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Energy Economics Group

The impact of second life applications of electric vehicle batteries on customer’s mobility cost

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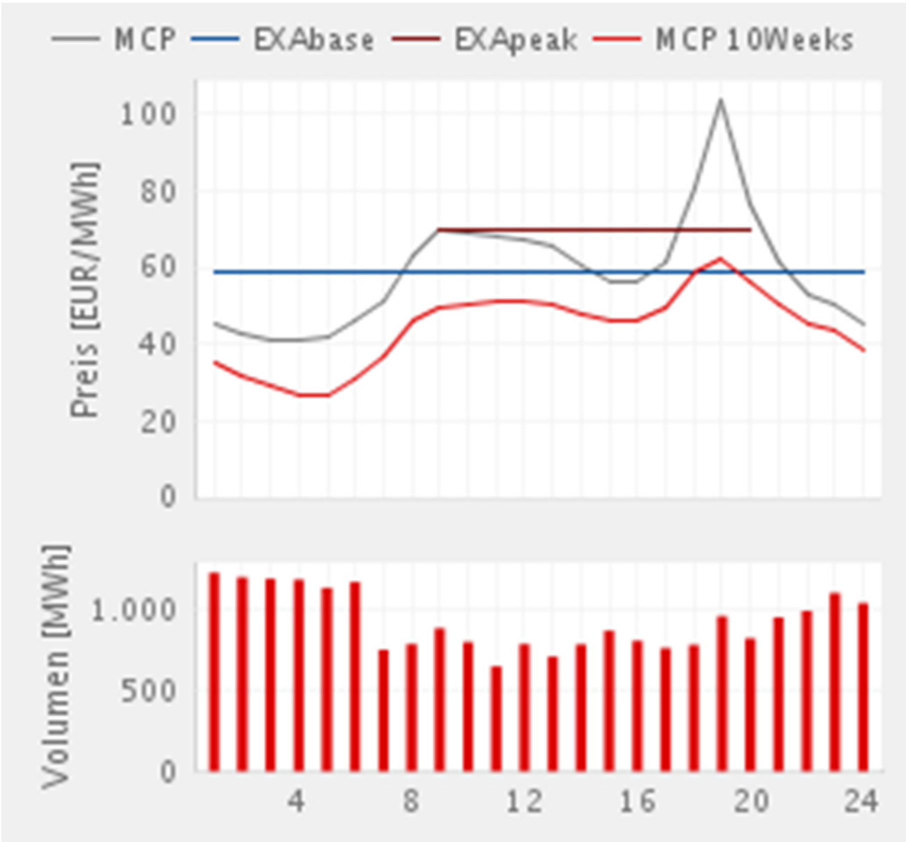
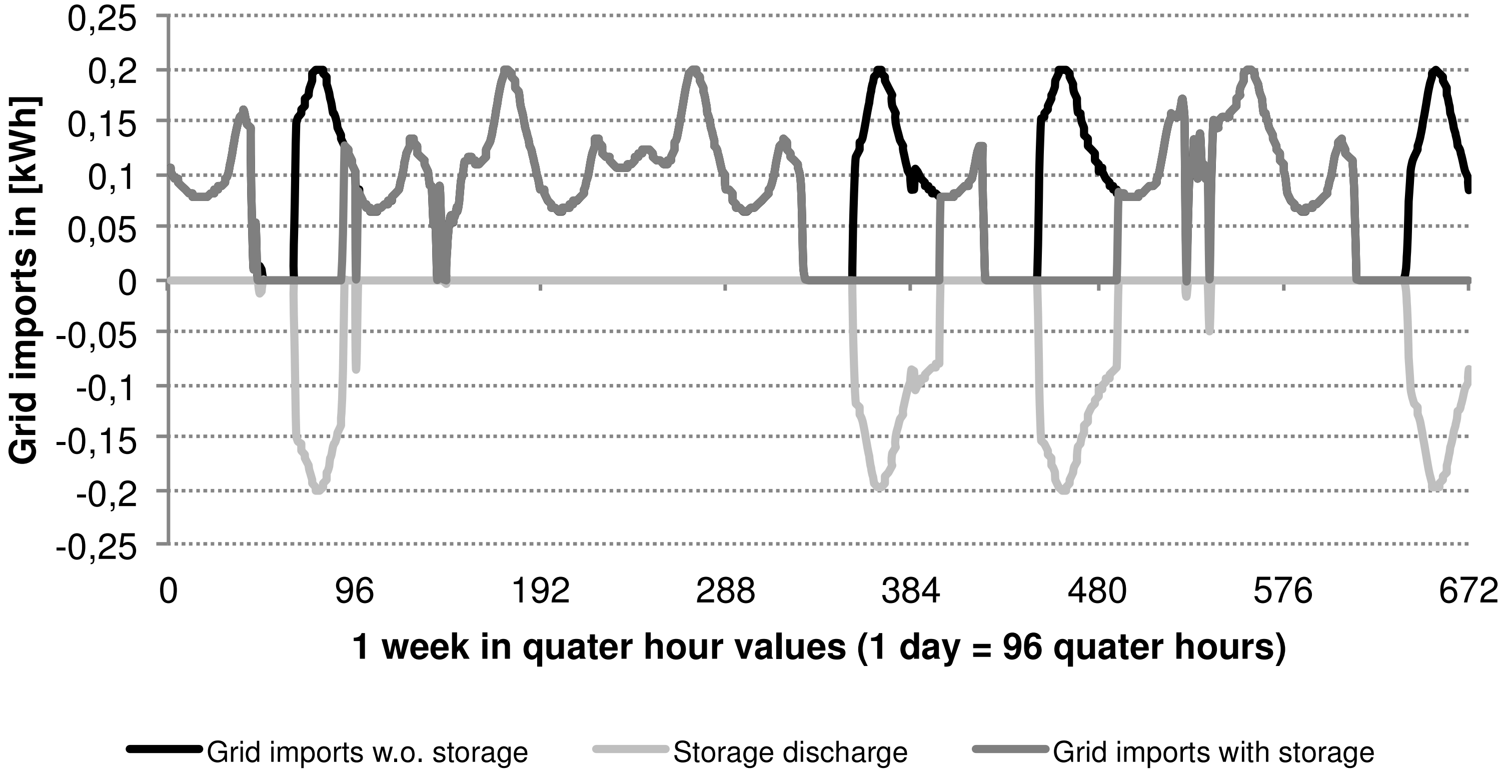


Quelle: www.exaa.at; Spot market electricity. 02.02.2012

Residential Load Following

H0 profile
4 kW PV generation
Battery 10 kW, 6 kWh



Data used

Battery assembling cost

Capacity of used batteries <= 80% of nominal value

Data type	Unit	Electric Energy Time-shift	Residential Load Following
Bat. Power	kW	10	10
Bat. Capacity	kWh	6	6
Battery life	yr	3,9	3,9
Project duration	yr	20	20
Battery purchases	-	6	6
Interest rate	%	6	6
Battery testing and packaging	$/module	96	96
BOS: Interface equipment, controls	$/kW	122	122
Operation and maintenance	$/kW	124	124

Source: Technical and Economic Feasibility of Applying Used EV Batteries in Stationary Applications, Sandia National Laboratories, Albuquerque, NM: 2002

E-mobility cost data

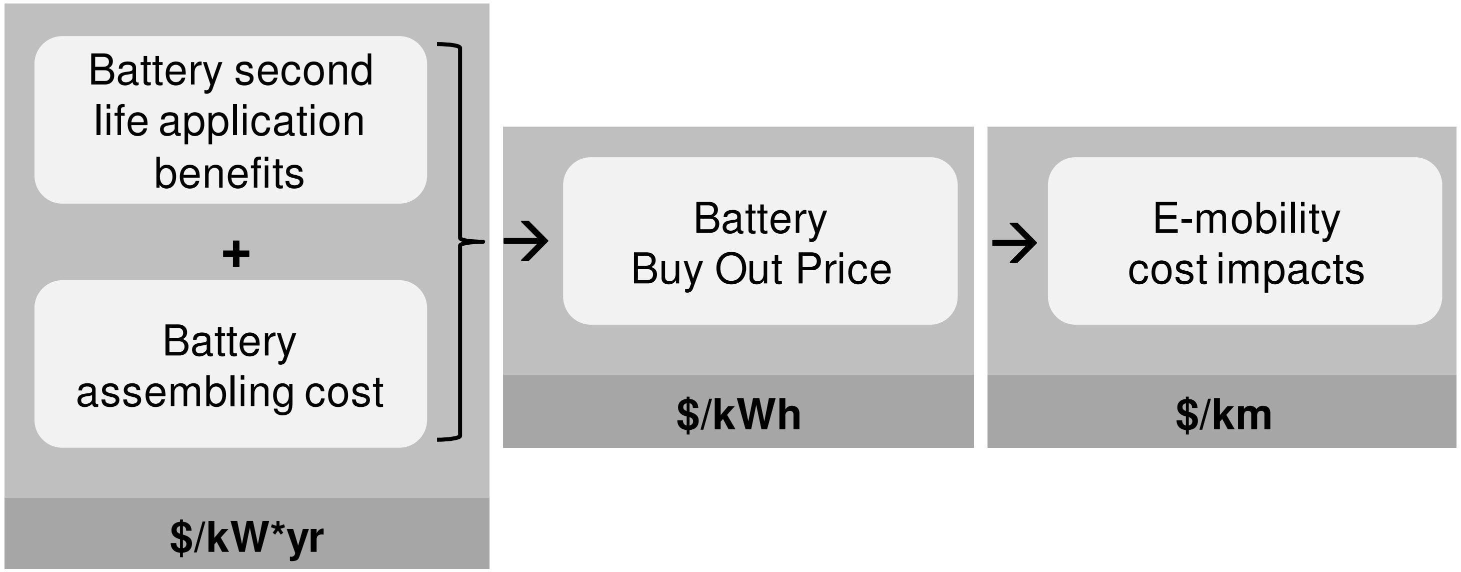
Data type	Variable name	Nissan Leaf (compact class)	Mitsubishi I-MiEV (compact class)	CODA Sedan (middle class)	Sources (see full paper)
Purchase price	EV_{cc}	32,780 $	42,160 $ (price in Japan) 30,000 $ (price goal in US)	44,900 $	[17], [18], [20]
Federal Tax Credit	TC	7,500 $	7,500 $	7,500 $	[5]
EV resale value	RV	5,000 $	5,000 $	7,000 $	assumption
Interest rate	r	6%	6%	6%	assumption
EV battery capacity	EV_{Cap}	24 kWh	16 kWh	33.8 kWh	[17], [19], [21]
Vehicle range per charge	-	160 km	130 km	160 km	[17], [19], [21]
Year of car return	V_c	6	6	6	assumption
Electricity cost of EV	RC_{EV}	0.015 $/km	0.012 $/km	0.021 $/km	Calculated at an electricity price of 0.1 $/kWh

Conventional cars cost data

Data type	Variable name	Gasoline compact class car	Gasoline middle class car	Source (see full paper)
Purchase price	EV_{cc}	14,8 k$	25 k$	[22]
EV resale value	RV	5,000 $	7,000 $	assumption
Interest rate	r	6%	6%	assumption
Fuel consumption per 100 km	-	6 litre	7.5 litre	[22]
Year of car return	V_c	6	6	assumption
Fuel cost of EV	RC_{EV}	0.044 $/km	0.055 $/km	Calculated at an average fuel price of 0.73 $/litre

Methodology

Overview



Electric Energy Time-shift

For an Electric Energy Time-shift battery application case the yearly benefits B_{Ts} calculate to

$$B_{Ts} = -\frac{C_{ch} - R_D}{NP_{Bat,Ts}} = -\frac{\sum_{d=1}^{365}\sum_{h=2}^{6} p_{d,h} * q_{d,h} - \eta * \left(\sum_{d=1}^{365}\sum_{h=12}^{13} p_{d,h} * q_{d,h} + \sum_{d=1}^{365}\sum_{h=19}^{20} p_{d,h} * q_{d,h}\right)}{NP_{Bat,Ts}} \quad (1)$$

with

B_{Ts}	Yearly benefits of Electric Energy Time-Shift	[$/kW*yr]
C_{Ch}	Yearly charging cost	[$/yr]
R_D	Yearly discharging revenues	[$/yr]
$NP_{Bat,Ts}$	Nominal power of battery storage for Time-shift application	[kW]
p	electricity price	[€/kWh]
q	quantity of sold or purchased electricity	[kWh]
d	day of the year	[1/yr]
η	storage efficiency	[%]
h	hour of the day	[1/d].

Residential Load Following

Yearly benefits of Residential Load Following applications including payments from the grid operator for reduced grid losses (L_r) are calculated by

$$B_{RLF} = \frac{R_{rg}}{NP_{Bat,LF}} + L_r = \frac{\eta * \sum_{i=1}^{n} q_i * IT}{NP_{Bat,LF}} + L_r \quad (2)$$

with

B_{RLF}	Yearly benefits of Residential Load Following	[$/kW*yr]
R_{rg}	Revenues for residentially generated and used electricity	[$/yr]
L_r	Grid loss reduction due to local energy storage	[$/kW*yr]
q	Quantity of stored and later used electricity	[kWh]
IT	Incentive tariff for own electricity use	[$/kWh]
i	Number of discharging event	[1]
$NP_{Bat,LF}$	Nominal power of battery storage for load following application	[kW].

Net Present Value of battery module purchases

For a given number of modules m, a dedicated project lifetime of P_{lt} and a specific battery pack lifetime (depending on yearly usage) the following Net Present Value of the battery storage system can be calculated (including reinvestments for depleted battery packs) by

$$NPV_{Bat} = (C_{t\&p} + C_{pack}) * \left(\frac{1}{(1+r)^0} + \frac{1}{(1+r)^a} + \frac{1}{(1+r)^b} + \dots + \frac{1}{(1+r)^z}\right) = (C_{t\&p} + C_{pack}) * Rf_{Bat} \quad (5)$$

with

NPV_{Bat}	Net Present Value of Battery	[$]
$C_{t\&p}$	Total cost of battery testing and packaging	[$]
C_{pack}	Total cost of necessary battery packs (used to calculate battery Buy Out Price – see equation (8))	[$]
a,b, ... z	Year of battery replacement	[1]
r	Interest rate	[%]
Rf_{Bat}	Repurchase factor for battery system	[1].

Overall battery system cost (incl. BOS)

In order to calculate overall battery system cost (B_{SC}) the following equation has to be considered

$$B_{SC} = \frac{(NPV_{Bat} + BOS_{Bat}) * \alpha + C_{O\&M,Bat}}{NP_{Bat}} = \frac{\left(\left(C_{t\&p} + C_{pack}\right) * Rf_{Bat} + BOS_{Bat}\right) * \alpha_{BS} + C_{O\&M,Bat}}{NP_{Bat}} \qquad (6)$$

with

B_{SC}	Overall battery system cost	[$/kW*yr]
BOS_{Bat}	Balance of System cost for battery storage system [$]	
α_{BS}	Annuity factor for battery system	[1/yr]
$C_{O\&M,Bat}$	Overall battery system Operation and Maintenance cost	[$/yr]
NP_{Bat}	Nominal power of battery storage system	[kW]

Battery Buy Out Price

$B_{SC} = B_{RLF} \vee B_{Ts}$

Out of equation (6) and a given overall battery system cost, which in the case of this paper are represented by the overall benefits of battery second life applications (B_{Ts}, B_{RLF} compare section 2), the cost for the battery pack (solely the used battery modules out of EVs) are given by

$$C_{pack} = \frac{(B_{SC} * NP_{Bat} - C_{O\&M,Bat}) - \alpha_{BS} * BOS_{Bat}}{\alpha * Rf_{Bat}} - C_{t\&p} \quad (7)$$

As a consequence, the Buy Out Price referred to the battery system capacity (in kWh) is then represented by

$$B_{OP} = \frac{C_{pack}}{S_{Cap}} \quad (8)$$

with

B_{OP}	Buy Out Price for electric vehicles batteries	[$/kWh]
S_{Cap}	Total battery storage capacity	[kWh]

EV cost impacts

Customer's EV related mobility cost taking into account case specific Buy Out Prices are given by

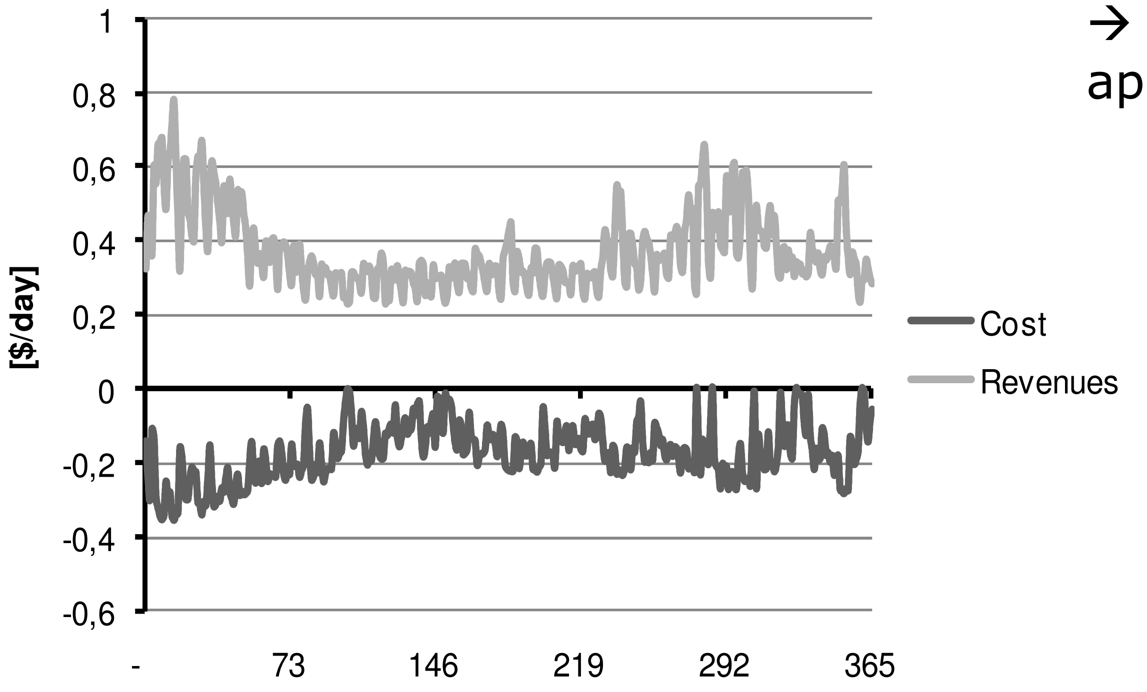
$$MC = \frac{\alpha_{EV} * \left(EV_{cc} - TC - \frac{RV}{(1+r)^{Vc}} - \frac{(EV_{Cap} * B_{OP})}{(1+r)^{Vc}}\right)}{D_d} + RC_{EV} \quad (9)$$

whereas

MC	Cost of electric mobility for customers	[$/km]
α_{EV}	Annuity factor for electric vehicle	[1/yr]
EV_{cc}	Electric vehicle purchase price	[$]
TC	Total tax credit for EV	[$]
RV	Rest value of vehicle when returned to dealer after V_c years	[$]
r	Interest rate	[%]
V_c	Year in which car is returned to car dealer and batteries first circle ends	
EV_{Cap}	Electricity storage capacity of EV battery	[kWh]
RC_{EV}	Running cost for fuel of electric vehicle	[$/km]
D_d	Distance driven per year	[km/yr]

Application Results

Electric energy time shift

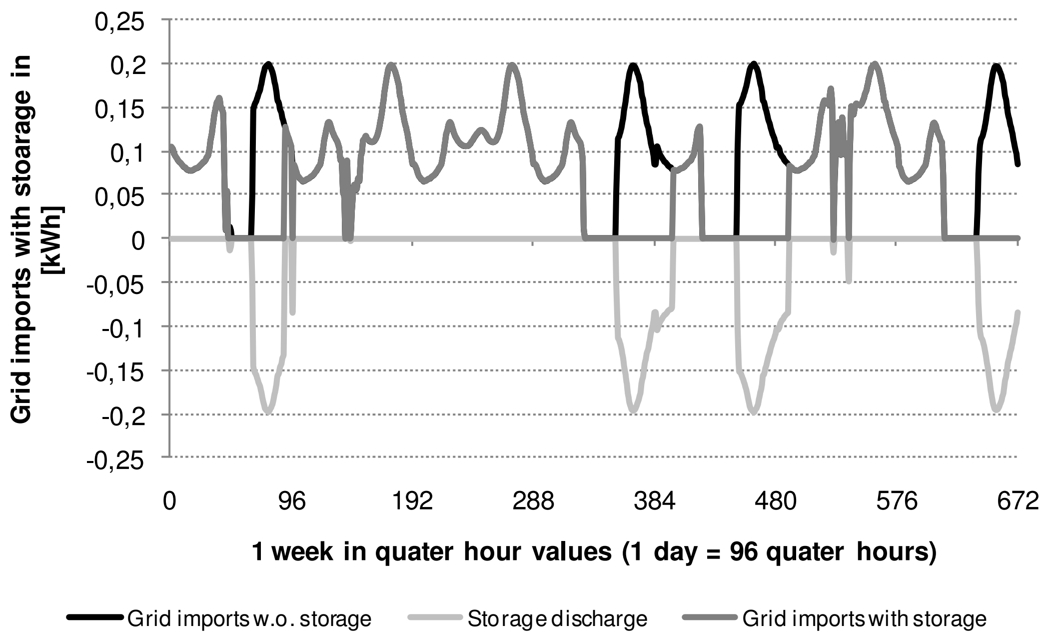


Benefits of 5.4 $/kW*yr are calculated for the case study

→ Not a feasible application

Application Results

Residential Load-Following



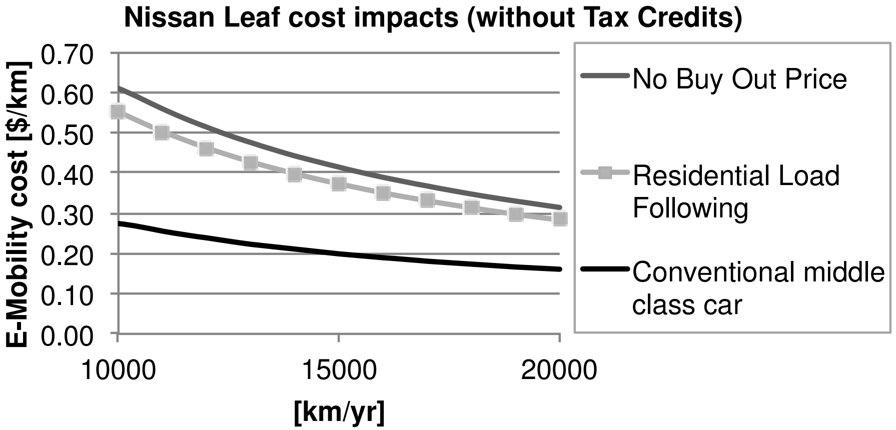
Benefits of 76.4 $/kW*yr are calculated for the case study

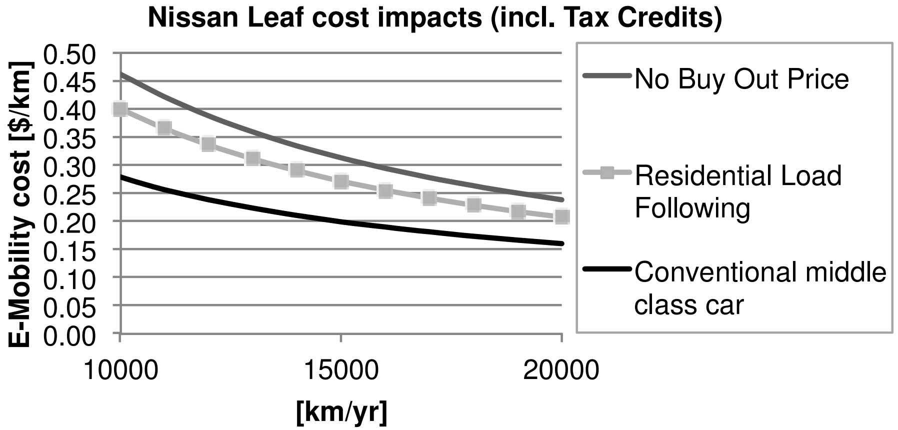
→ Max. Buy Out Price calculates to approx. 180 $/kWh (battery capacity)

EV cost impacts

„Nissan Leaf"

13% cost reduction if 10.000 km/yr are driven (incl. Tax Credit)



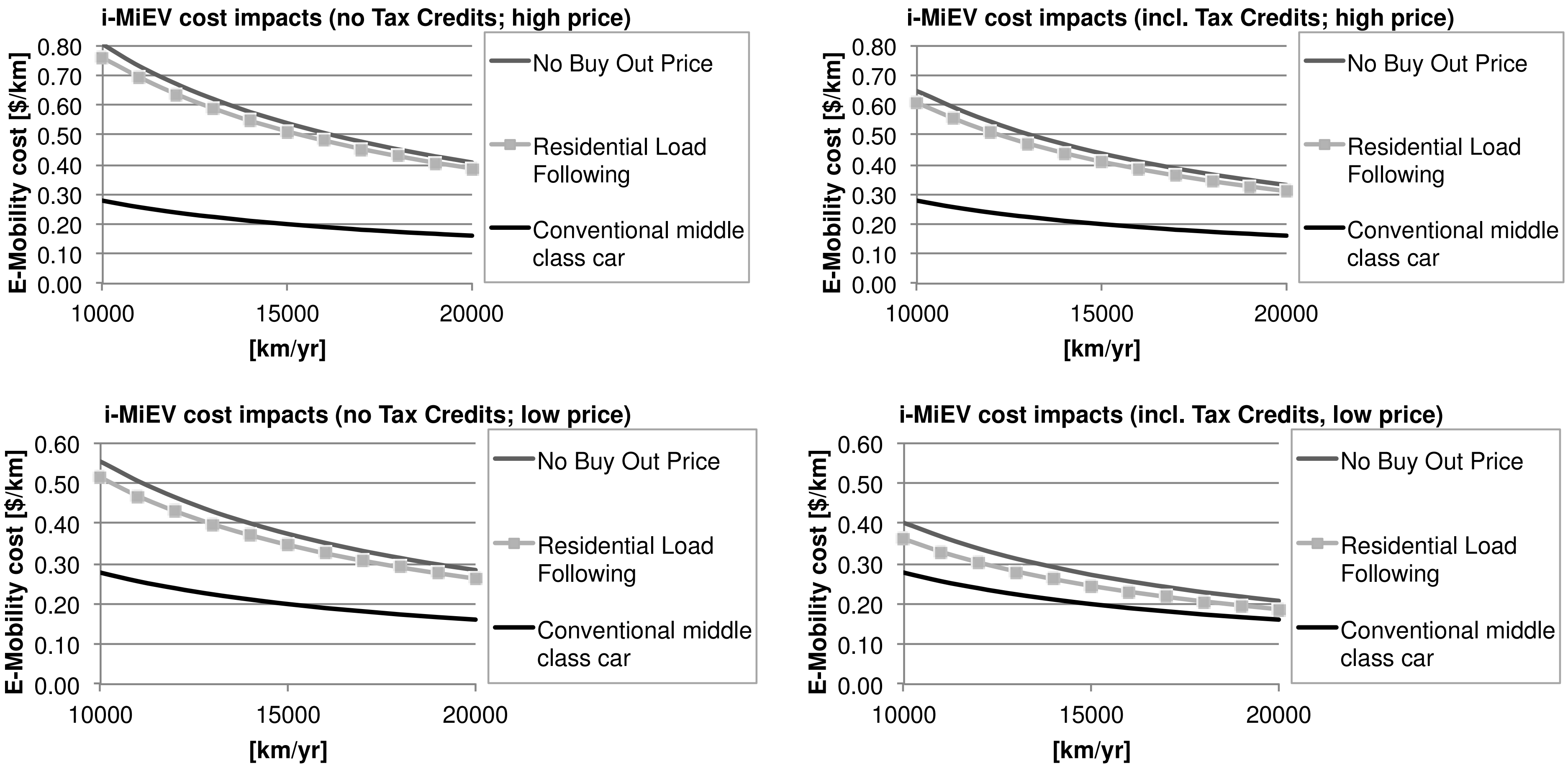


Gap of about 5 c$/km if 20.000 km/yr are driven (incl. Tax Credit)

EV cost impacts

6.3% to 8.9% cost reduction if 10.000 km/yr are driven (incl. Tax Credit)

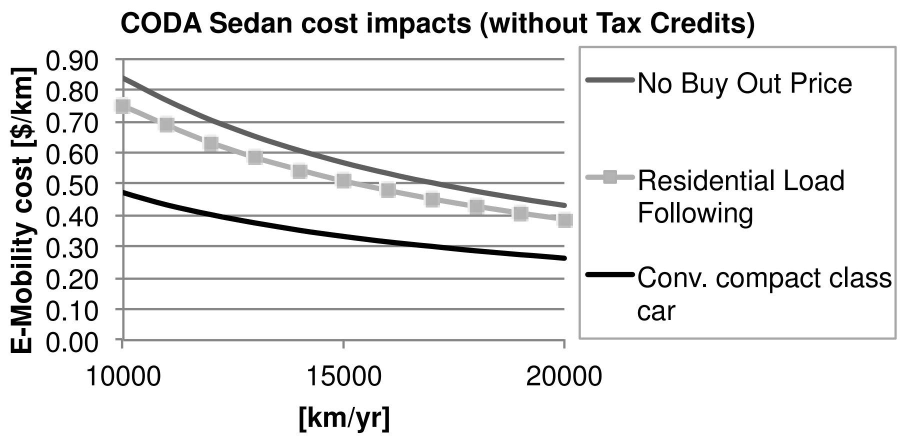
„iMiev" (EV cost = 42 k$ vs. 30 k$)

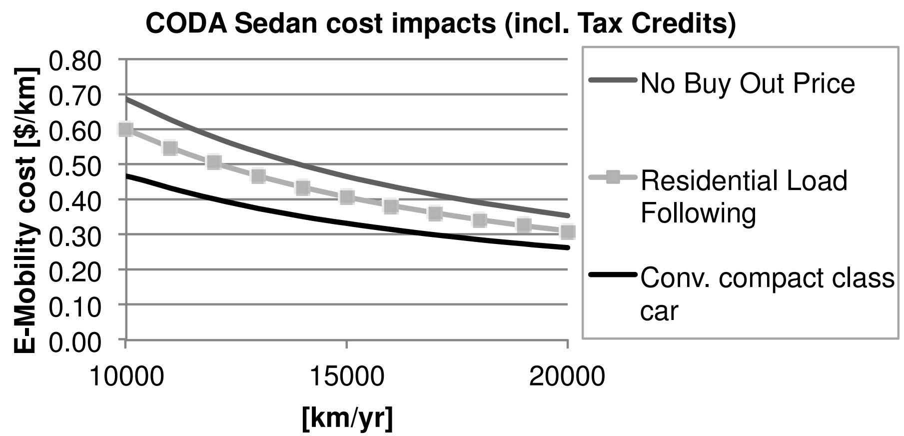


EV cost impacts

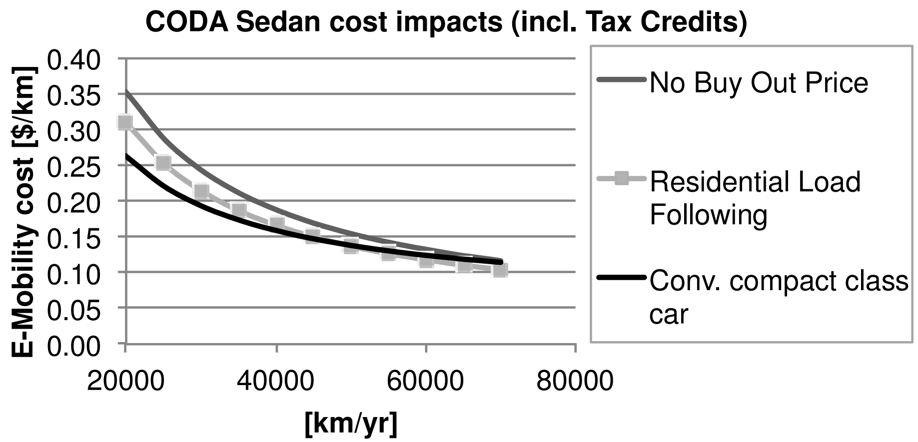
„Coda Sedan"

12.7% cost reduction if 10.000 km/yr are driven (incl. Tax Credit)





Cost become equal at about 50.000 km of yearly usage



Conclusions I

- Electric Energy Time-shifting is not feasible; benefits (5.4 $/kW*yr) are lower than battery assembling cost (even if only incremental inverter cost are assumed)
- Residential Load Following may derive benefits of 76.4/kW*yr. Buy Out Prices approx. 180 $/kWh (if incremental inverter cost are assumed)
- Technological feasibility (e.g. battery degradation, achievable charging cycles) of battery reuse still needs to be demonstrated

Conclusions II

- Nissan Leaf, Mitsubishi i-MiEV and CODA Sedan mobility cost reduced up to 13% by applying battery Buy Out Prices
- The higher the yearly driven EV kilometres - the lower the gap between EV and conventional cars
- BUT: currently 50.000 km/yr needed for Coda Sedan case = unlikely to happen
- At current EV cost: Only if very high Buy Out Prices are achieved (e.g. in other 2nd life applications), the necessity of subsidies (e.g. Tax Credits) could be reduced

Questions?

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