Connecting vehicles to grid

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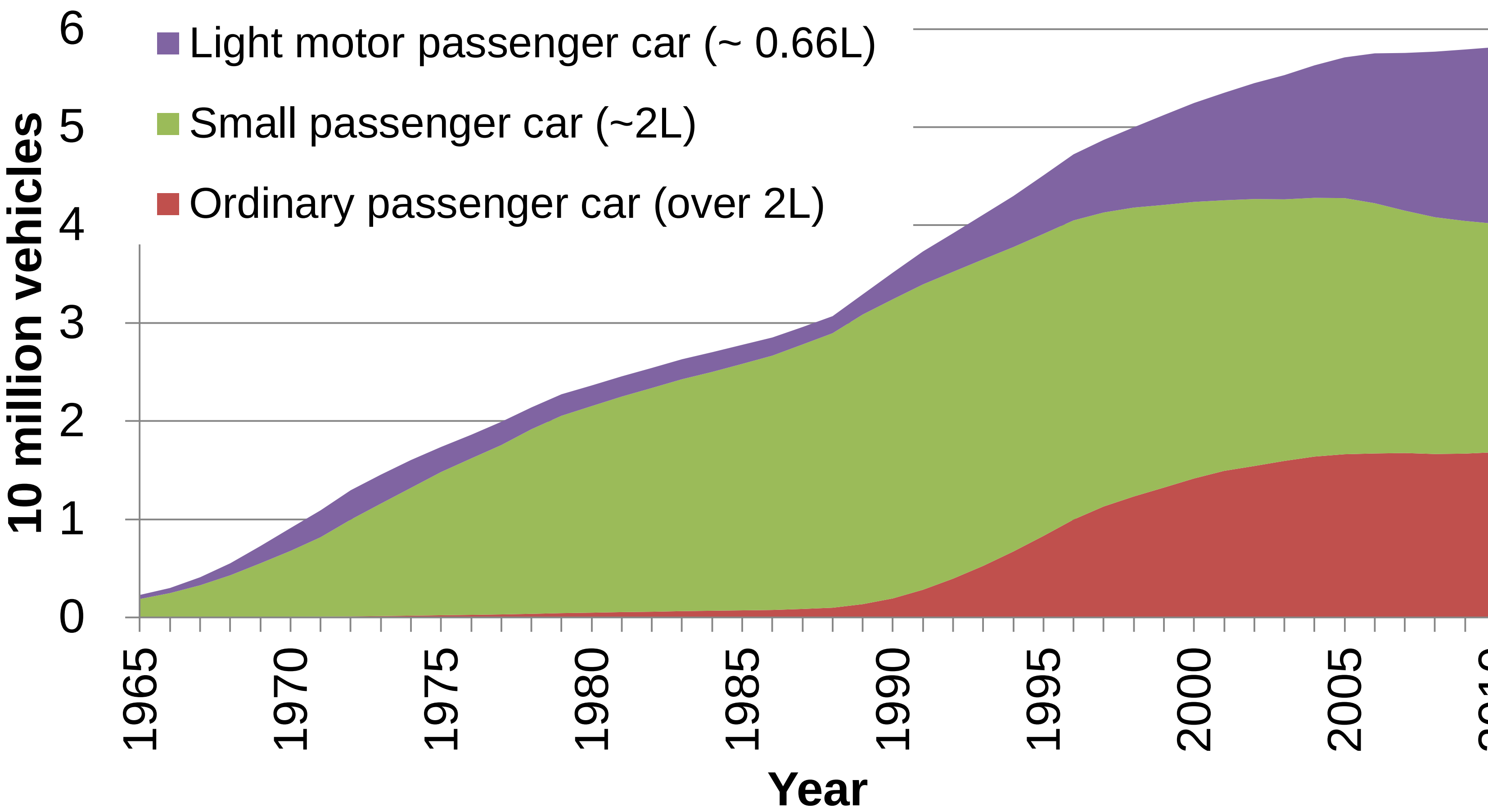
Outline

- Background
- Battery charging behavior
  - At home
  - Within trip
- Vehicle to grid
- Conclusions

Passenger car ownership in Japan



Source: MLIT

Passenger car sales ranking in Japan in 2013

Rank	Model (Automaker)	Sales	Engine type
1	Aqua (Toyota)	262,367	**HV**
2	Prius (Toyota)	253711	**HV**
3	N BOX (Honda)	234,994	Light motor
4	Move (Daihatsu)	205,333	Light motor
5	Wagon R (Suzuki)	186,090	Light motor
6	Fit (Honda)	181,414	Small / **HV**
7	Mira (Daihatsu)	157,276	Light motor
8	Note (Nissan)	147,634	Small
9	Tanto (Daihatsu)	144,629	Light motor
10	Alto (Suzuki)	111,361	Light motor

HV: hybrid vehicle

Source: Japan Automobile Dealers Association & Japan Mini Vehicle Association

Electric vehicles and Plug-in hybrid vehicle in Japan

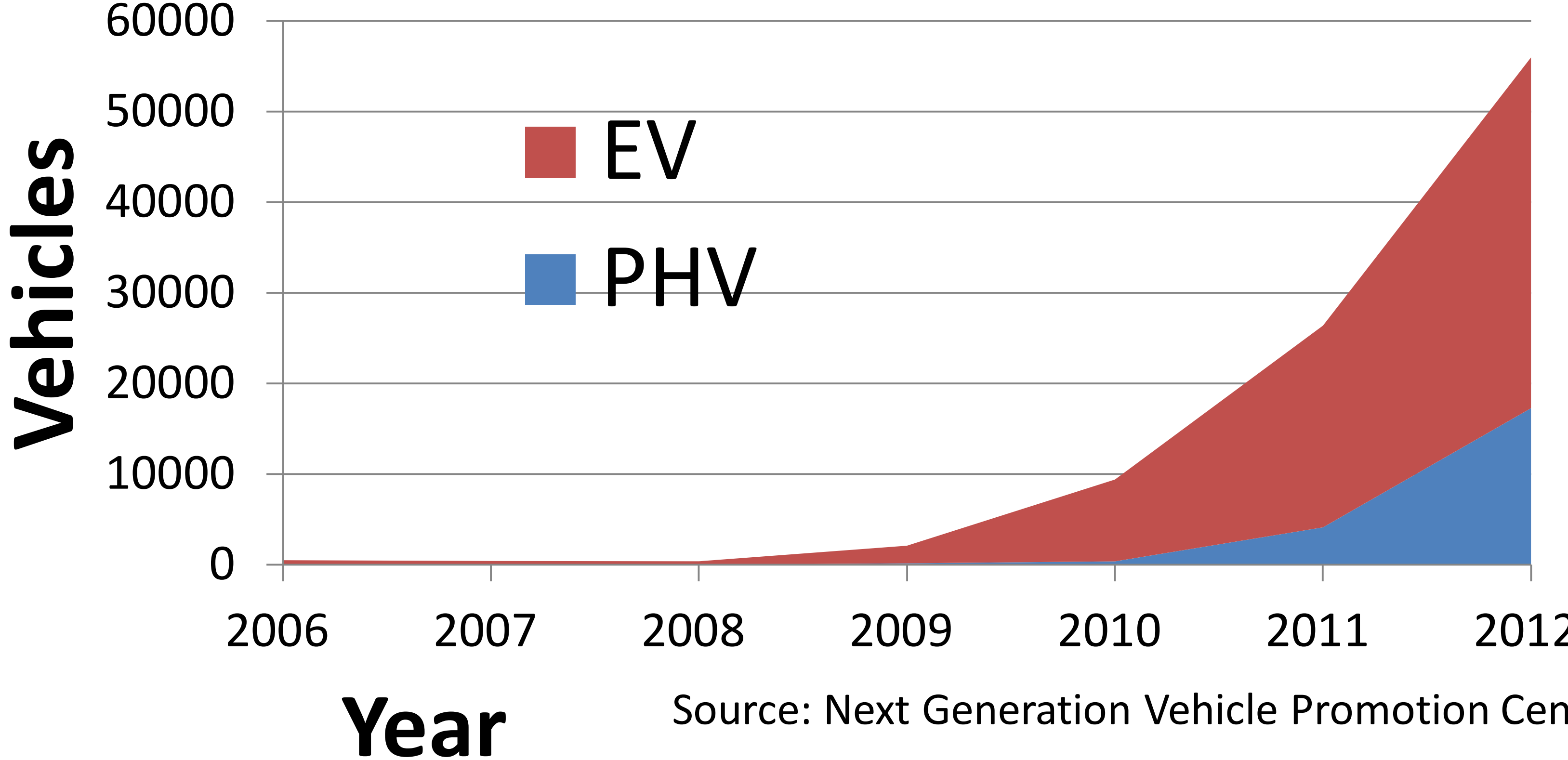
i-MiEV
2009

Leaf
2010

Prius plug-in hybrid
2012

More EVs and PHVs on the market

Electric vehicles and plug-in hybrid vehicles in Japan



Source: Next Generation Vehicle Promotion Center

More energy efficient, but more electricity dependent

Battery charging at home

- Analysis on charge timing choice behavior of plug-in hybrid vehicles in Toyota City, Japan
  - This is a part of the results obtained by joint research with Toyota Motor Corporation

Smart Mobility & Energy Life project in Toyota City

- Toyota City, Japan
- 67 new houses, some with plug-in hybrid Prius
- HEMS（Home Energy Management System）
- DRP (demand response point) system

Smart house

Visualization by HEMS (home energy management system)

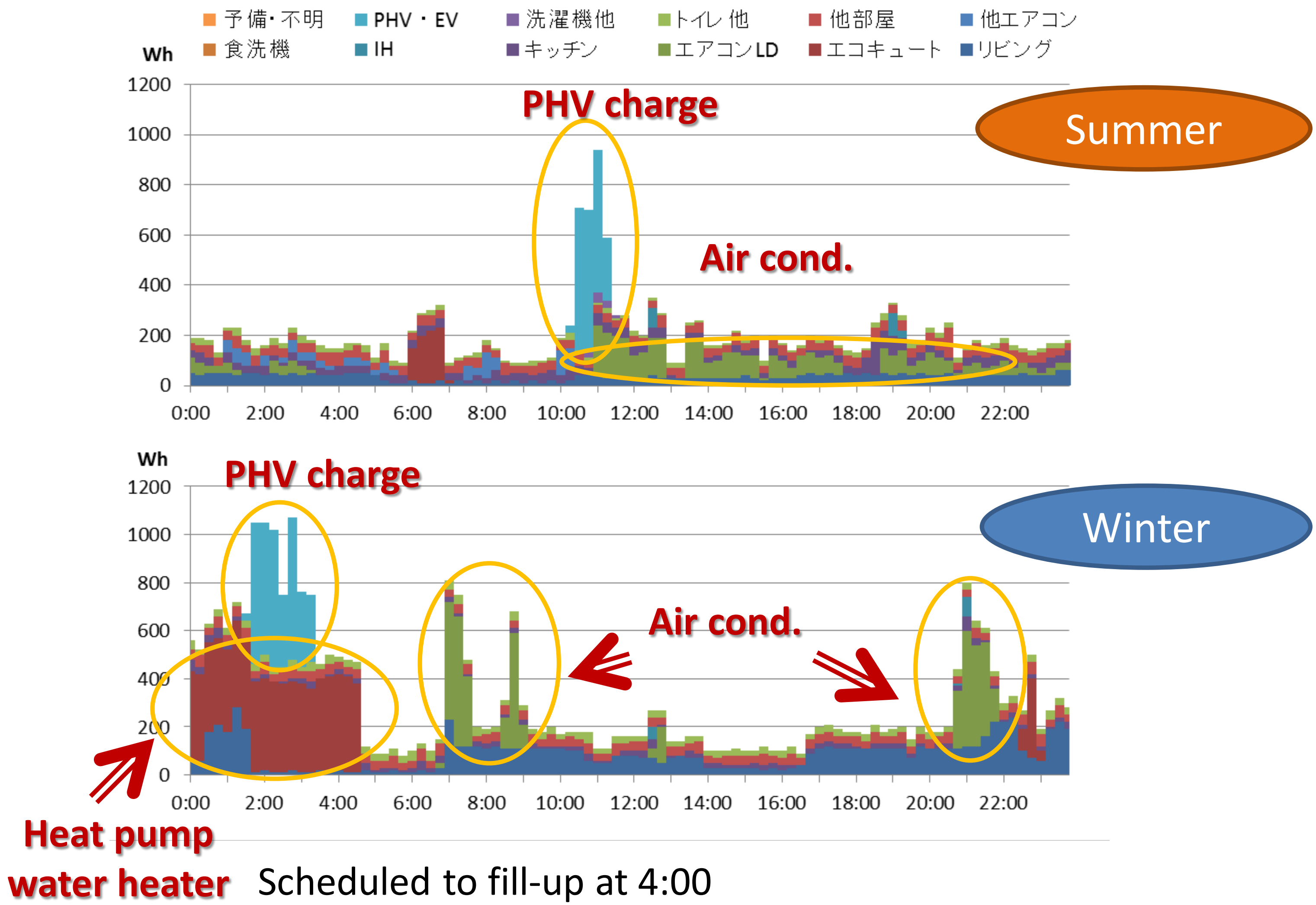
DRP (demand response point) portal

PHV charger

PHV

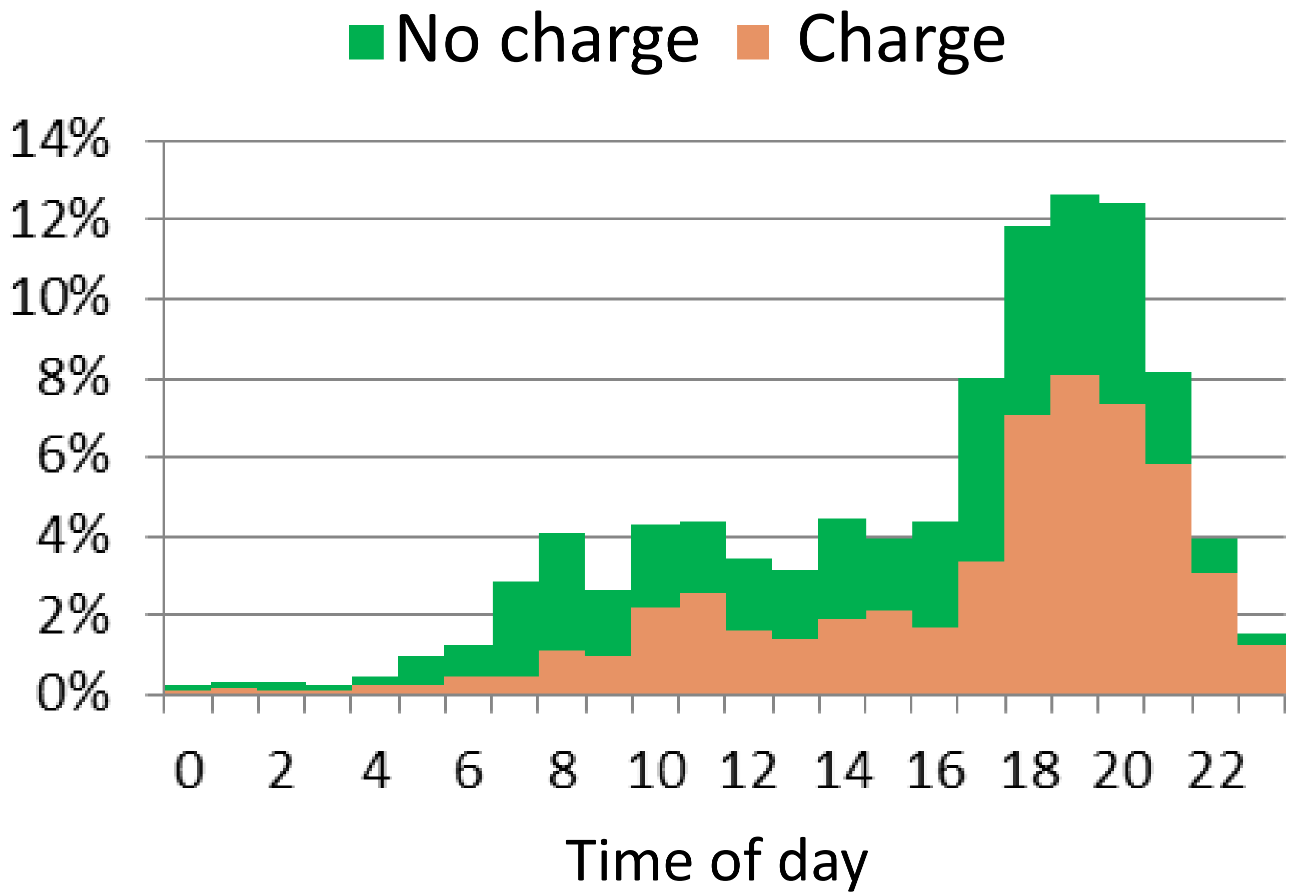
PHV charging monitor

Example of electricity demand curve



Scheduled to fill-up at 4:00

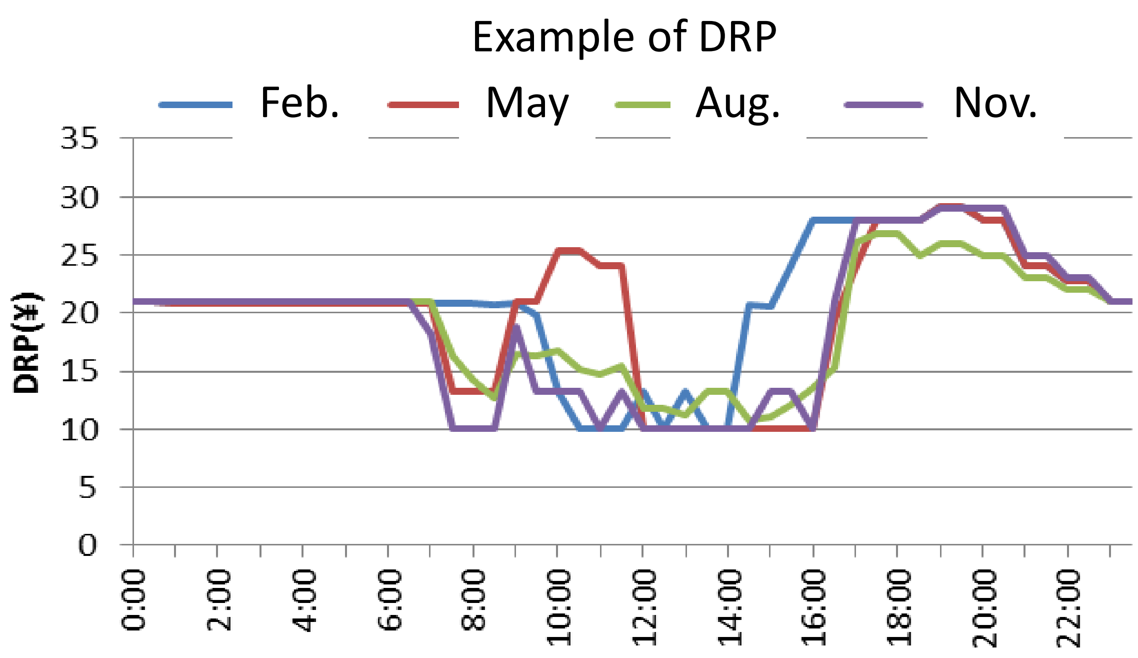
Distribution of returning home timing



Many cars return home at 18 to 20 o’clock, which potentially cause peak demand

DRP (demand response point)

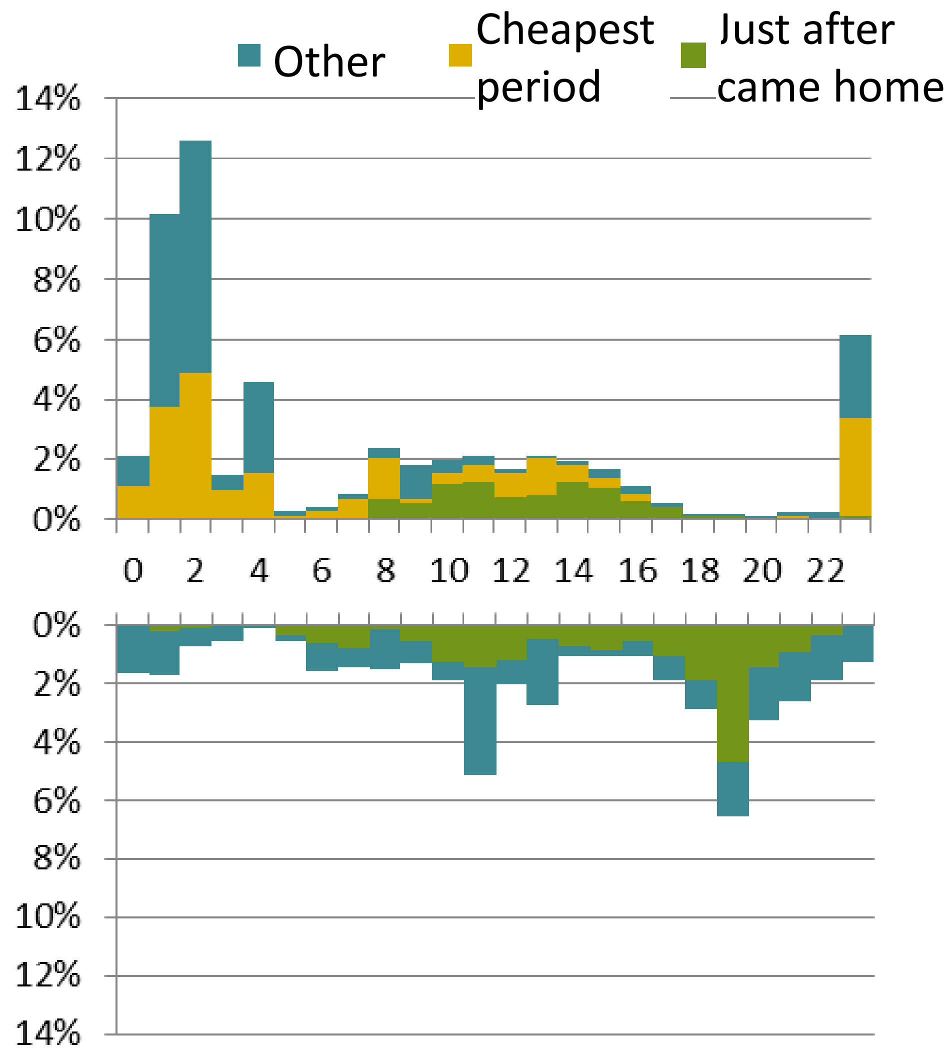
- Peak pricing by point system
- Low at daytime (solar energy) &
  high at evening (more activity at home)



Charging time is shifted by demand response point system

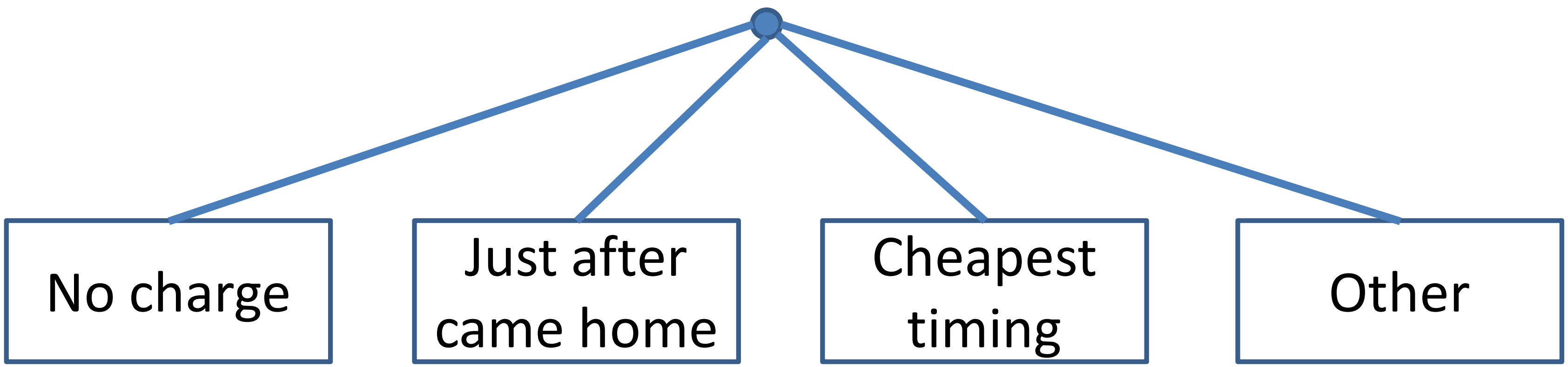
With demand response point

W/O demand response point



Charge timing choice model

- Multinomial logit model



PHV can run even without charge

Cheapest timing before the next vehicle use

Didn't change the setting of on-timer previously set, or by mistake

  - 12 Prius plug-in hybrid vehicles
  - 2011/10/1 to 2012/10/31
  - 4615 cases

Charge timing choice model

Alternative	Variable	Coef.	
No charge	Constant	1.34	**
	Drive distance (<24 km)	-0.10	**
	Long distance dummy (>24 km)	-0.38	**
Just after came home	**Price** for energy conscious person	-0.044	**
	Price for energy unconscious person	-0.065	**
	Return home at daytime (9-16)	0.70	**
Cheapest time	Constant	-0.69	**
	Price for energy conscious person	-0.016	**
	Price for energy unconscious person	0.001	
	Housewife dummy	0.66	**
	Return home at evening (17-23)	1.41	**
Other	Constant	-0.96	**
	Return home at evening (17-23)	0.65	**
	Same as the last charge dummy	2.21	**
Log-likelihood (0)		-5774	
Log-likelihood at convergence		-4415	
Adjusted rho-square		0.233	

** 1%, * 5%

Sensitivity of the estimated model

Base case: High energy conscious male driver returned home in evening after 10 km drive

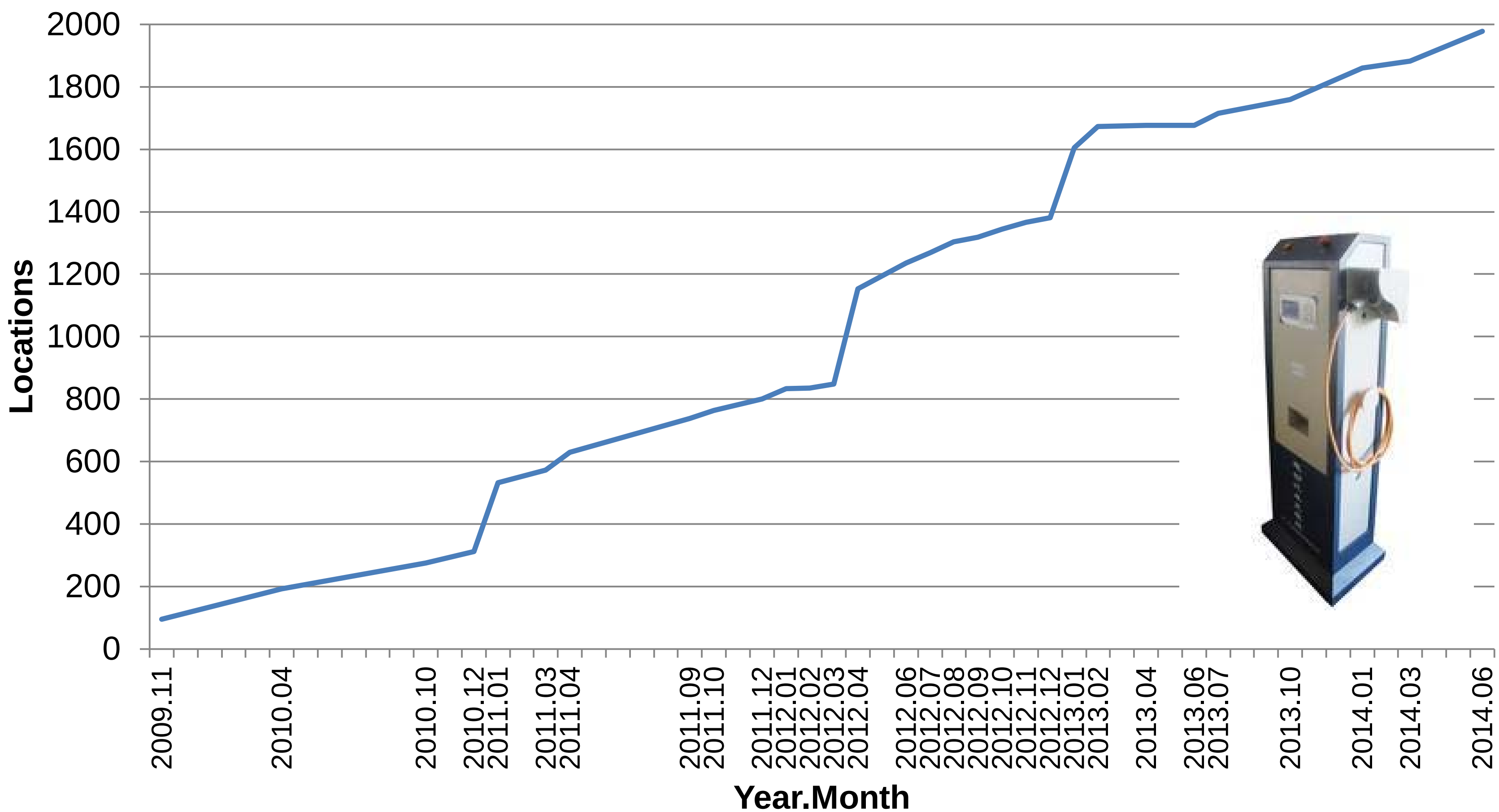
Electricity price	No charge	Just after came home	Cheapest timing	Other
No DRP (20.9 JPY)	35%	47%		18%
Evening price 20.9 -> 28 JPY	36%	**8%**	**38%**	19%
+ Midnight price 20.9 -> 10 JPY	34%	**7%**	**42%**	18%

Charge timing is easier to change than the timing of air conditioner usage, etc.

Battery charging within trip

- The timing of mid-trip electric vehicle charging
  - This is a part of the results obtained by the Project Consigning Technology Development for Rational Use of Energy (Promotion of aggregation and sharing of probe information)
  - The dataset was provided by Japan Automobile Research Institute (JARI)

Fast charger deployment in Japan



Source: CHAdeMO Association

Trade-off between battery size and fast charger density

How to optimize battery size & fast charger deployment?

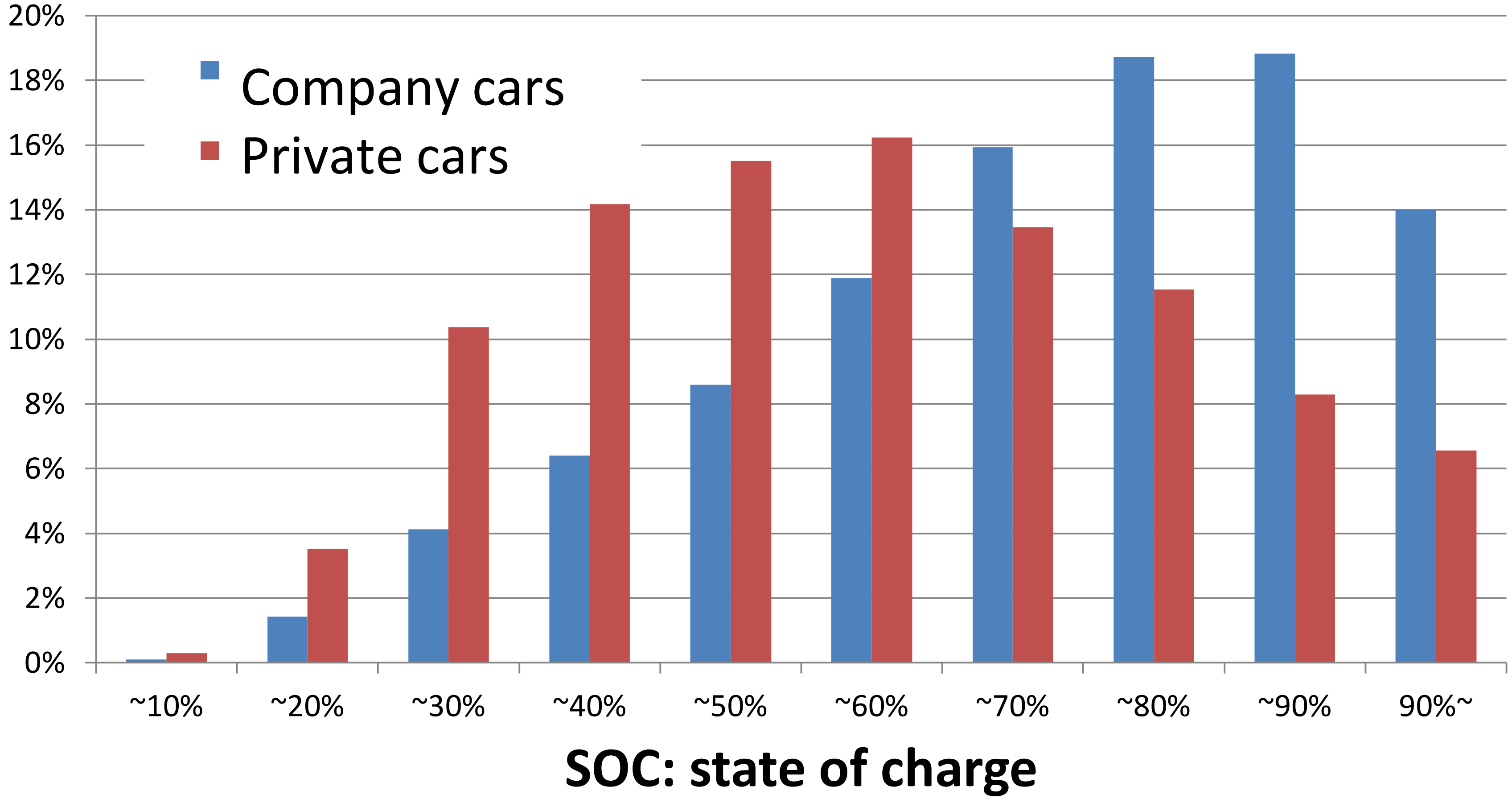
- Drivers charge battery before empty
- Charging behavior should be understood

Data

- Investigator: Japan Automobile Research Institute
- Sample: 252 company cars & 247 private cars
- Survey period: 2 years (2011.2-2013.1)
- Survey area: 42 out of 47 prefectures in Japan

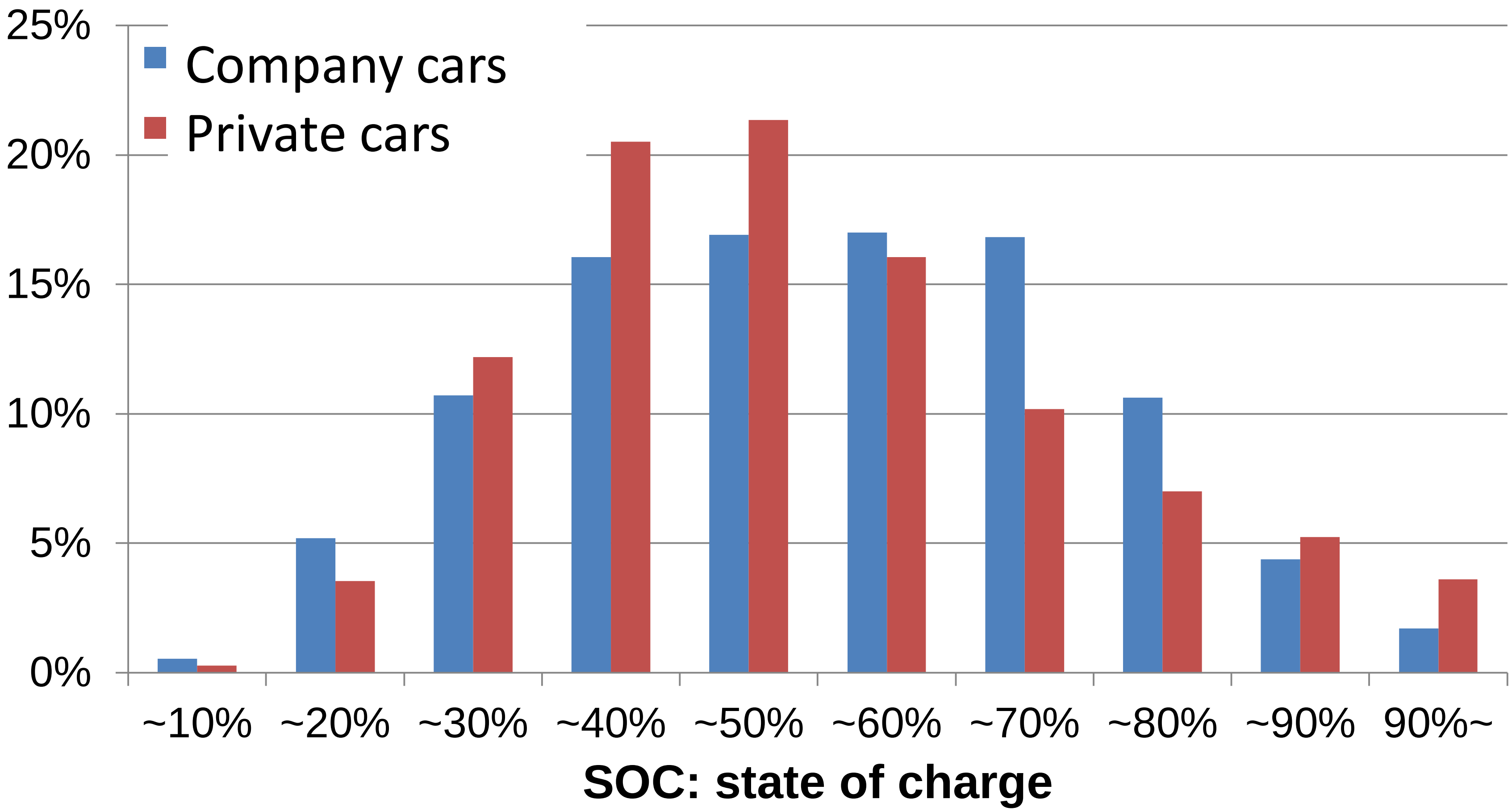
- **Built-in data logger with GPS & communication unit**: clock time, location, vehicle state (driving, normal charging, fast charging), odometer reading, use of air-conditioner & heater, state of charge

Distribution of SOC at normal charge



Company cars are charged at the end of the working hours regardless of SOC

Distribution of SOC at fast charge



Battery capacity is not fully utilized

Stochastic frontier model of SOC at fast charging within trip

- Driver avoids running out of power

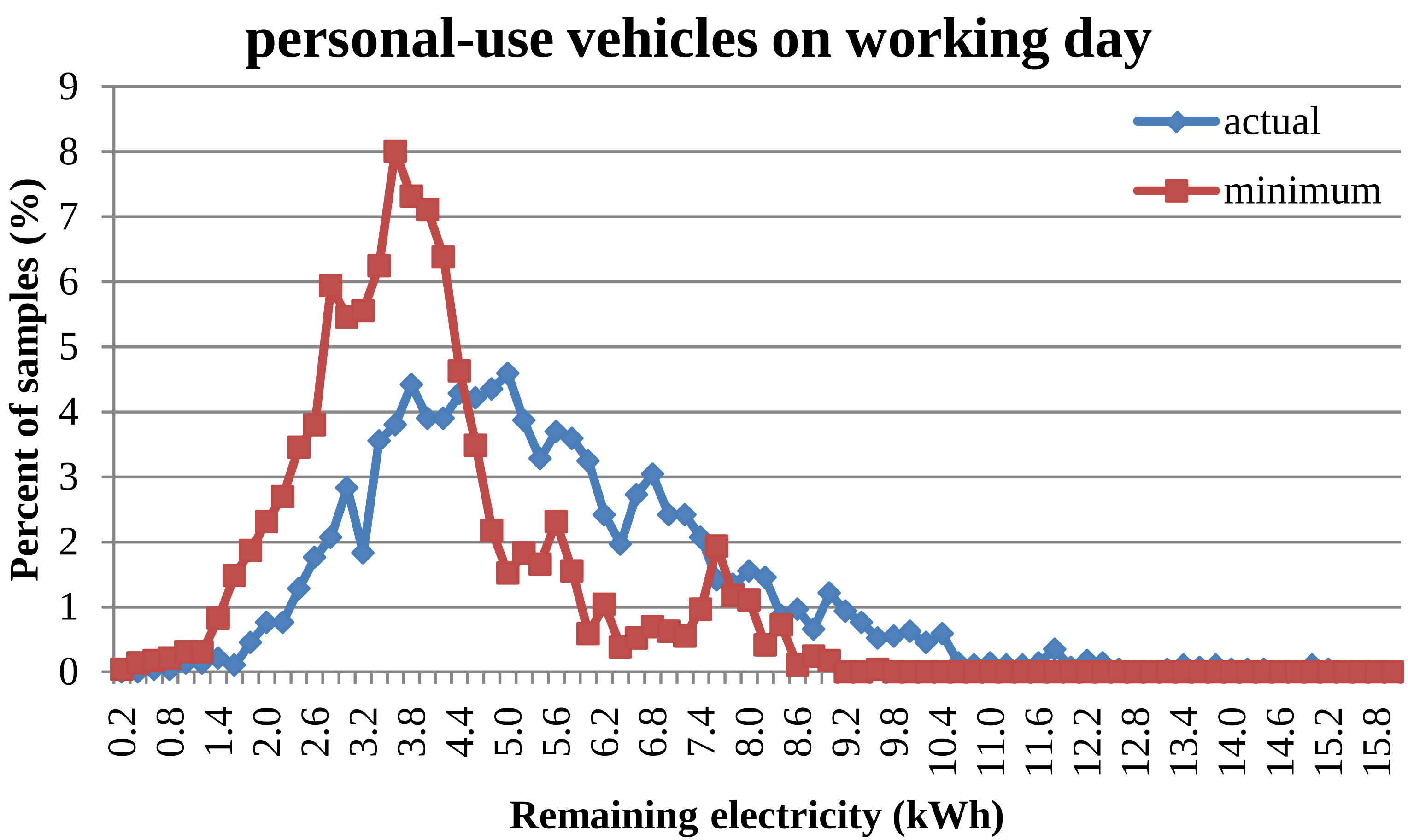
$$\boxed{\text{Actual remaining electricity to start charging}} \geq \boxed{\text{Subjective minimum electricity}}$$

- Inefficiency is added to minimum electricity

$$\boxed{\text{Actual remaining electricity}} = \boxed{\text{Subjective minimum electricity}} + \boxed{\text{Inefficiency}}$$

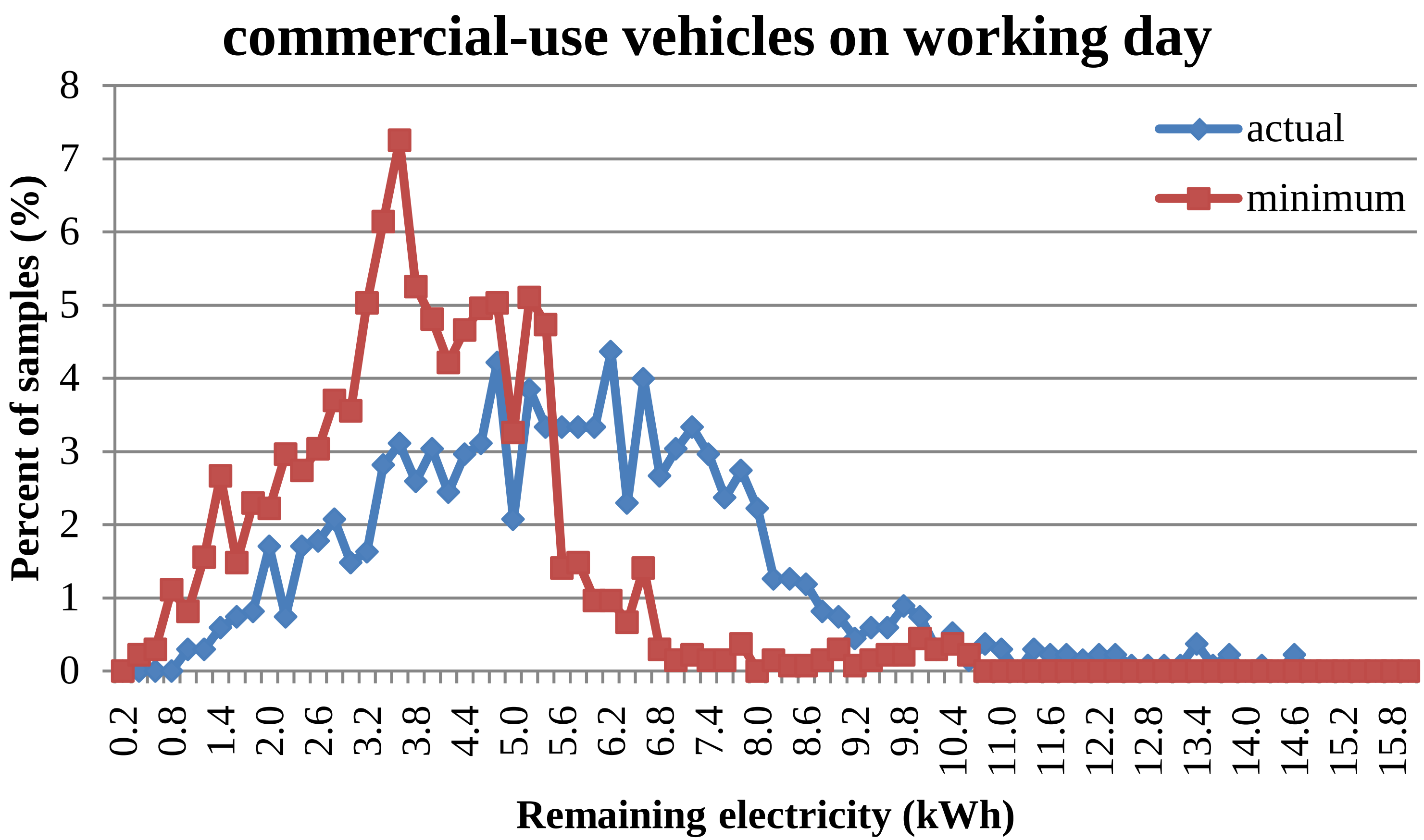
- Stochastic cost frontier model is applied

Distribution of subjective minimum and actual remaining charge



- Subjective minimum remaining charge has peak at 3.6kWh
- 1.5kWh of average inefficiency is estimated

Distribution of subjective minimum and actual remaining charge

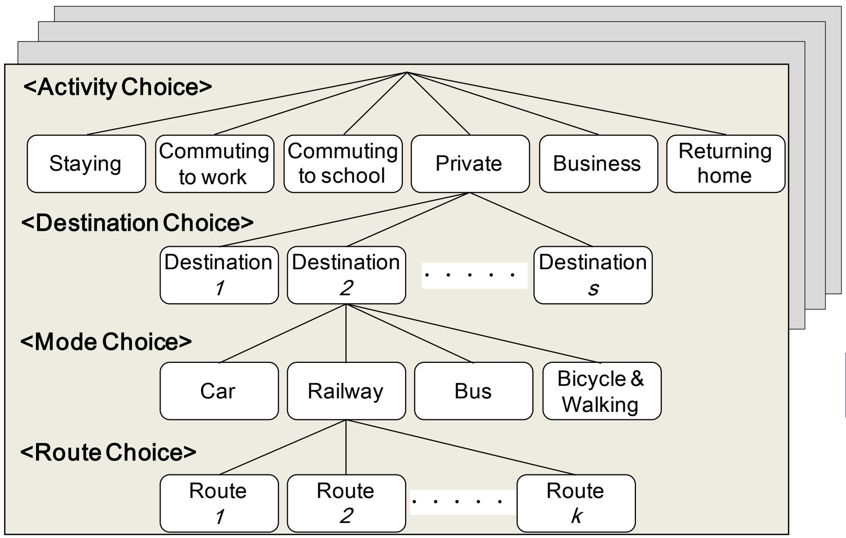


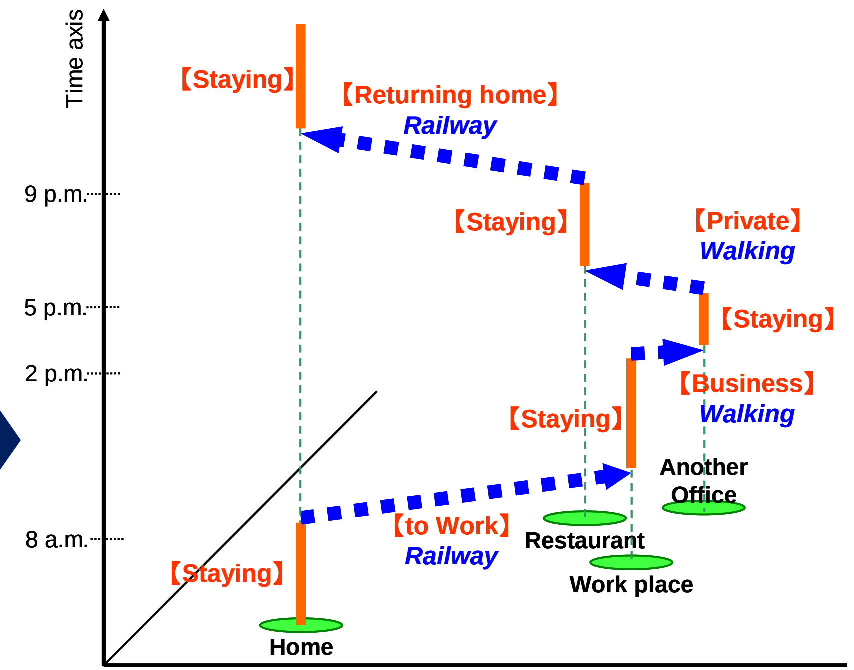
- Same peak of minimum remaining charge
- Larger (1.8kWh) average inefficiency is estimated

Vehicle to grid

- Impact of electric vehicles on electricity demand curve in Nagoya, Japan
  - This is a part of the research results funded under the Environmental Research and Technology Development Fund by Ministry of the Environment

Micro simulation model of individual's activity-travel pattern

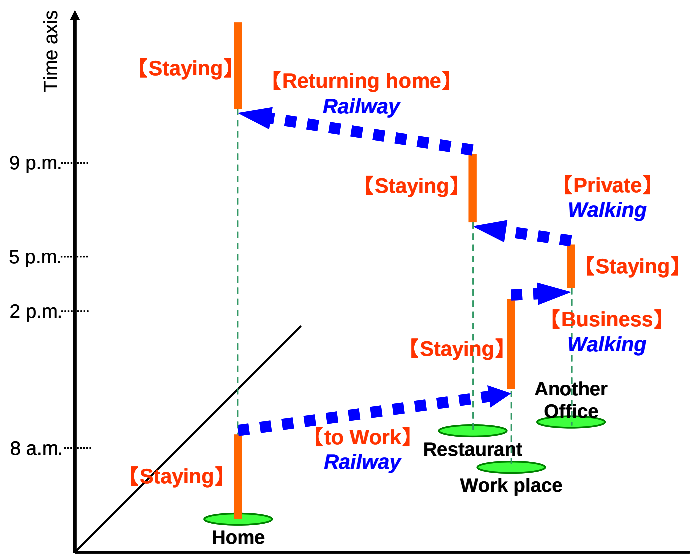




- Nested logit model of activity type, destination, mode and rail route choice at each time period
- Sequence of activity-travel pattern is simulated

Interaction between activity-based model & dynamic traffic assignment

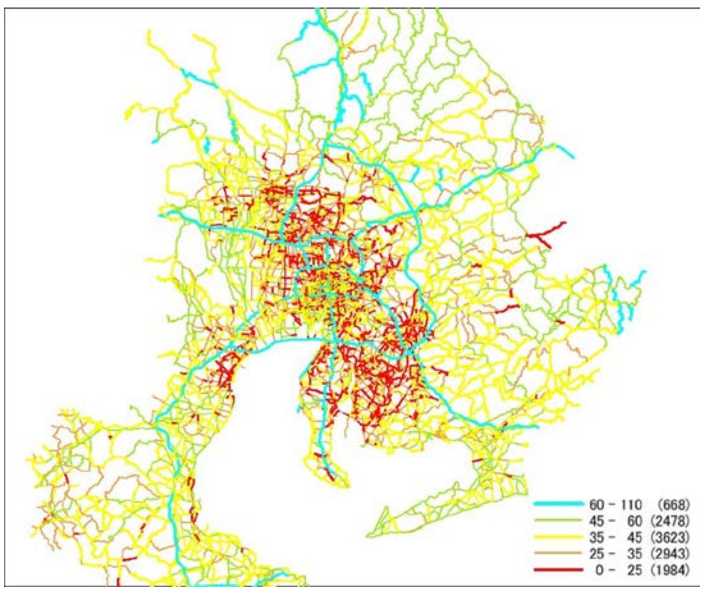
Equilibrium state is calculated



Travel pattern

OD demand

OD travel time

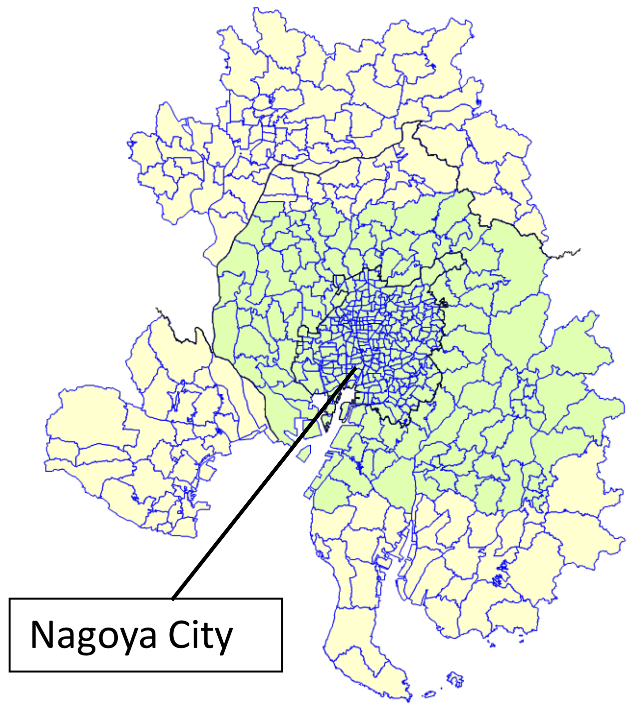


Link travel speed

- Parking location, parking duration, and SOC of each EV are simulated along time of day

Scenario analysis at Nagoya, Japan

■ Nagoya Metropolitan Area



<Population in 2020>

Over 8.0 million

<Zone>

520 zones

(Nagoya City is divided into 259

Average area is 1.3km^2)

<Road Network>

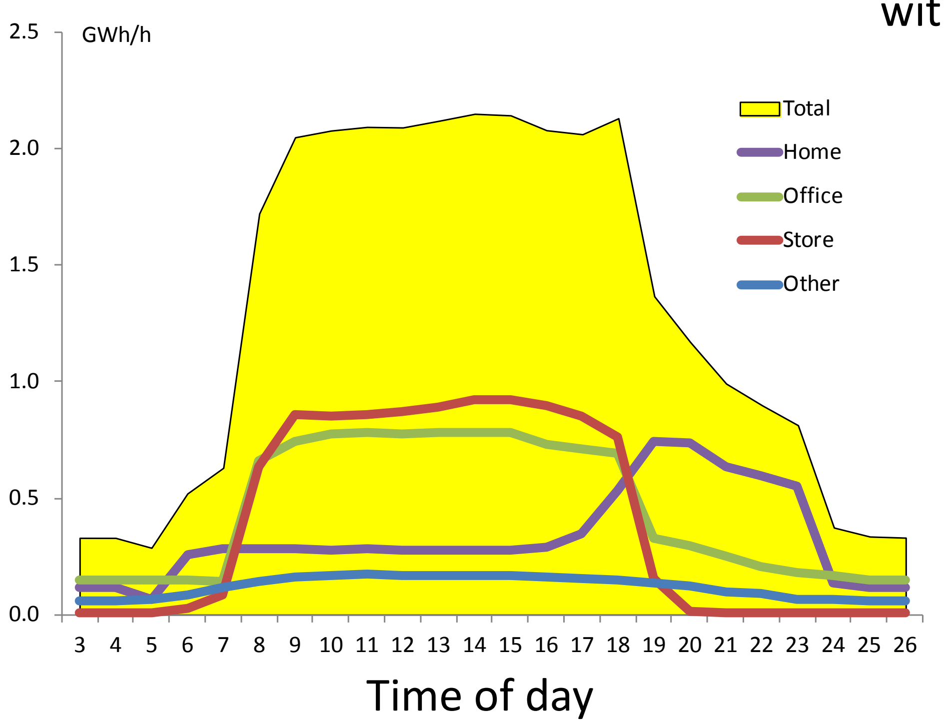
Link:22,466

Node:7,600

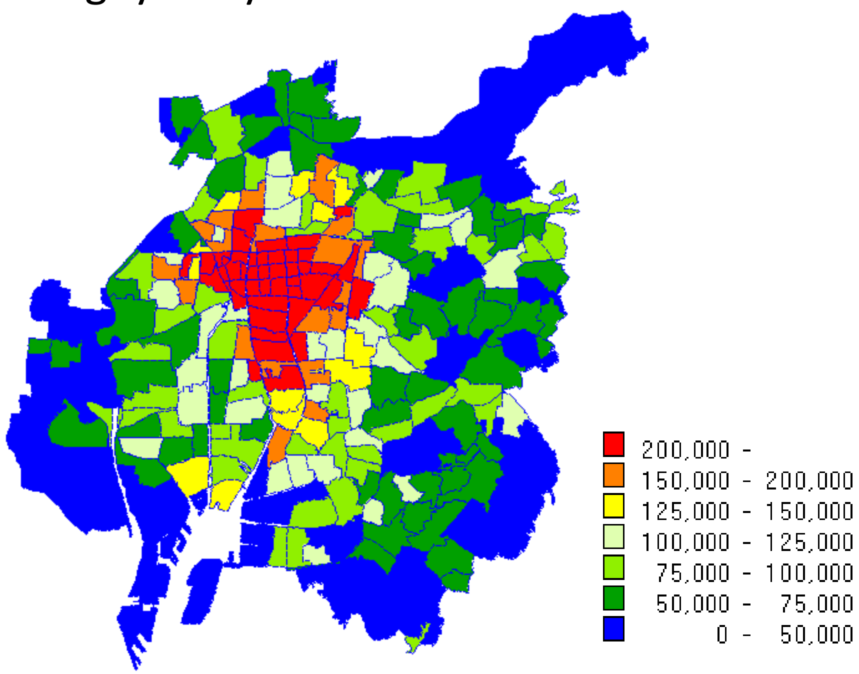
10% of vehicles are assumed to be replaced by EV, which means 472,000 EVs

Distribution of electricity demand

Electricity demand curve



Spatial distribution of electricity demand within Nagoya City

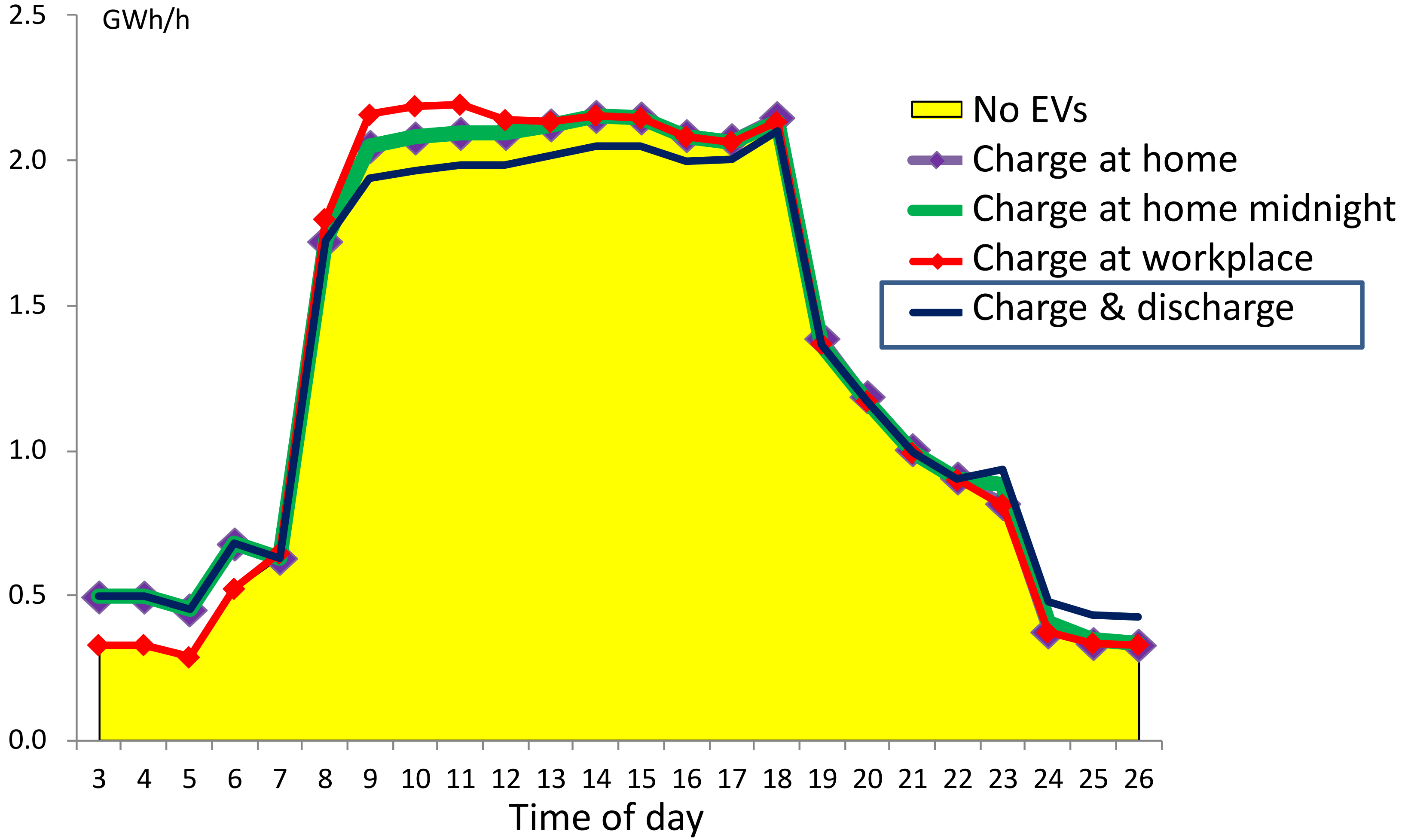


- Total demand is about 31GWh
- Higher demand at midday and at CBD

Scenarios for EV charging/discharging

- Case 0: No EVs
- Case 1: Charge at home immediately after returning home
- Case 2: Charge at home during midnight
- Case 3: Charge at workplace immediately after arriving at work
- **Case 4: Charge at home during midnight and discharge at workplace during daytime**
  (until the remaining charge at 5 kWh)

Impact on electricity demand curve



- 0.1GW of daytime demand (9:00 to 16:00) can be cut by vehicle to grid at workplace

Conclusions

- Battery charging at home causes significant electricity demand, but the timing can be controlled by peak pricing
- Battery capacity is not fully utilized, and measures to improve efficiency are needed
- Potential to cut down peak demand by vehicle to grid at workplace