용의 변동에 대한 EV들의 반응을 모델링해야한다**

Paper_Abstract



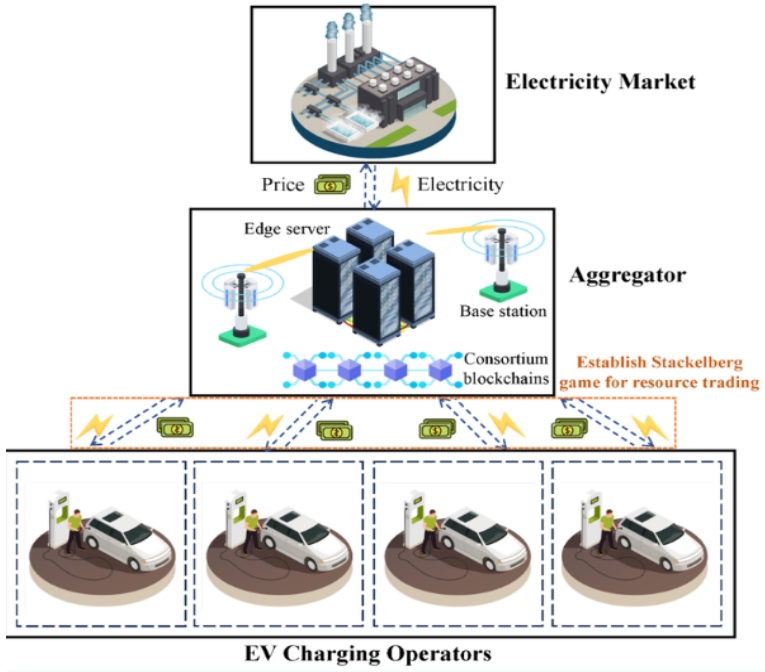
- The interaction between the building and EVs is structured using a **Stackelberg game**
- **Buildings incentive EVs** through discounted energy pricing
- Using Stevens' Law method to **quantify EVs responsiveness**
- Using Mixed-Integer Linear Programming (MILP) to minimize overall costs

Stackelberg?



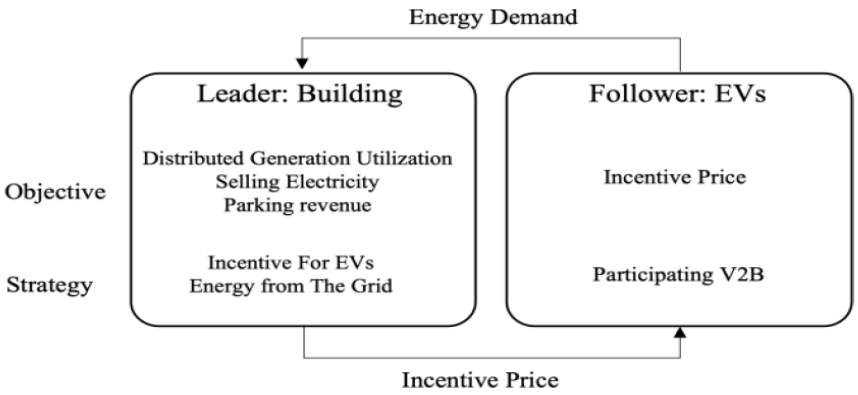
- **Leader**, who commits to their strategy first
- **Followers**, chooses their best response given the leader's startegy

Stackelberg?

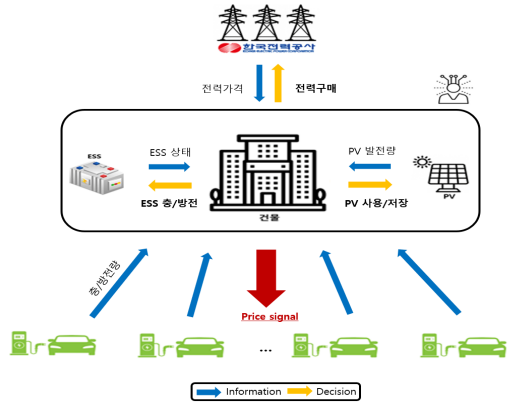


- **(Leader)** Aggregator
  - (strategy) determine the price at which to sell the electricity
- **(Followers)** EV Owners
  - (response) decide whether or not to charge their EV based on the offered electricity price

V2B based on Stackelberg Game



[Framework of paper]



[Framework of proposal]

1. The building proposes pricing strategies to influence the EVs
2. The EVs respond based on these pricing strategies
3. The building then aims to devise an optimal operational strategy based on the EVs' responses

Objective function of EVs

$C_{EV,i}$: cost for the ith EV under the incentive pricing

$$C_{EV,i} = \sum_{t \in T} a_t + b_0 \cdot (U_i' - V_i) + K_1 \cdot (U_i - U_i')^2$$

- a_t : incentive price at time t provided by building

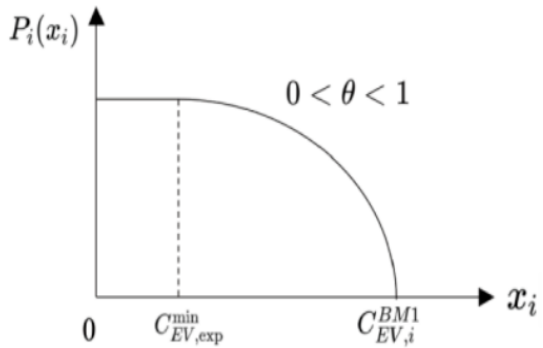
- b_0 : charging cost per unit time
- U_i' : actual charge of the ith EV upon leaving
- V_i : initial charge

- K_1 : dissatisfaction cost coefficient for deviation in departing charge
- U_i : expected charge

EVs response_Stevens' Law

$P_i({}_i x_i)$: response rate of the ith EV under incentive a_t

$$P_i(x_i) = \begin{cases} 1 & \text{if } x_i < C_{V,i}^{min} \\ \left(\frac{C_{EV}^{BM1} - x_i}{C_{EV}^{BM1} - C_{EV,i}^{min}} \right)^{\theta} & \text{if } C_{EV}^{min} \leq x_i \leq C_{EV,i}^{BM1} \\ 0 & \text{if } x_i > C_{EV,i}^{BM1} \end{cases}$$



- x_i: cost for the ith EV under the incentive
- C_{EV}^{BM1}: cost without any incentives
- $C_{\text{EV,exp}}^{\min}$: minimum expected cost, that EV will definitely participate in V2B

Stevens' Law

Stevens' Law : 자극의 강도와 그에 따른 반응의 크기 사이의 관계를 설명하는 법칙

$$S = k \cdot I^{\theta}$$

- S : 반응의 크기
- I : 자극의 강도
- θ : 자극 유형에 따라 값이 달라짐

Objective function of Building

The building's objective function aims to maximize its total revenue R_B

$$\max R_B = \sum_i R_{\text{rev},i}(C_{EV,i}) - \sum_t f_{BG,t} \cdot u_{BG,t}$$

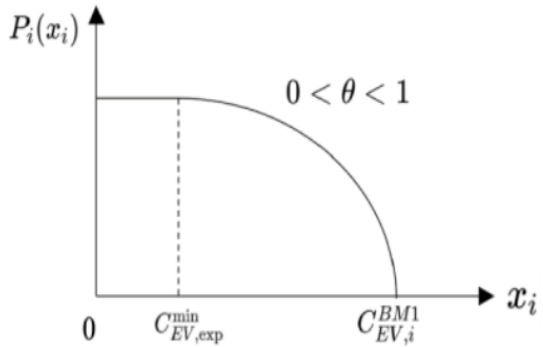
- $R_{\text{rev},i}(C_{EV,i})$: revenue from interaction with EV i
- $f_{BG,t}$: cost of grid interaction at time t
- $u_{BG,t}$: amount of energy interaction with the grid at time t

Objective function of Building

The revenue from EV i is given by:

$$R_{\text{rev},i}(C_{EV,i}) = \begin{cases} \sum_{t \in T_a} a_t + b_0 \cdot (U_i' - V_i) & \text{if } P_i(x_i) \geq P_{\text{def}} \\ a_0 \cdot T_a + b_0 \cdot (U_i - V_i) & \text{if } P_i(x_i) < P_{\text{def}} \end{cases}$$

- $P_i(x_i)$: response rate of EV i
- P_{def}: threshold response rate for EVs to participate in V2B



Objective function of Building

$$R_{\text{rev},i}(C_{EV,i}) = \begin{cases} \sum_{t \in T_a} a_t + b_0 \cdot (U_i' - V_i) & \text{if } P_i(x_i) \geq P_{\text{def}} \\ a_0 \cdot T_a + b_0 \cdot (U_i - V_i) & \text{if } P_i(x_i) < P_{\text{def}} \end{cases}$$

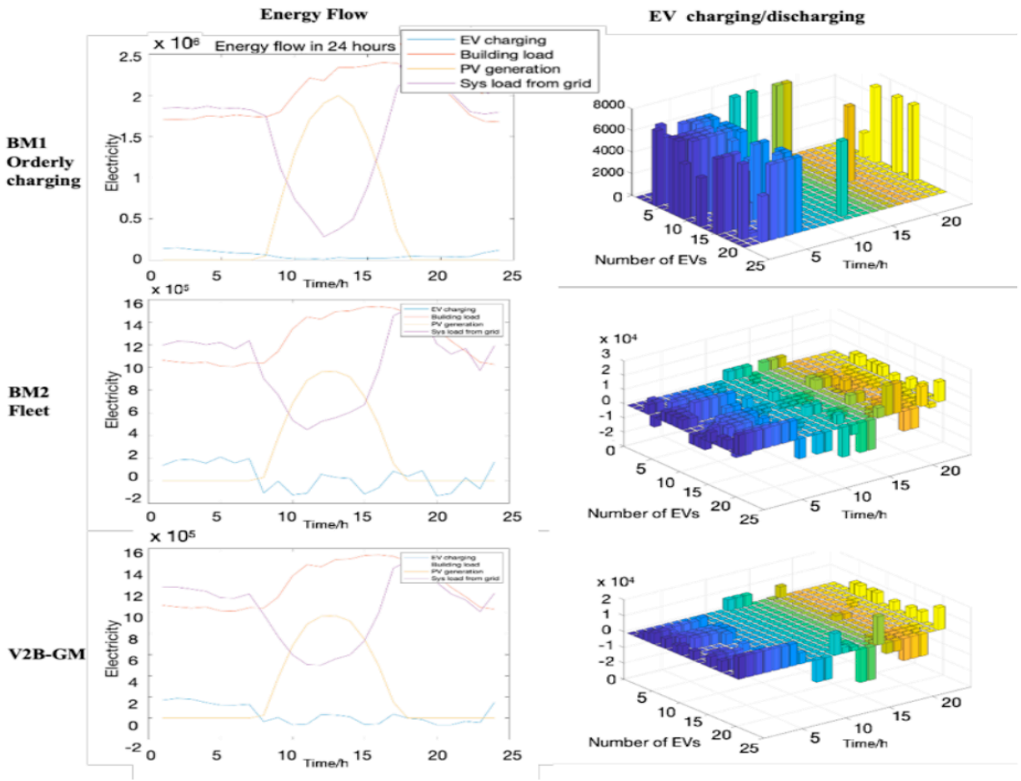
- a_t: incentive price
- b_0: charging cost
- U_i': actual charge level of EV i when it leaves
- V_i: initial charge level

Objective function of Building

$$R_{\text{rev},i}(C_{EV,i}) = \begin{cases} \sum_{t \in T_a} a_t + b_0 \cdot (U_i' - V_i) & \text{if } P_i(x_i) \geq P_{\text{def}} \\ a_0 \cdot T_a + b_0 \cdot (U_i - V_i) & \text{if } P_i(x_i) < P_{\text{def}} \end{cases}$$

- a_0: parking cost
- T_a: duration time that EV remains
- U_i: expected charge level of EV i

Results

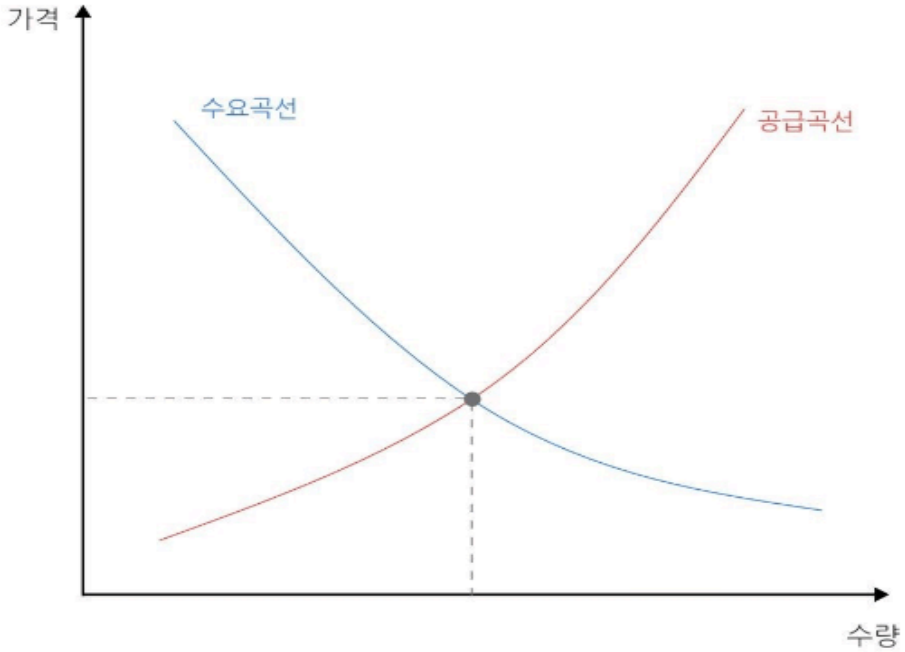


	Benchmark 1		Benchmark 2		V2B Game Model	
	value		value		value	
Building Cost	8925.3	0%	8328.5	7%	8747.9	2%
EVs'Cost	4533.7	0%	4533.7	0%	4262.7	6%
System Cost	13459.1	0%	12862.2	4%	13010.7	3%
Fluctuation	395928	0%	441382	-11%	377168	5%

- overall cost is similar to Benchmark 2 while achieving comparable performance in terms of peak shaving and load fluctuation
  - Benchmark 1: without discharging
  - Benchmark 2: building has full control over EVs

Discussion

1. EV의 가격 탄력성 (price elasticity) 모델링에 Stevens' Law 를 사용한 것이 타당한 방법인가?
2. EV의 response가 가격에 의해서만 모델링되는게 적절한가?



- SOC,SOH 등과 함께 고려되어야 하는 것이 아닌지 궁금합니다

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"Thank you for listening"
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