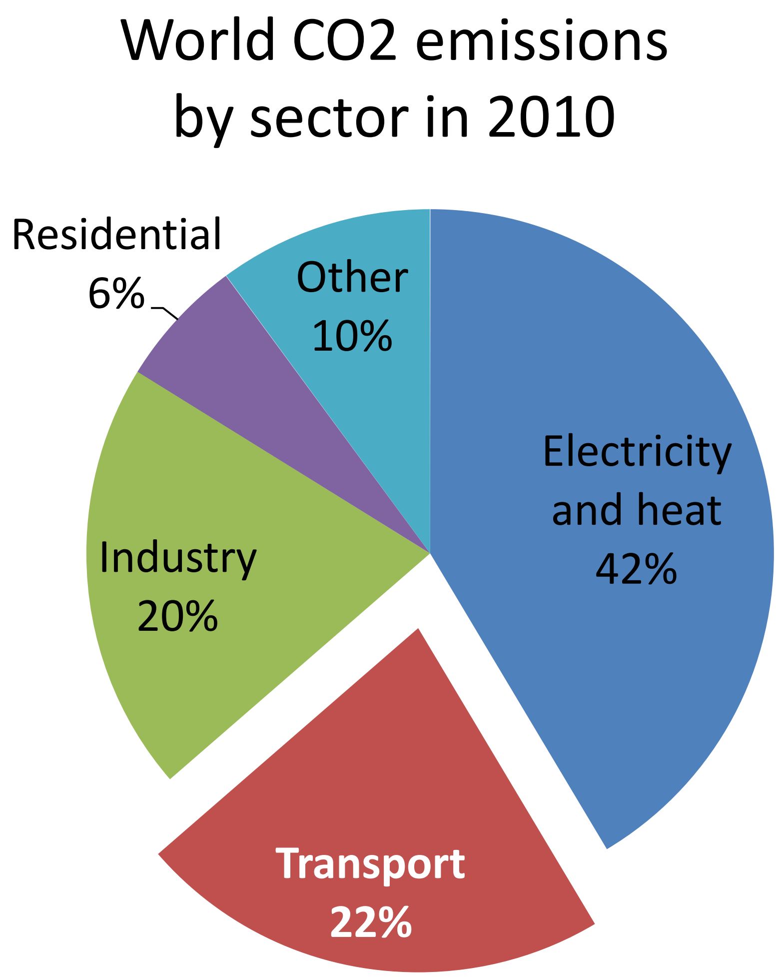
Analysis on the battery size and charging of plug-in hybrid vehicles

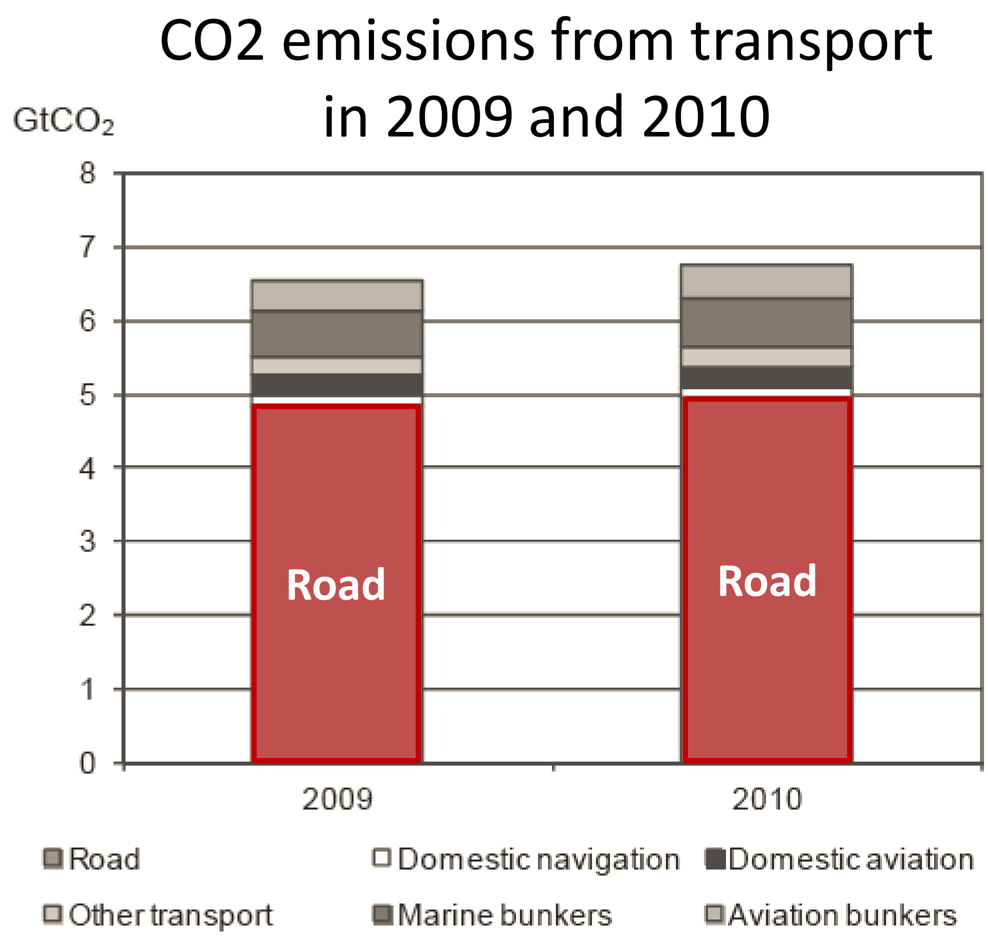
Toshiyuki Yamamoto
Nagoya University, Japan

Table of contents

- Background
  - EST: environmentally sustainable transport
- Car market in Japan
  - Fuel efficient cars: hybrid, plug-in hybrid, electric, etc.
- Analyses on battery of plug-in hybrid cars
  - Optimization of battery size
  - Off-peak battery charging

Transport accounts for a significant share of CO_2 emissions





Source: CO2 Emissions from Fuel Combustion, IEA, 2013

History of transport planning & EST

EST: environmentally sustainable transport

Structural strategy

Demand adjust
- TDM

Capacity increase
- Construction

Psychological strategy
- Mobility Management

Vehicle improvement
- Low emission
- Alternative fuel

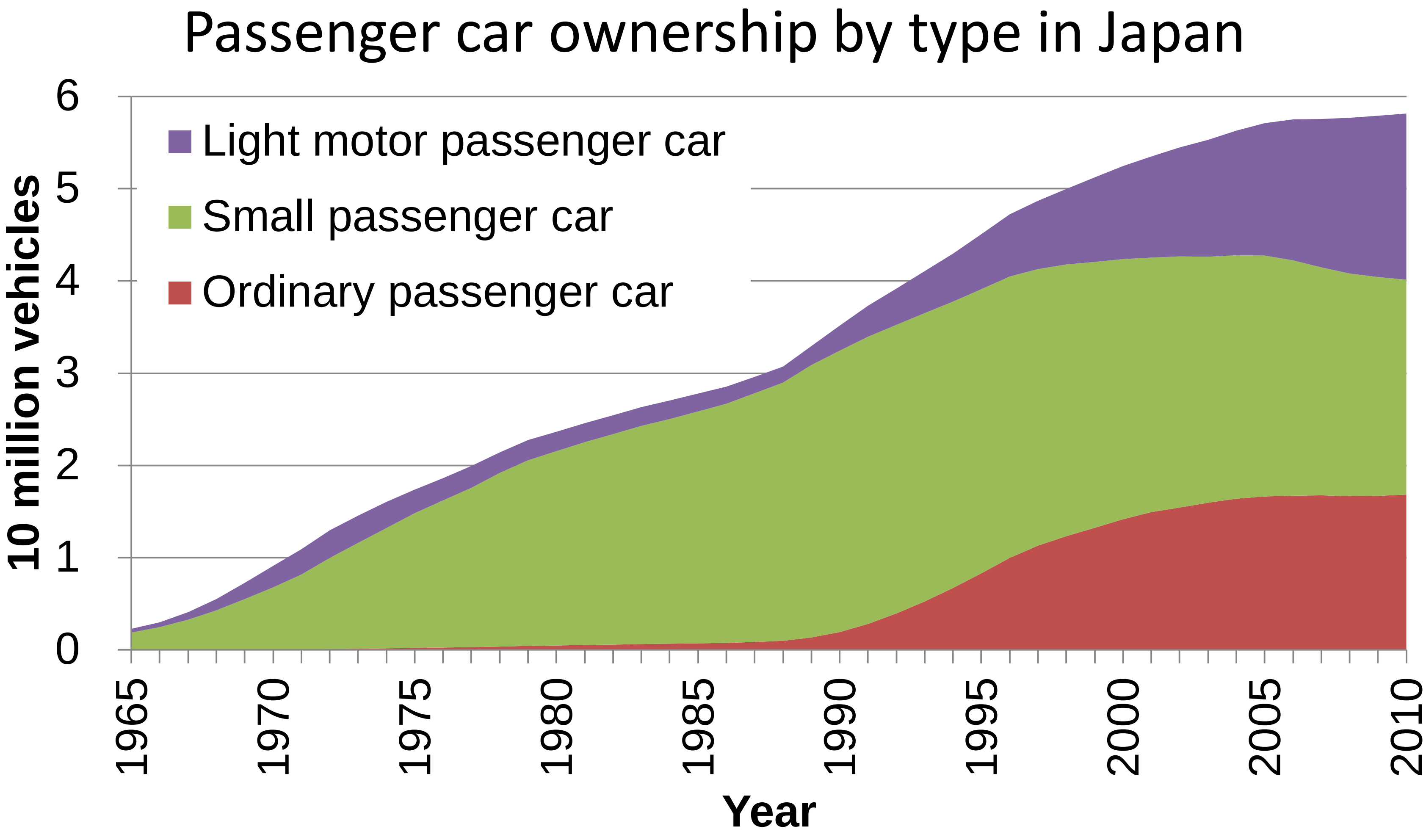
EST scenarios

- EST 1: The high-technology scenario
- EST 2: The capacity constraint scenario
- EST 3: The optimum-combination scenario

	EST 1	EST 2	EST 3
Technology development	>>BAU	=BAU	>BAU
Transport activity	=BAU	<<BAU	>BAU

Source: OECD, 1998

Car market in Japan



Source: MLIT

Passenger car sales ranking in Japan in 2012

Rank	Model (Automaker)	Sales	Engine type
1	Prius (Toyota)	317,675	**HV**
2	Aqua (Toyota)	266,567	**HV**
3	Mira (Daihatsu)	218,295	Light motor
4	N BOX (Honda)	211,156	Light motor
5	Fit (Honda)	209,276	Small / **HV**
6	Wagon R (Suzuki)	195,701	Light motor
7	Tanto (Daihatsu)	170,609	Light motor
8	Move (Daihatsu)	146,016	Light motor
9	Alto (Suzuki)	112,002	Light motor
10	Freed (Honda)	106,316	Small / **HV**

HV: hybrid vehicle

Source: Nikkei Newspaper

Electric vehicles and Plug-in hybrid vehicle in Japan

i-MiEV
2009

Leaf
2010

Prius plug-in hybrid
2012

More energy efficient, but
more electricity dependent

Optimization of battery size

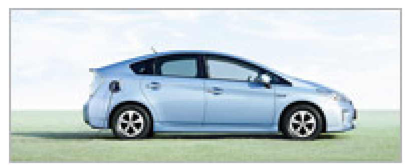
- Analysis on efficiency of plug-in hybrid vehicle using GPS survey data in Toyota City, Japan

Plug-in hybrid vehicle

- EV to HV after running out battery

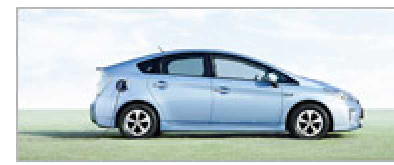
Charge at home

Run as EV



Daily trip

Run as HV



Longer trip

- Effect of battery size on efficiency

Small battery
- Lighter weight
- Shorter EV range
- Less expensive

Large battery
- Heavier weight
- Longer EV range
- More expensive

Vehicle use survey at Toyota City

CAN: Control area network
ODB: On-board diagnostics

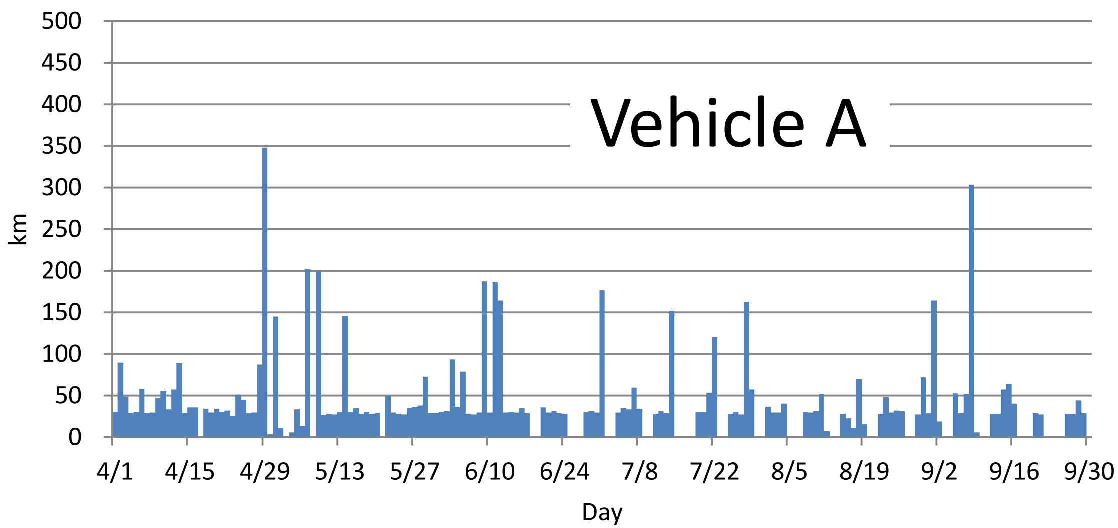
- April to Sept. 2011
- 157 vehicles (54 HVs)
- Trajectory by GPS & CAN logger

LED indicator

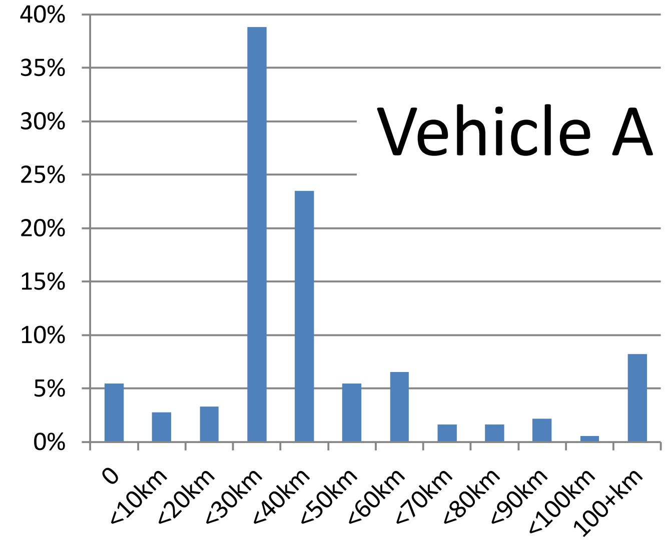
ODBII adapter

Observed vehicle usage patterns

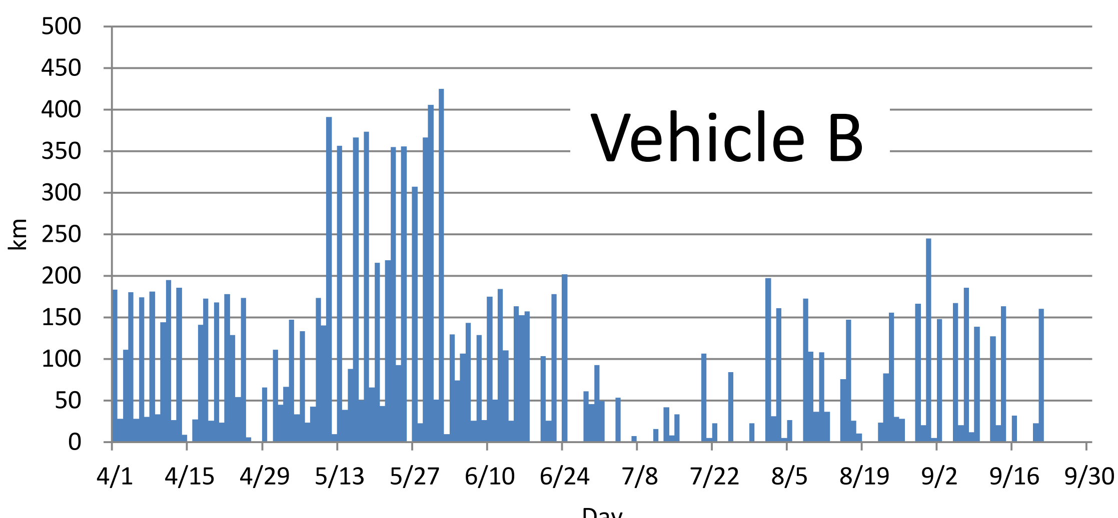
Travel distance by day



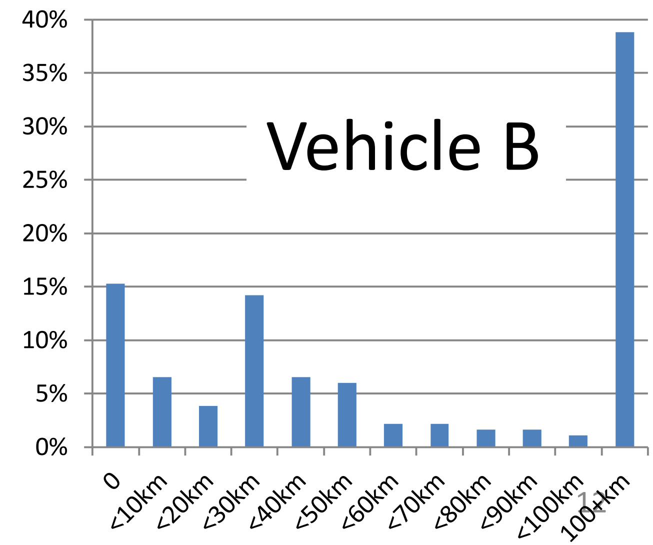
Distribution of dist.



Travel distance by day



Distribution of dist.

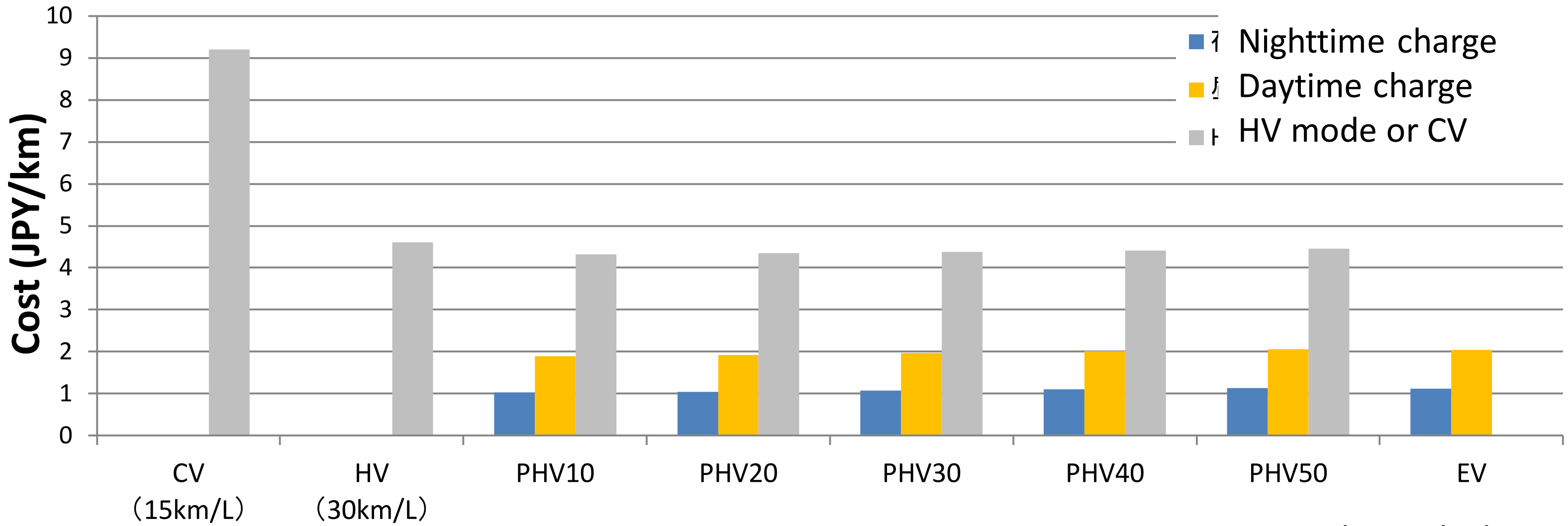


Assumptions: energy efficiency

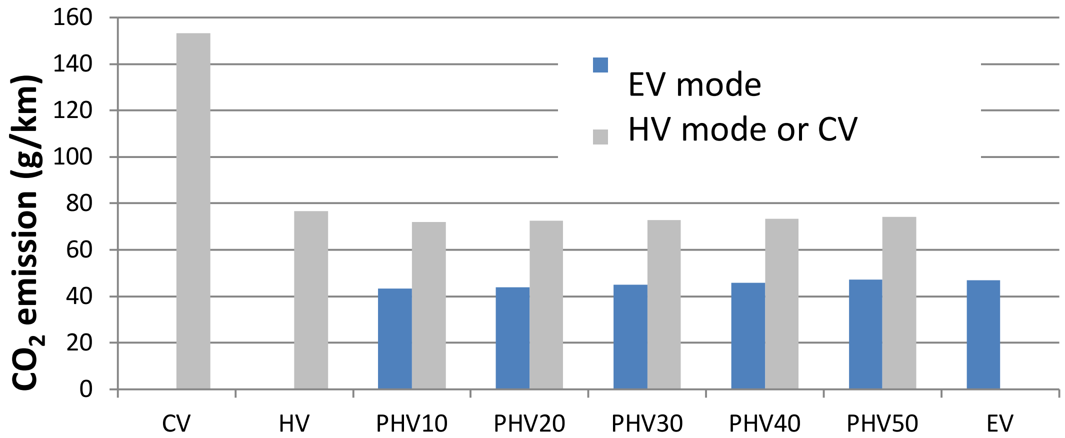
- Larger battery causes heavier weight, then lower running efficiency
- +100kg -> EV mode: -0.55 km/kWh
  HV mode: -0.67 km/L

Hypothetical Spec.	PHV10	PHV20	PHV30	PHV40	PHV50
EV range (km)	10	20	30	40	50
Battery size (kWh)	1.60	3.28	5.07	6.98	9.06
EV mode (km/kWh)	9.02	8.85	8.67	8.48	8.27
HV mode (km/L)	31.94	31.74	31.52	31.29	31.04

Assumption: Cost and CO2 per km



CV: gasoline vehicle

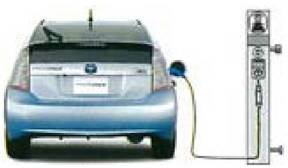


Gasoline (JPY/L)		138
Electric (JPY/kWh)	Daytime	17.05
	Nighttime	9.33
CO_2 emission (g)	Gasoline	2.3
	Electric	0.39

Assumption: charging timing

Charge once in a day at the beginning of the day

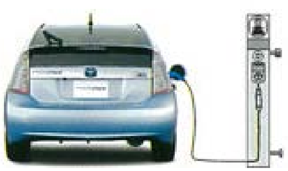
Case 1: One day travel distance < EV range



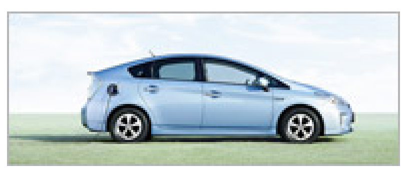
Run as EV

Cost = electricity price (JPY/km) × distance

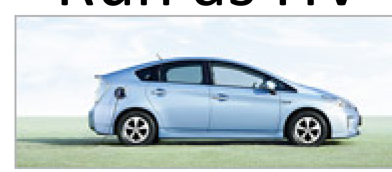
Case 2: One day travel distance > EV range



Run as EV

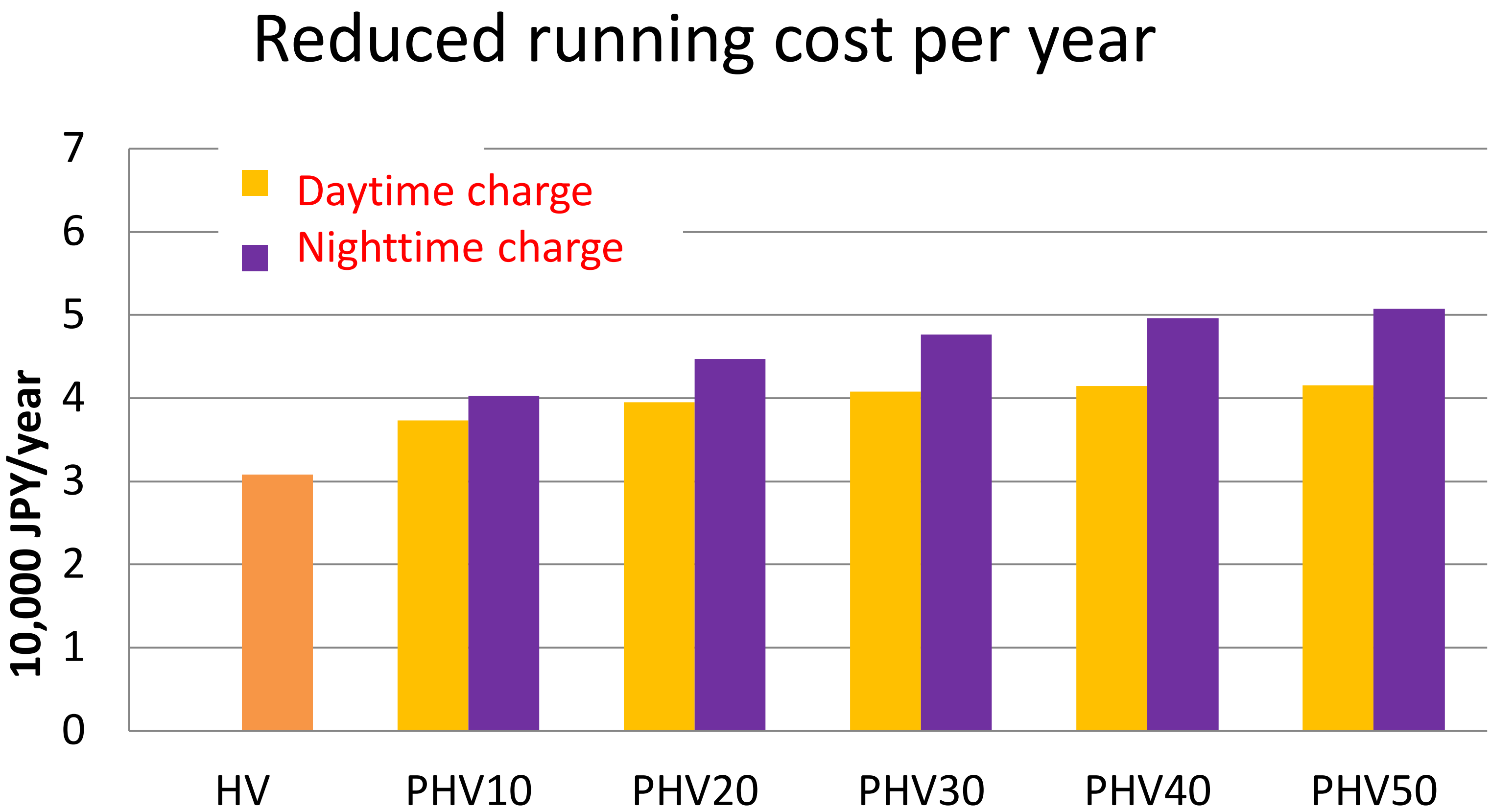


Run as HV



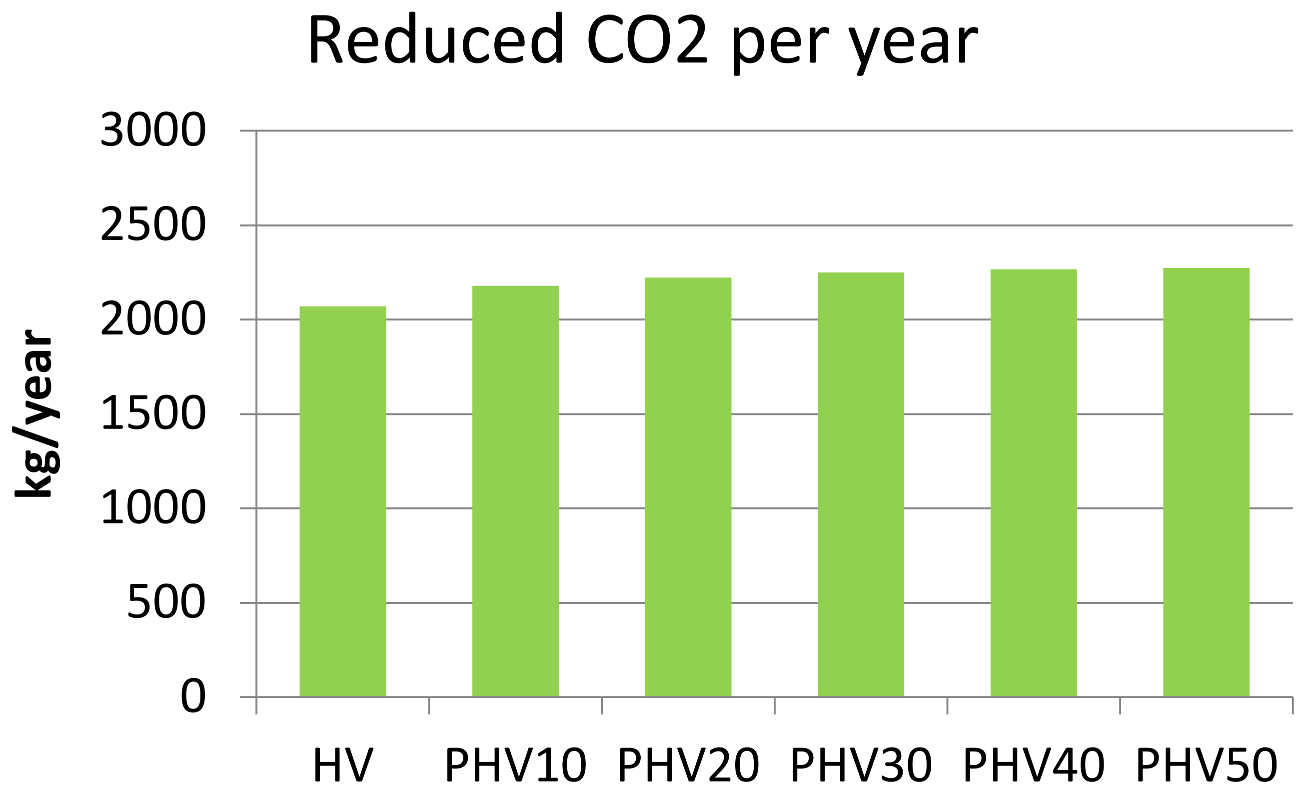
Cost = electricity price (JPY/km) × EV range
+ gasoline price (JPY/km) × (distance – EV range)

Results: All vehicles changes to one type of vehicle



- PHV is more cost effective than HV
- Larger battery is better for running cost, but the difference is small

Results: All vehicles changes to one type of vehicle



- PHV is more energy efficient than HV
- Larger battery is better for CO_2 reduction, but the difference is small

Results: if car price is considered?

Vehicle price	
Prius (grade S)	2,320,000 JPY
Prius PHV	3,200,000 JPY

Difference＝3,200,000 – 2,320,000
- 450,000 (subsidy by Government)
＝430,000 JPY

Average reduced running cost by replacing Prius to Prius PHV is **18,500 JPY**

More than 20 years ownership is needed to cover initial cost!

Average difference in running cost per year between HV（30km/L）and PHV

	PHV10	PHV20	PHV30	PHV40	PHV50
Running cost (JPY / year)	-10386	-15878	-19504	-22081	-23650
CO_2 emission (kg/year)	-110.7	-155.1	-181.9	-197.8	-204.1

Assumption: hypothetical subsidy

Government subsidy

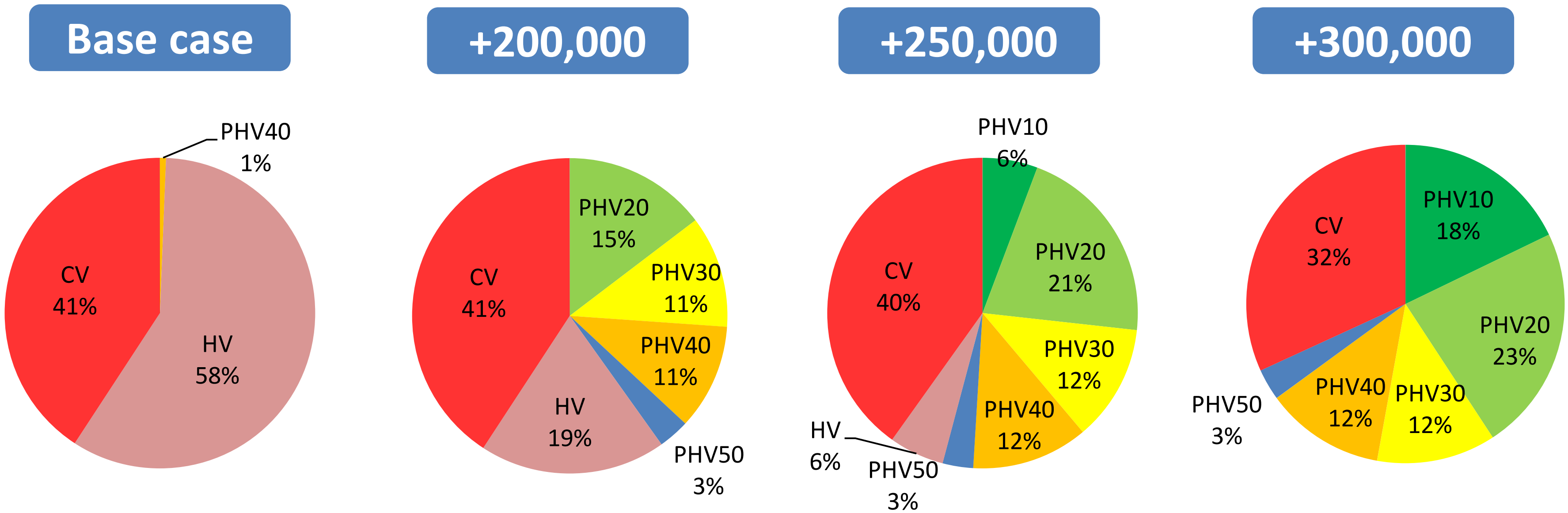
+200,000, +250,000, +300,000 JPY
(Tokyo & Aichi pref. exempt car tax for 5 years, which means about 200,000 JPY)

Car price

30,000 JPY / kWh for battery cost is assumed, and car price is adjusted according to battery size

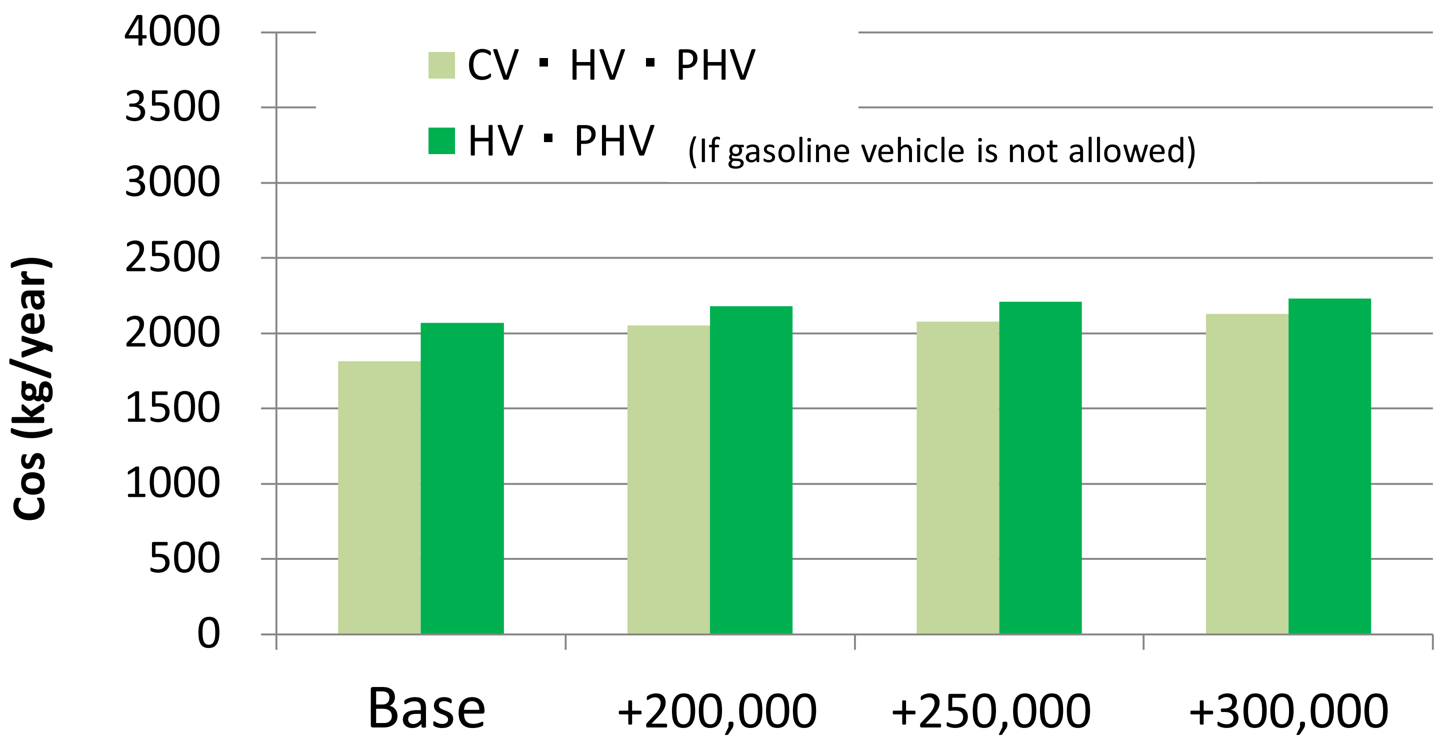
→ Most cost efficient vehicle is chosen for each driver considering 10 years of ownership

Results: most cost efficient car



- Without additional subsidy, PHV is not chosen
- More subsidy replaces HV by PHV

Results: CO2 reduction



- If gasoline car is prohibited, more reduction is gained
- More subsidy contributes few more reduction

Off-peak battery charging

- Analysis on charge timing choice behavior of plug-in hybrid vehicles in Toyota City, Japan

Smart Melit（Smart Mobility & Energy Life in Toyota City）project

- 67 new houses
- HEMS（Home Energy Management System）
- DRP (demand response point) system

Smart house

Visualization by HEMS (home energy management system)

DRP (demand response point) portal

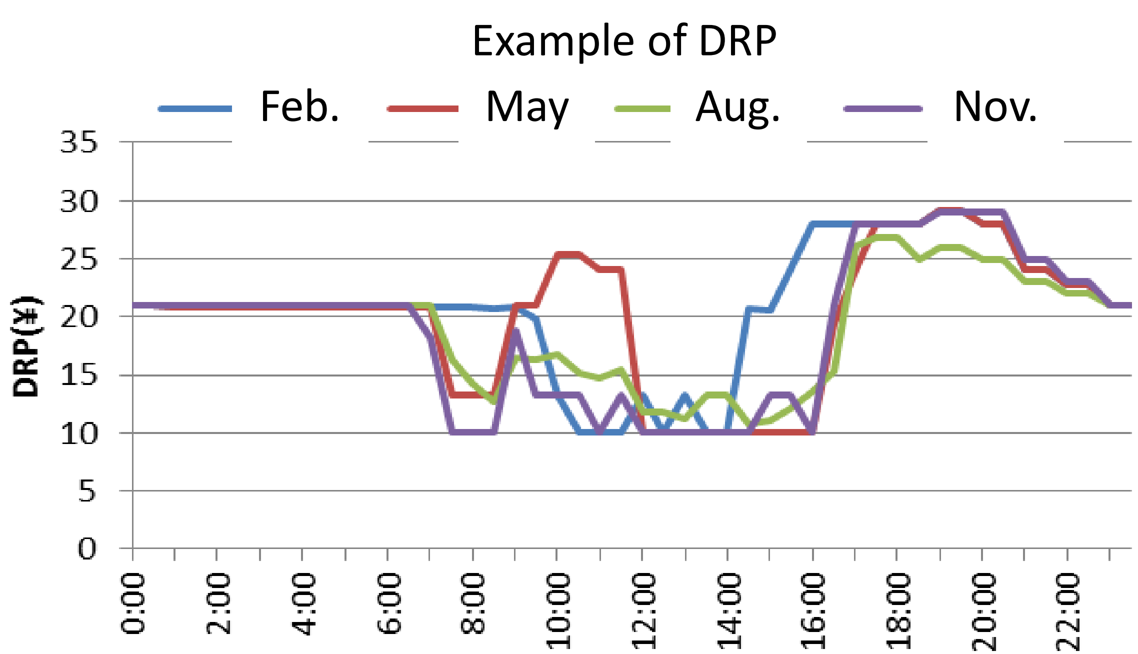
PHV charger

PHV charging

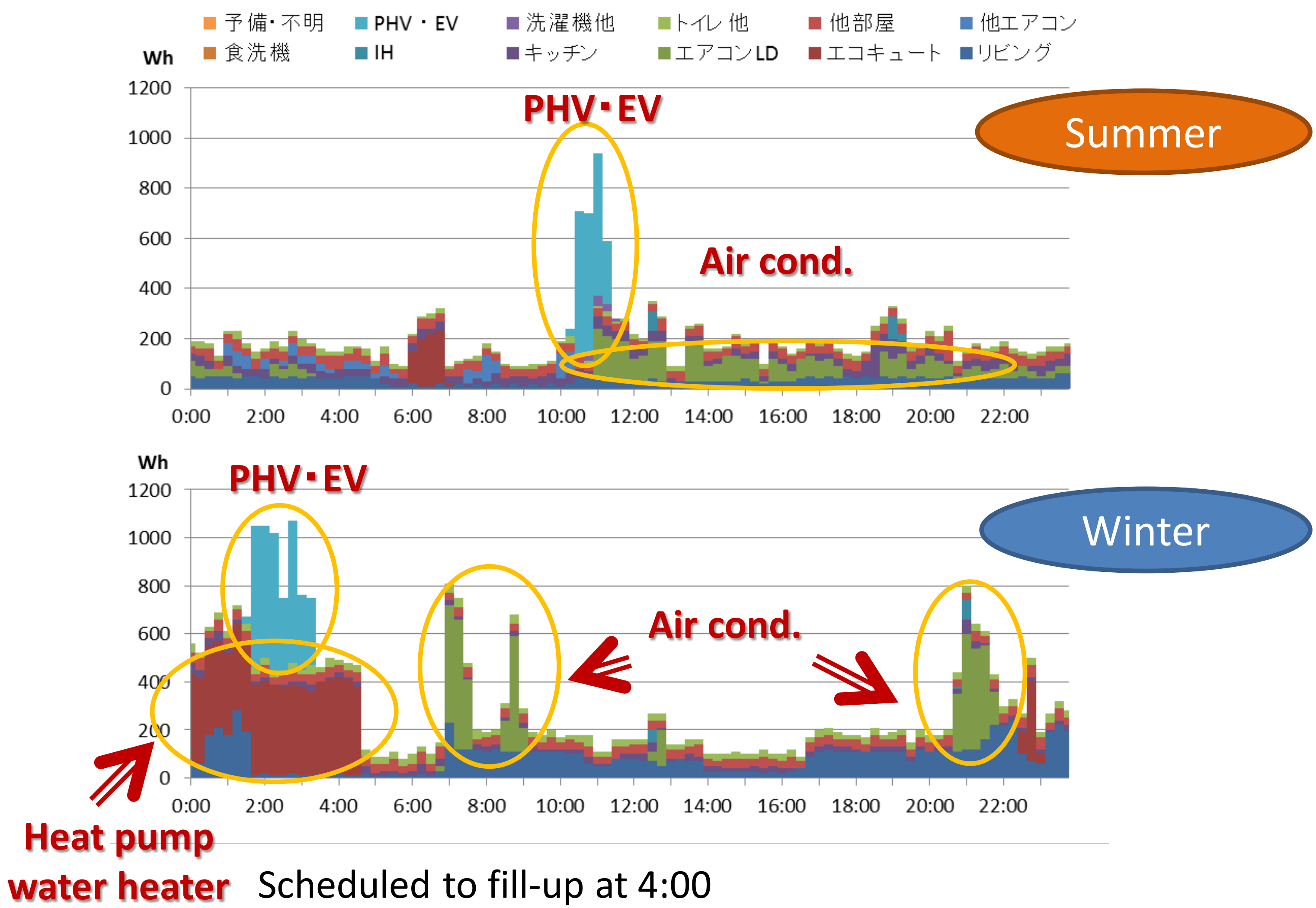
PHV charging

DRP (demand response point)

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



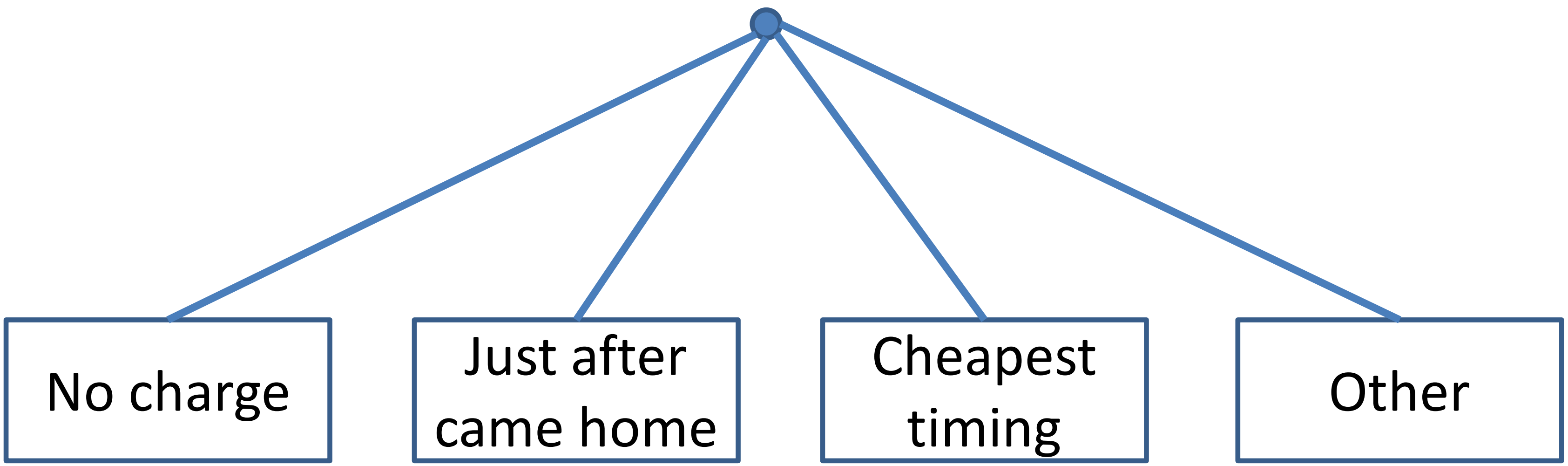
Example of electricity demand pattern



Scheduled to fill-up at 4:00

Charge timing choice behavior

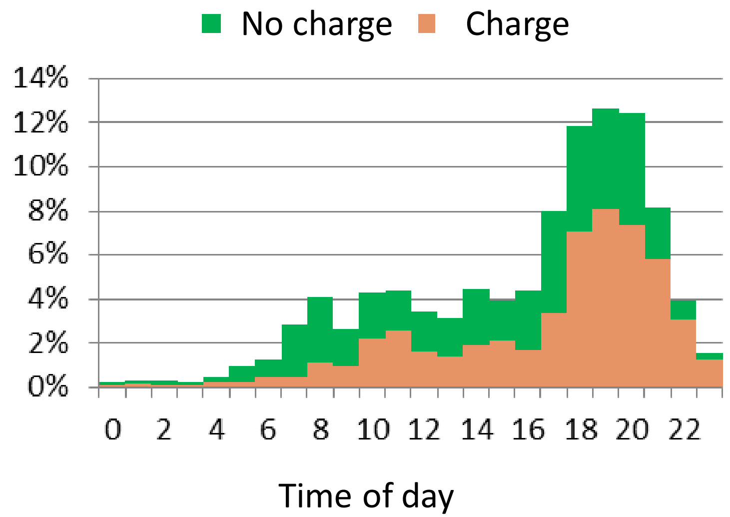
- Multinomial logit model



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

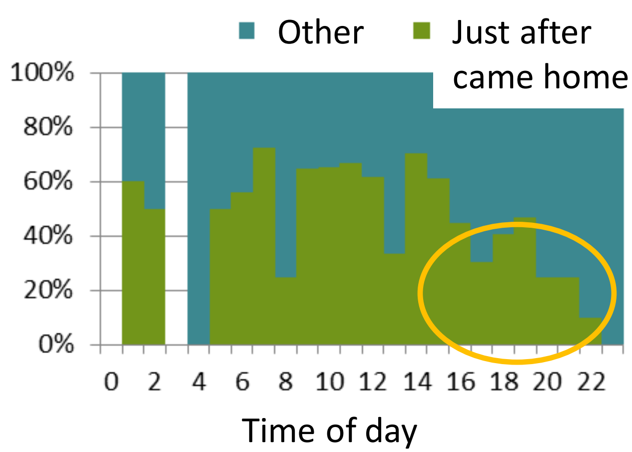
Descriptive analysis

Distribution of returning home timing

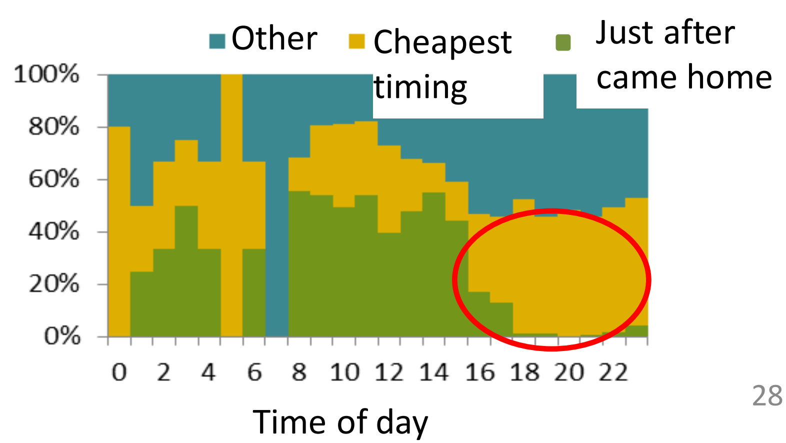


Charge timing choice by returning home timing

Without DRP

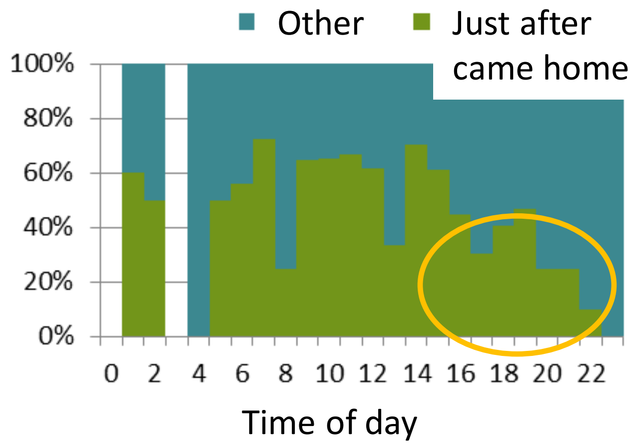


With DRP

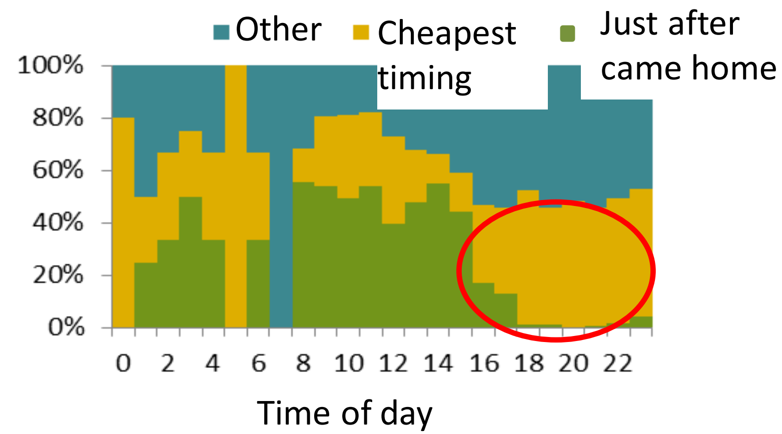


Charge timing choice by returning home timing

Without DRP

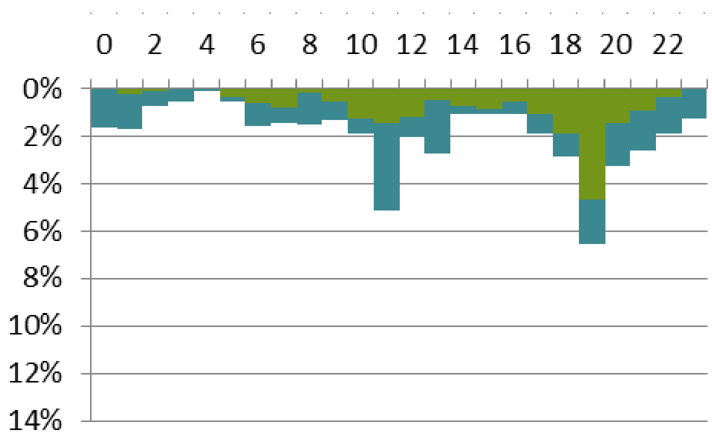


With DRP

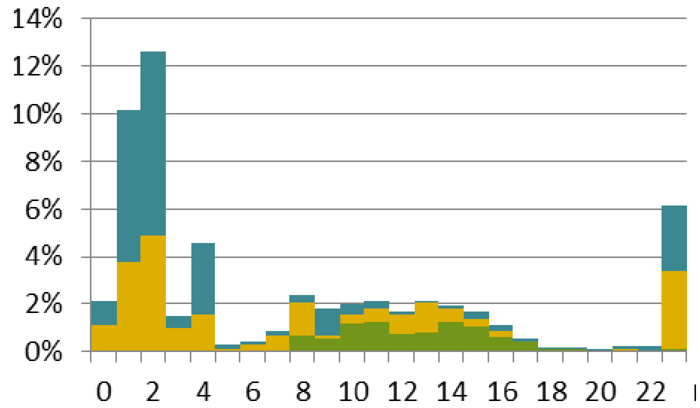


Resulting charge timing distribution

Without DRP



With DRP



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	**DRP** price for high ecological minded person	-0.044	**
	DRP price for low ecological minded person	-0.065	**
	Return home at daytime (9-16)	0.70	**
Cheapest time	Constant	-0.69	**
	DRP price for high ecological minded person	-0.016	**
	DRP price for low ecological minded 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:
Higher ecological minded male driver returned home in evening after 5 km drive

	No charge	Just after came home	Cheapest timing	Other
No DRP (20.9 JPY)	67%	12%		21%
Evening price 20.9 -> 28 JPY	48%	6%	**31%**	15%
Midnight price 20.9 -> 10 JPY	46%	6%	34%	14%
Distance 5km -> 20km	16%	9%	**53%**	22%

Conclusions

- More energy efficient vehicles, but more electricity dependent
- Larger battery does not necessarily means more energy efficient
- Peak spreading for battery charge can be brought by pricing