Rate design with distributed energy resources and electric vehicles: A Californian case study

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version

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OUTLINE

OUTLINE

1.1 BIO

Icaro completed his bachelor degree in Electrical and Computer Engineering at the Federal University of Ceará in Brazil in 2015. He then joined the CentraleSupélec Engineering School to obtain his master degree with a specialization in energy conversion. He is currently a Phd student in energy economics at École CentraleSupélec and has been a researcher-doctoral student at the VEDECOM Institute (Versailles, France) since September 2018.

VEDECOM

A lead French ITE devoted to decarbonized mobility research.

1.2 VEDECOM IN BRIEF

VEhicule DEcarboné et COmmunicant et sa Mobilité:

- Founded in 2014 ;
- French ITE (Institut pour la Transition Energétique);
- Public and private co-investment;
- Dedicated to individual, decarbonized and durable mobility;
- Develop researches in disruptive technologies;

ÉLECTRIFICATION DES VÉHICULES

DÉLÉGATION DE CONDUITE & CONNECTIVITÉ

MOBILITÉ & ÉNERGIE PARTAGÉES

VÉHICULE

ÉCO-MOBILITÉ

FORMATION

Entreprises
Companies

Recherche
Research

Institutionnels
Institutional

FONDATEURS
FOUNDERS

DONATEURS
DONORS

EN COLLABORATION AVEC
IN COLLABORATION WITH

SOUTENU PAR
SUPPORTED BY

50 members & partners from different sectors **collaborate** on **pre-competitive** and **pre-normative research projects**

OUTLINE

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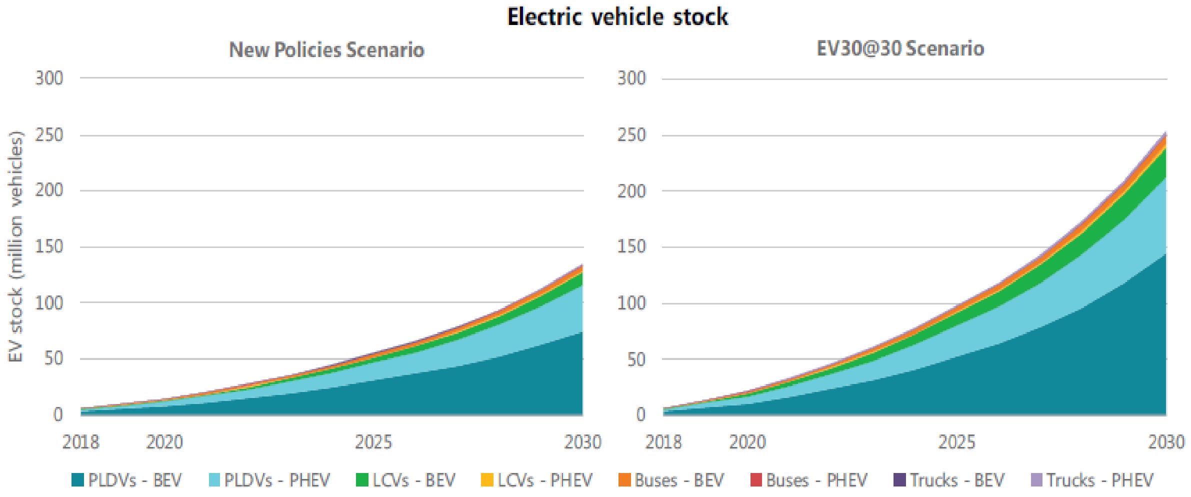
INTRODUCTION

A reflection about the electricity rates actual context.

Automotive Industry

Increase of electric vehicles sales:

- Decarbonization of transport sector (CO_2 emission restrictions).
- Supported by public policy (Subsidies).



Source: EV Outlook, 2019

What are the existing tariff types?

Electricity Industry

Decarbonization of electricity sector:

- Rapid development of wind and solar energy (PV).
- Increasing flexibility needs to avoid duck curve.
- Increasing adoption of stationary batteries (BESS).

Are EVs a threat in this context?

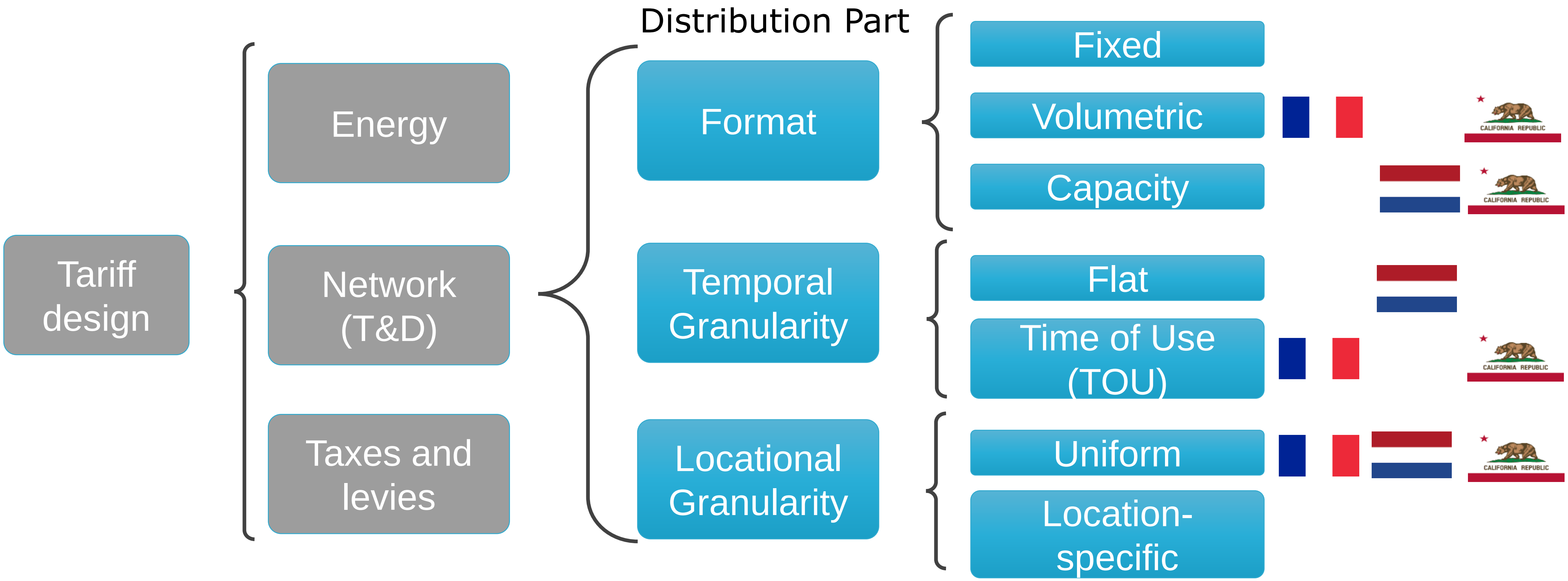
- Context of decrease of electricity consumption.
- But important contribution to peak consumption.
- Opportunity as new flexibility source with V2G.
- In the flexibility market, are EVs and batteries competing or complementary?

What are the tariff roles?

- Reflect user's total consumption (demand and energy).
- Recover utility costs due to previous investments.
- Avoid cost-shifting due to the spiral of death.
- Push a specific type of DERs (PV with feed-in tariffs).

2 – INTRODUCTION

2.2 – Electricity tariff decomposition



Which is the optimal tariff design from the perspective of utilities and facilities?

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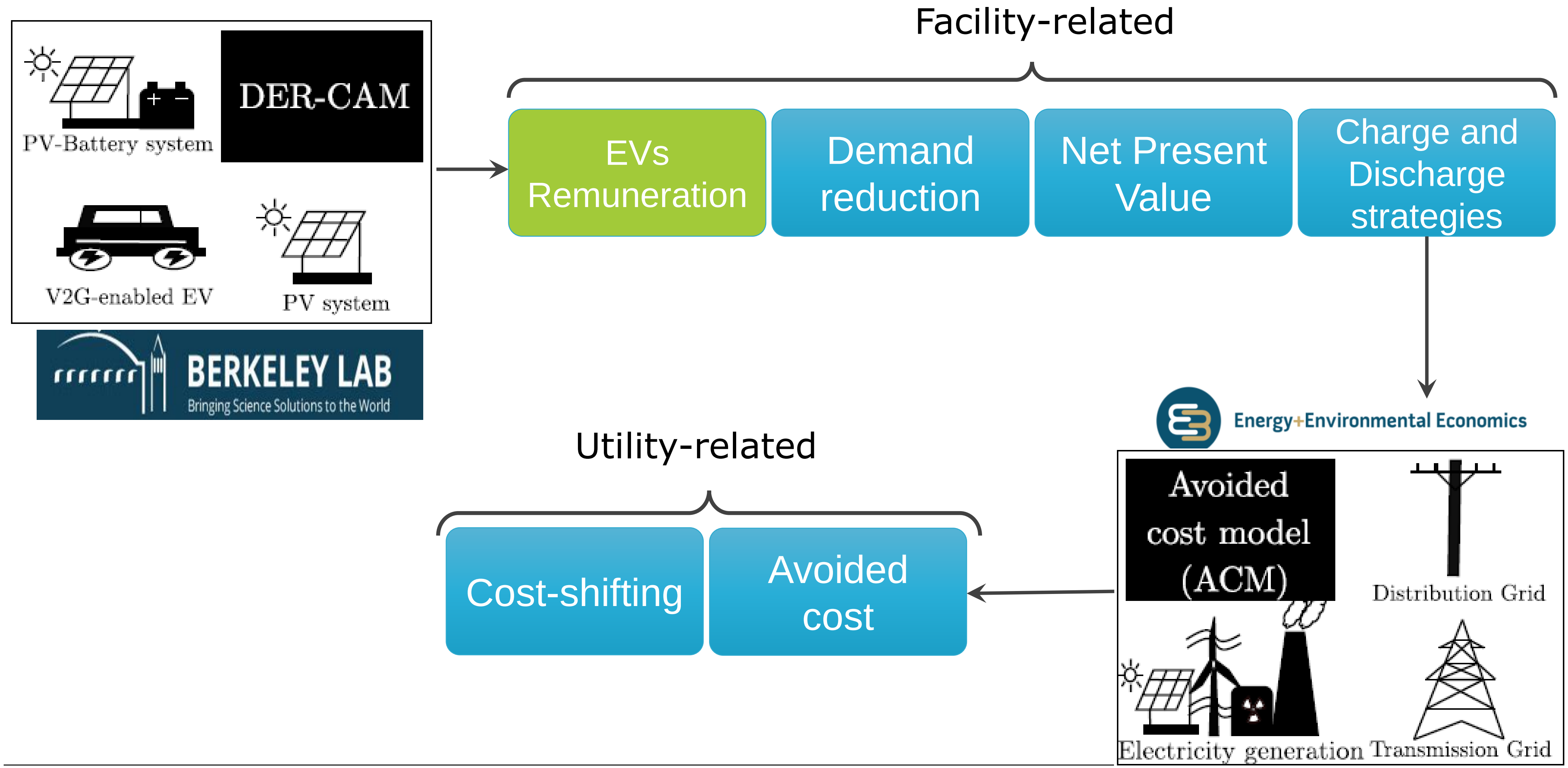
METHODOLOGY AND INPUT DATA

3 – METHODOLOGY AND INPUT DATA

3.1 Model description*



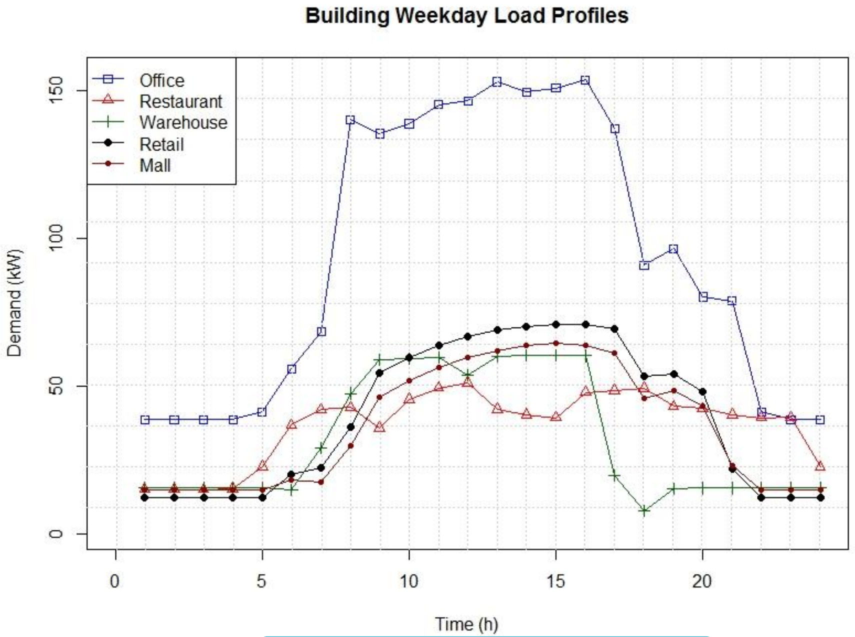
*Methodology proposed by Boampong, R. and Brown, D. ,2020.

DERCAM Mathematical modelling* (MILP) of the local microgrid:

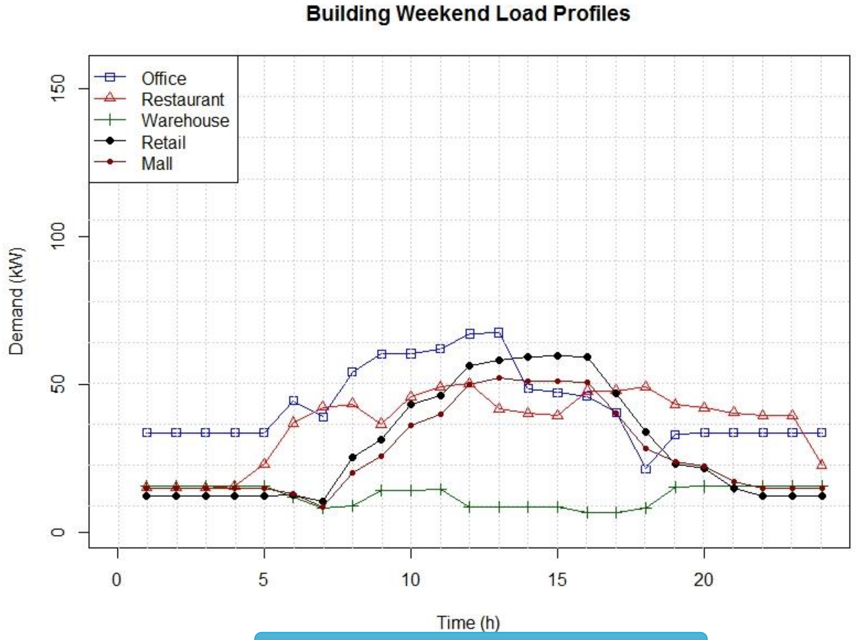
$$Min\ c_{total} = c_{elec} + c_{DER} + c_{EV} - \sum_{m}\sum_{d}\sum_{h} GenS_{PV,m,d,h} \cdot TEx_{m,d,h}$$

Main inputs parameters:

- Load profiles commercial and industrial (C&I) sites in Los Angeles area (Source: OpenEI).

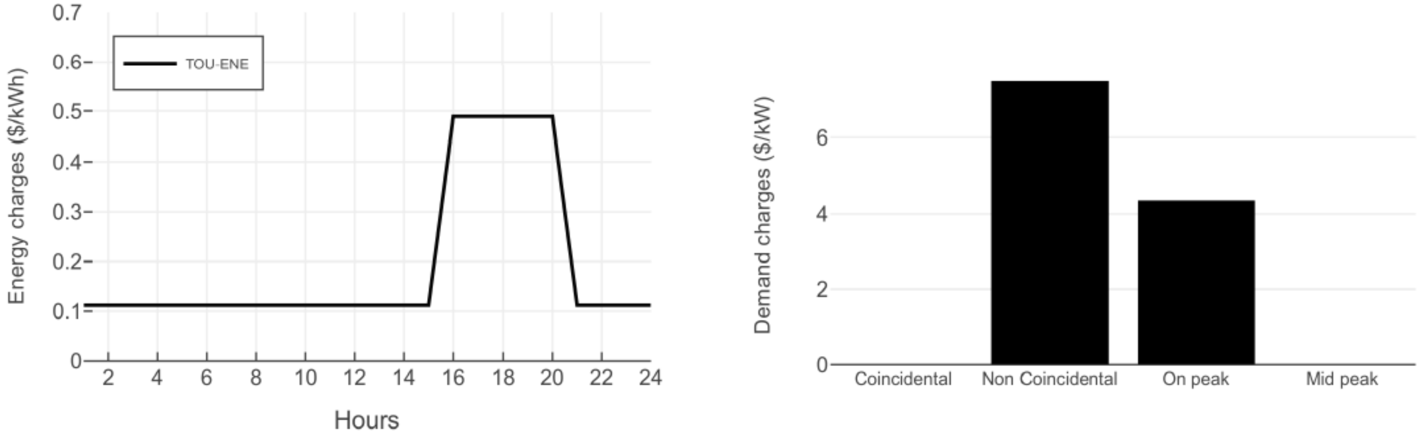


R-squared = 0.86

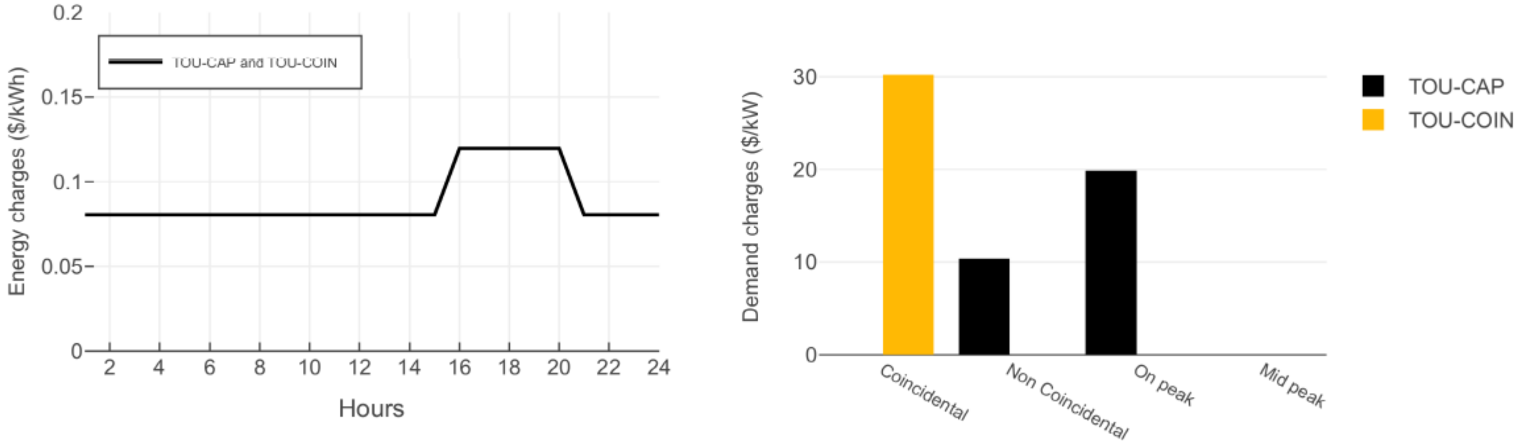


R-squared = 0.73

*See the annex to verify the constraints.



(a) Energy-based tariff during summer ($/kWh)



(b) Capacity-based and coincident peak tariff during summer ($/kW)

Table 1: Adopted DER costs.

	Solar PV	Battery	Electric Vehicles
Fixed cost	-	Cons*: \$ 500 Opt: \$ 0	-
Cost per kW(h) (After subsidies)	Cons: 2,100 \$/kWac Opt: 1,250 \$/kWac	Cons: 215 \$/kWh Opt: 100 \$/kWh	Cons: 32.74 \$/kWh Opt: 16.37 \$/kWh
Lifetime	20 years	10 years	10 years
O&M (per month)	0.66 \$/kW	0	0.28 \$/kWh
Subsidy	-	Cons: 250 \$/kWh (SCE incentive program) Opt: -	Cons: \$1,950 (50% of station cost) (SCE workplace rebate) Opt: -

*The acronym 'Cons' stands for the conservative scenario and 'Opt' for the optimistic scenario.

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RESULTS

The results according to each type of investment.

Exogenous Investments

Average electricity cost changes:

- PV+BESS and PV+BESS+EV have similar electricity costs reduction for all scenarios with DERs.

Net present value (Over 20 Years → PV lifetime):

- Energy tariffs have higher and positive NPV in most of cases due to the high valuation of PV generation.

Cost-shifting (Private savings – system avoided costs) :

- On the other hand, capacity tariffs decrease the cost shifting value by increasing avoided system costs and reducing private savings.

Endogenous Investments

Net present value:

- Cons: The highest NPV is achieved under coincidental tariff due to great electricity cost reduction with small investments.
- Opt: The highest NPV is under energy tariff due to high valuation of Solar PV.

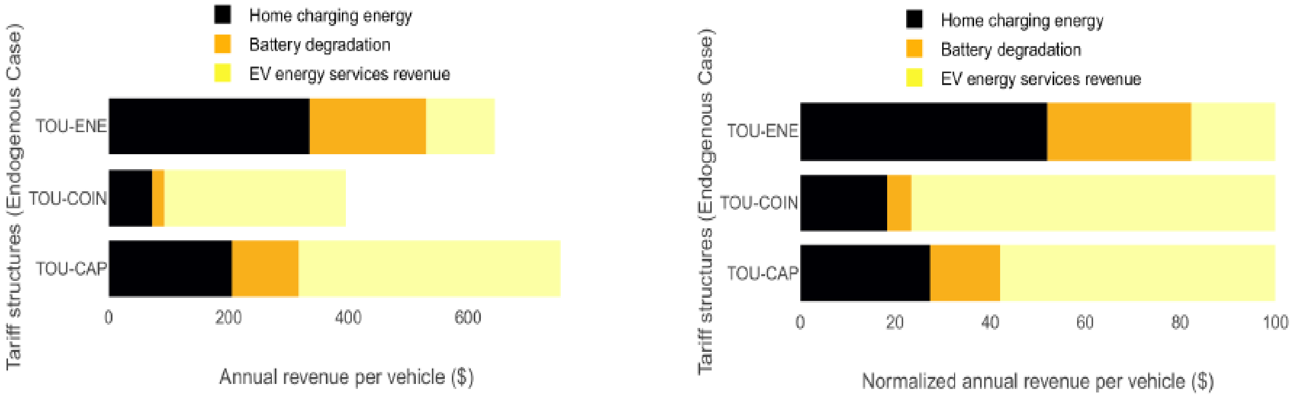
Cost-shifting :

- Cons: The coincidental tariff presented the lowest cost shifting (high share of capacity avoided costs).
- Opt: For the capacity tariff, the avoided costs increase more than the electricity savings, achieving the lowest cost-shifting.

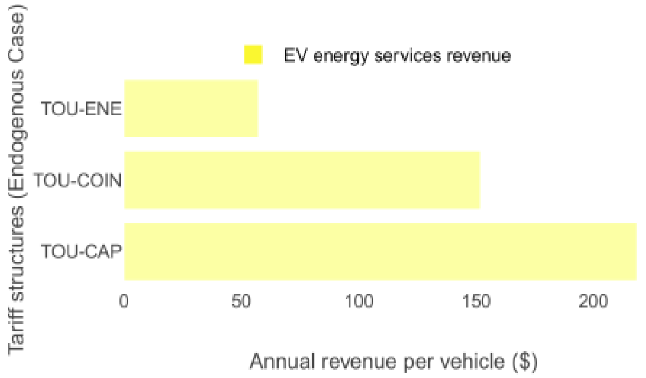
Endogenous Investments

EVs:

- Tariff design has a strong influence on battery and EV charging and discharging strategies.
- EVs remuneration highly depends on the adopted tariff.
- Batteries would substitute all EVs as main storage for commercial buildings private investments in near future (optimistic scenario).



(a) Average EV financial flow per vehicle per year - Endogenous case.



(b) Average EV net income per vehicle per year - Endogenous case. ($)

OUTLINE

CONCLUSION

5. CONCLUSION

Conclusion

EVs as a DER:

- EVs have helped in the mix to enhance private economic gains in most cases → EVs and batteries can work together to increase facility gains.

EVs stack remuneration:

- Varying between $ 57 – $ 216, the remuneration from bill management services highly depends on the tariff design and their availability.

Policy recommendations:

- Incentive solar PV production → Energy tariffs.
- To reduce cost-shifting in short-term → Coincidental tariffs.
- To reduce cost-shifting in long-term (DER price decrease) → Capacity tariffs.

Future Research

Change the tariff power rate:

- Analyze buildings with power demand higher than 200 kW (SCE ToU GS-3).

Simulate for more building load units:

- Verify the result's robustness.
- Check the mean, standard deviations and percentiles.

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Thank you for your attention
Merci de votre attention

Together to accelerate the mobilities of tomorrow!

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*The acronym 'Cons' stands for the conservative scenario and 'Opt' for the optimistic scenario.

Exogenous investment: The DERs sizing is chosen by an external method with a fixed amount.

Objective: **Isolate the impact of changes in tariffs on the private and system value of the technologies.**

Table 3: Average percentage total electricity costs change (%).

PV+BESS		TOU-CAP	TOU-COIN	TOU-ENE
	Baseline			
	TOU-CAP	-50.2	-49.9	-58.9
	TOU-ENE	-43.9	-43.3	-51.4
PV+EV		TOU-CAP	TOU-COIN	TOU-ENE
	Baseline			
	TOU-CAP	-37.2	-35.5	-48.2
	TOU-ENE	-32.9	-30.9	-42.3
PV+EV+BESS		TOU-CAP	TOU-COIN	TOU-ENE
	Baseline			
	TOU-CAP	-46.7	-42.6	-55.1
	TOU-ENE	-41.0	-37.0	-48.2

Endogenous investment: The DER optimal sizes are chosen by the model.

Objective: **Find the optimum net private investment with the available DERs**.

Table 7: Average DER amount in endogenous case.

	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
PV (kW)	32.2	0.0	77.2	137.8	83.8	145.8
(St. Dev.)	(21.0)	(0.0)	(25.3)	(66.1)	(38.2)	(73.8)
#> 0[a]	5.0	0.0	5.0	5.0	5.0	5.0
BESS (kWh)	83.2	183.2	235.2	418.6	258.8	442.4
(St.Dev.)	(65.4)	(103.6)	(73.0)	(207.9)	(152.4)	(219.7)
#>0	5.0	5.0	5.0	5.0	5.0	5.0
EV (kWh)	116.3	72.3	273.7	77.7	0.0	0.0
(St. Dev.)	(58.5)	(29.2)	(273.1)	(47.5)	(0.0)	(0.0)
#>0	3.0	4.0	3.0	3.0	0.0	0.0

[a] #>0 values count the facilities with positive DER capacity installed.

Table 8: Private financial gains - Endogenous case.

Average total electricity costs - Endogenous case ($)						
	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
Basecase	50,144	43,729	57,517	50,144	43,729	57,517
(St. Dev.)	(23,538)	(20,931)	(27,012)	(23,538)	(20,931)	(27,012)
With DER	37,554	30,887	27,685	13,020	16,927	12,174
(St. Dev.)	(17,452)	(13,845)	(16,713)	(6,341)	(8,956)	(5,374)
Average percentage total electricity costs change - Endogenous case (%)						
	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
Baseline						
TOU-CAP	-24.94	-24.97	-60.89	-73.87	-53.15	-89.86
TOU-ENE	-22.42	-21.39	-52.77	-64.68	-45.72	-78.35
Average net present value (NPV) - Endogenous case. ($)						
	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
Mean NPV	30,718	77,518	55,558	160,710	150,596	248,208
(St. Dev.)	(22,225)	(47,911)	(29,053)	(77,811)	(84,651)	(118,181)
$\# > 0^a$	5	5	5	5	5	5

[a] #>0 values count the facilities with positive NPV.

ANNEX

Table 9: Average avoided costs and cost-shifting - Endogenous case. ($)

Avoided costs - Endogenous case 1						
	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
Total Mean	6,278	9,363	22,127	33,330	20,450	34,390
(St. Dev.)	(4,005)	(5,405)	(10,142)	(16,158)	(9,901)	(17,196)
Energy	2,625	2,575	8,645	15,558	9,327	16,129
(St. Dev.)	(1,713)	(1,573)	(3,484)	(7,483)	(4,415)	(7,887)
Capacity	3,653	6,789	13,482	17,772	11,122	18,261
(St. Dev.)	(2,434)	(3,839)	(7,294)	(8,701)	(5,487)	(9,350)
Cost-shifting - Endogenous case 1						
	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
Total Mean	6,312	3,479	7,704	3,794	6,353	10,953
(St. Dev.)	(4,338)	(2,227)	(1,972)	(5,452)	(3,989)	(5,937)
% from savings	50.1	27.1	25.8	10.2	23.7	24.2

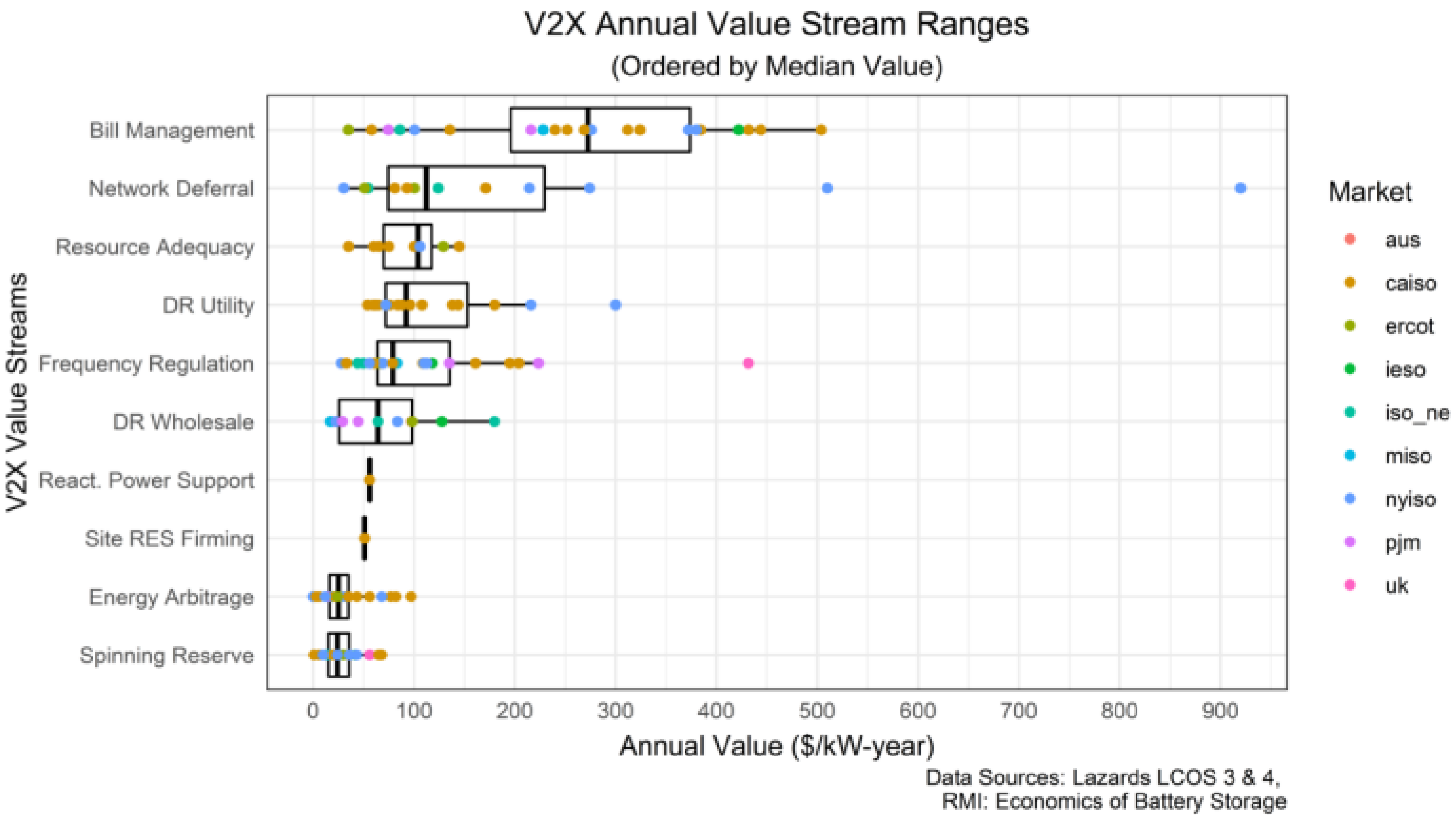
ANNEX

- Final EV Profit:
  - The EV remuneration is formed by the energy payment, battery degradation and the EV standalone gains for the facility (Energy costs without EV – Energy costs with EV).

Table C.22: EV remuneration breakdown - Endogenous case. ($)

	Conservative scenario			Optimistic scenario		
	TOU-CAP	TOU-COIN	TOU-ENE	TOU-CAP	TOU-COIN	TOU-ENE
Home charging energy	205.7	72.1	334.9	133.4	0.0	0.0
(St. Dev.)	(22.4)	(37.1)	(16.5)	(71.6)	(0.0)	(0.0)
Battery Degradation	111.3	20.5	194.6	83.1	0.0	0.0
(St. Dev.)	(14.5)	(9.8)	(10.8)	(24.3)	(0.0)	(0.0)
Energy service	436.4	303.5	114.5	51.7	0.0	0.0
(St. Dev.)	(129.2)	(232.3)	(46.6)	(18.9)	(0.0)	(0.0)
Total Mean	753.4	396.2	644.0	198.3	0.0	0.0
(St. Dev.)	(128.1)	(273.9)	(73.8)	(7.6)	(0.0)	(0.0)
#> 0[a]	3.0	4.0	3.0	3.0	0.0	0.0

[a] #>0 values count the facilities with EVs.



Source: Thompson, A. and Perez Y., 2019

DERCAM Mathematical modelling (MILP) of the local microgrid:

$$Min\ c_{total} = c_{elec} + c_{DER} + c_{EV} - \sum_{m}\sum_{d}\sum_{h} GenS_{PV,m,d,h} \cdot TEx_{m,d,h}$$

Where:

$$c_{elec} = \sum_{m} TF_m + \sum_{m}\sum_{d}\sum_{h} UL_{m,d,h} \cdot TE_{m,d,h} + \sum_{s}\sum_{m\in s}\sum_{p} TP_{s,p} \cdot \max\left(UL_{m,(d,h)\in p}\right)$$
$$+ \sum_{m} TPNC_m \cdot \max\left(UL_{m,d,(h)\in NonCoin}\right) + \sum_{m} TPC_m \cdot UL_{m,d,(h)\in Coin}$$

$$c_{DER} = \sum_{i} (CFixcost_i \cdot Pur_i + CVarcost_i \cdot Cap_i) \cdot An_i + Cap_i \cdot DEROMFix_i$$

$$c_{ev} = \sum_{m}\sum_{h} P_{EV} \cdot \left(\frac{E_{m,h}^{r\to c}}{SCEff_{k=\{EV\}}} - E_{m,h}^{c\to r} \cdot SDEff_{k=\{EV\}}\right) + \sum_{m}\sum_{h} EVCL \cdot EVFRC \cdot \left(SIn_{k=\{EV\}} + SOut_{k=\{EV\}} + E_{m,h}^{r\to c} + E_{m,h}^{c\to r}\right)$$

*See the annex to verify the constraints.

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ANNEX: MODEL CONSTRAINTS

Microgrids energy balance:

$$load_{m,d,h} + \sum_k \frac{SIn_{k,m,d,h}}{SCEff_k} = \sum_k SOut_{k,m,d,h} \cdot SDEff_k + GenU_{PV,m,d,h} + UL_{m,d,h} \ \forall \ \mathrm{m, d, h.}$$

PV output constraint:

$$GenU_{PV,m,d,h} + GenS_{PV,m,d,h} \leq \frac{Cap_i}{ScPeakEff_{PV}} \cdot SCEff_{PV,m,h} \cdot SI_{m,d,h} \ \forall \ \mathrm{m, d, h}: \ \mathrm{i} \in \{\mathrm{PV}\}$$

$$\frac{CAP_{PV}}{ScPeakEff_{PV}} \leq ScArea_{PV}$$

Storage constraints:

$$Cap_k \cdot \underline{SOC_k} \leq \sum_{n=0}^{h} (SIn_{k,m,d,n} - SOut_{k,m,d,n}) \cdot (1 - \varphi_k) \leq Cap_k \cdot \overline{SOC_k} \ \forall \ \mathrm{k, m, d, h.}$$

$$SIn_{k,m,d,h} \leq Cap_k \cdot SCEff_k \ \forall \ \mathrm{k, m, d, h.}$$

$$SOut_{k,m,d,h} \leq Cap_k \cdot SDEff_k \ \forall \ \mathrm{k, m, d, h.}$$

General constraints:

$$UL_{m,d,h} \leq psb \cdot M \ \forall \ \mathrm{m, d, h.}$$

$$GenS_{PV,m,d,h} \leq (1 - psb) \cdot M \ \forall \ \mathrm{m, d, h}$$

$$Cap_i \leq Pur_i \cdot M \ \forall \ \mathrm{i}$$

$$An_i = \frac{IR}{1 - \left(\frac{1}{(1+IR)^{Lt_j}}\right)} \forall \ \mathrm{i}$$

$$C \leq BAUCost + \sum_i (CFixcost_i \cdot Pur_i + CVarcost_i \cdot Cap_i) \cdot (An_i - \frac{1}{PBPeriod})$$