

How are driving patterns adjusted to the use of a battery electric vehicle in two-car households?

Niklas Jakobsson, Sten Karlsson, Frances Sprei

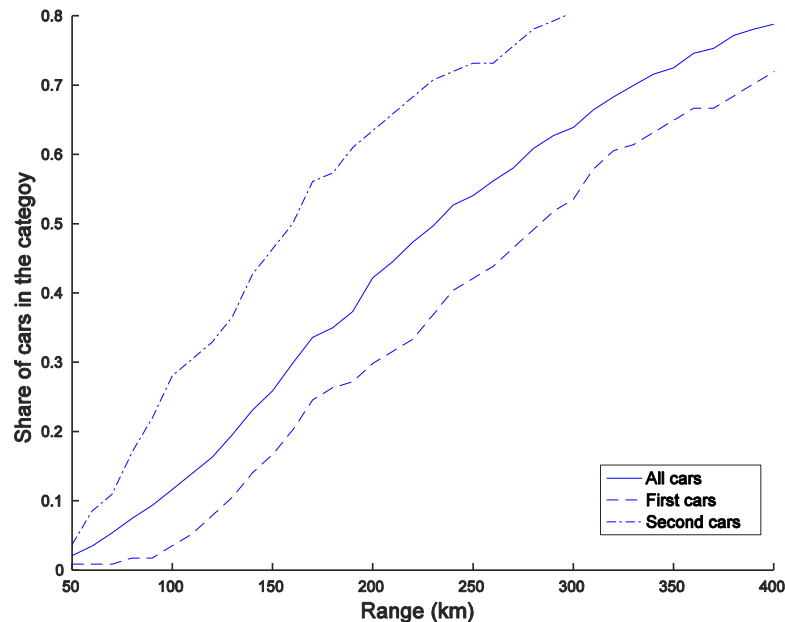
BEVs in Multi-Car Households

- Two arguments for multi-car households:
 - A household has a 'first' car that is used for long distance trips, and a second car that is used for short everyday trips.
 - A household could optimize the use of a BEV so that it takes more short trips, and the conventional car more long trips.



BEVs in Multi-Car Households

Without household adaptation:



Fulfill all driving at range 120 km:

First cars < 10%

All Cars ≈ 15%

Second cars ≈ 30%

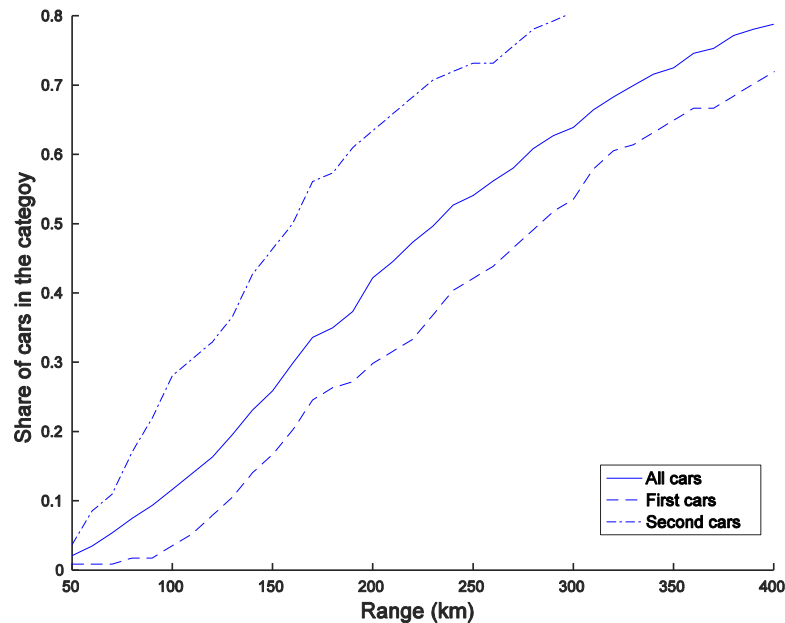
With optimization of BEV Usage:

- Roughly 70% more driving on the BEV compared to second car replacement.

[Sten Karlsson, EVS29 Seminar 2F]

BEVs in Multi-Car Households

Without household adaptation:



Fulfill all driving at range 120 km:

First cars < 10%

All Cars ≈ 15%

Second cars ≈ 30%

With optimization of BEV Usage:

- Roughly 70% more driving on the BEV compared to second car replacement.

[Sten Karlsson, EVS29 Seminar 2F]

Question addressed in this work:

How are driving patterns adjusted to the use of a BEV?

GPS measured data set

Comparing two measurement periods:

- Comparison period: Two conventional cars
- Evaluation period: One car replaced by a BEV (VW e-Golf)

Comparison Period

Random sampling with inclusion criteria:

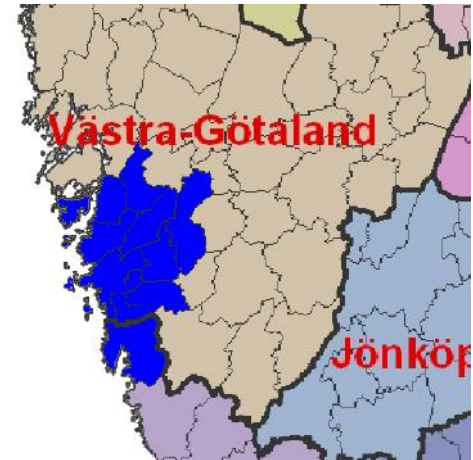
Households

- Gothenburg region (13 municipalities)
- 2-car households
- ≤ 65 years old
- Commuters (> 10 km)

Cars

- Model Year 2002+
- Weight ≤ 2000 kg
- Engine Power ≤ 200 kW

Part of Sweden



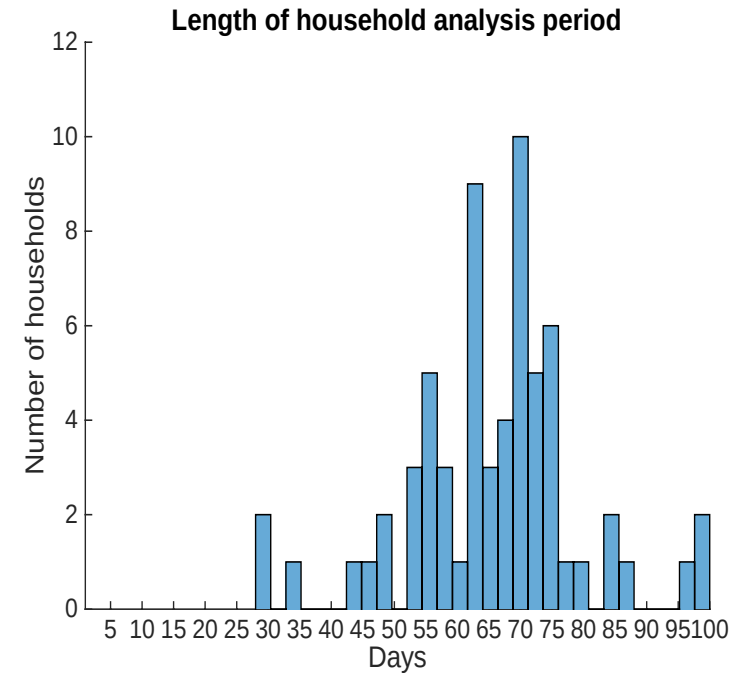
Private cars	<u>Number</u>	<u>% Of all</u>	<u>% Of two-car hh</u>
- in region	331 000	100%	
- in many-car households		48%	
- in 2-car households		33%	100%
- the further restrictions	37 000	11%	33%

(Note: do not include company cars)

Comparison Period

Positive Response Rate $\approx 5\%$

64 households with good data for
2 months on average.



Evaluation Period

- Households were offered a VW e-Golf to replace a car of their choice (3-4 months).

Inclusion criteria:

- Small changes: same home, same workplace, etc.
- High quality of data from comparison period.
- Positive response rate: $\approx 90\%$.

Result: 25 participating households, of which 10 are included here.

Some Early Results

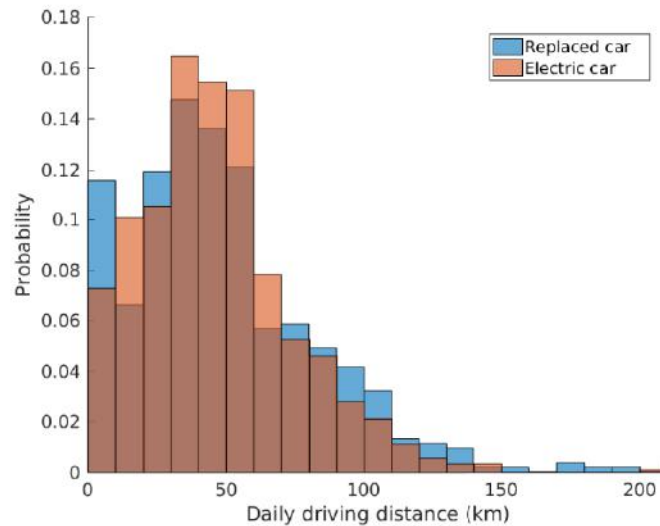
- Fraction of total distance driven on the BEV compared to the replaced car.
- Distribution of daily driving distance for the EV, replaced car, and kept conventional car.

Share of driving on BEV and replaced car

Household	BEV	Replaced car	Increase
1	65%	63%	2%
2	32%	29%	12%
3	52%	20%	160%
4	59%	59%	-1%
5	45%	47%	-4%
6	45%	42%	7%
7	50%	48%	3%
8	35%	34%	4%
9	58%	52%	12%
10	57%	63%	-8%

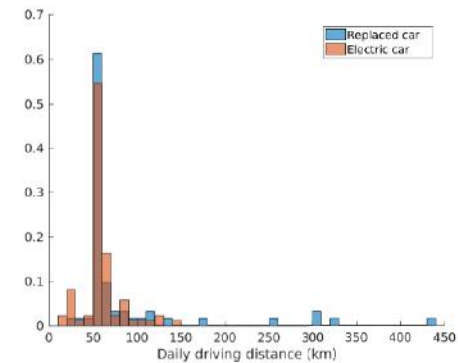
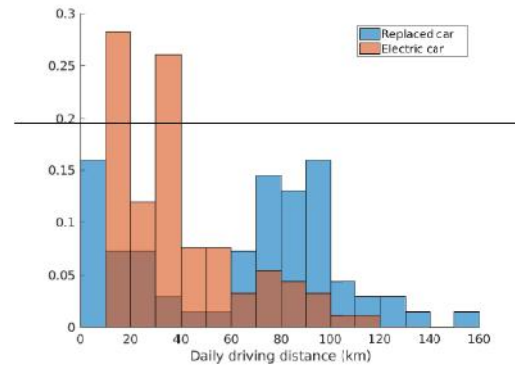
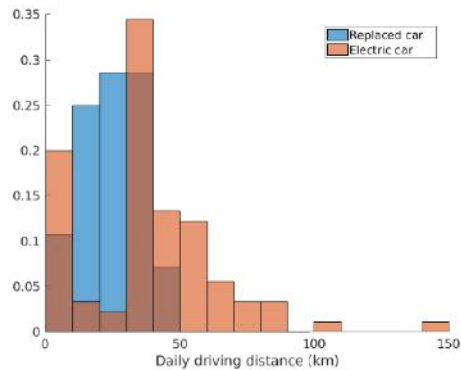
- There is mostly a small change in share of total distance driven by the BEV.
- In 5 out of 6 cases where a car with the lower VKT in the household is replaced by a BEV, it retains the lower VKT.

Distribution of daily VKT, EV and replaced car

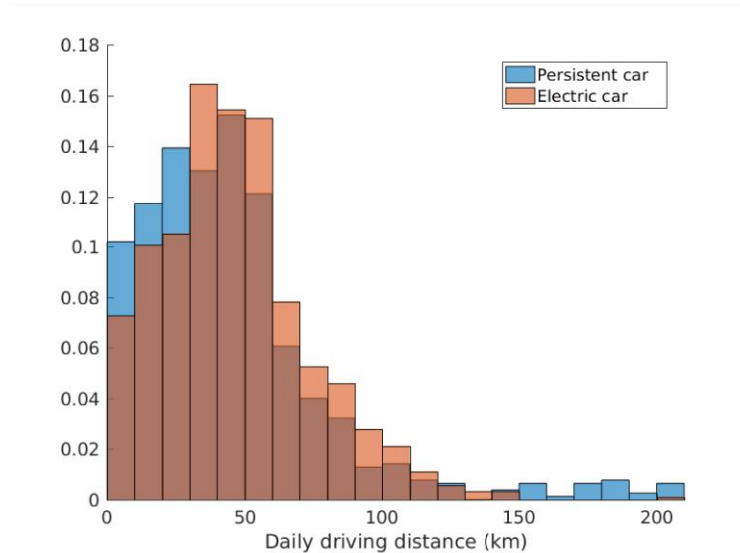


On Average:

- Long daily driving distances are reduced.
- Short daily driving distances are reduced.
- Distances congregate at 40-70 km.

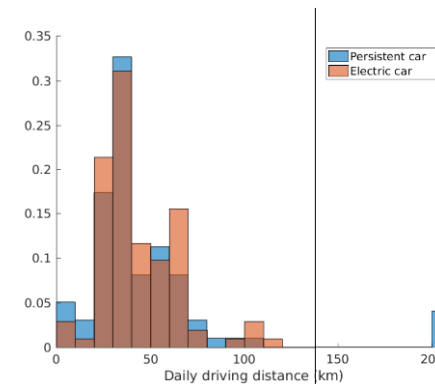
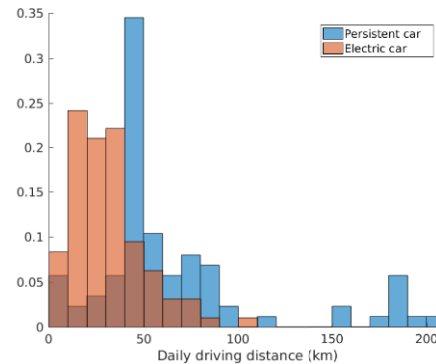
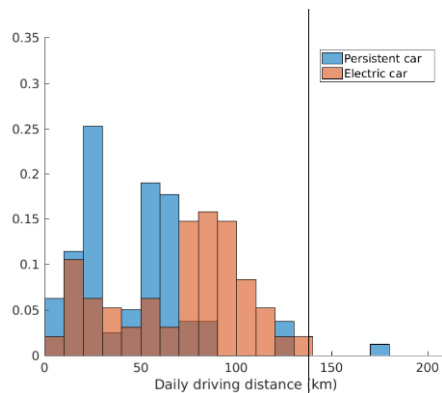


Distribution of daily VKT, EV and conventional car



On Average:

•The BEV is used more than the CV for daily VKTs around 40-140 km.



Conclusions

- There is a large heterogeneity in how driving is adjusted to the use of a BEV.
- On average, there is a small increase in driving on the BEV.

Thank you for your attention!

Niklas Jakobsson

niklas.jakobsson@chalmers.se

Physical Resource Theory
Department of Energy and Environment
Chalmers University of Technology
SE-412 96 Gothenburg, SWEDEN
<http://www.chalmers.se/ee>

List of Publications

- (1) Niklas Jakobsson, Till Gnann, Patrick Plötz, Frances Sprei, Sten Karlsson, “**Are multi-car households better suited for battery electric vehicles? – Driving patterns and economics in Sweden and Germany**”, *Transportation Research Part C: Emerging Technologies*, Volume 65, April 2016, Pages 1-15.
- (2) Patrick Plötz, Niklas Jakobsson and Frances Sprei, “**On the distribution of individual daily driving distances**”. Working paper (2016).
- (3) Niklas Jakobsson, Sten Karlsson and Frances Sprei, “**How are driving patterns adjusted to the use of a battery electric vehicle in two-car households?**”. In Proceedings to EVS29 Montréal, Canada, June 19-22, 2016.
- (4) Till Gnann, Daniel Goldbach, Niklas Jakobsson, Patrick Plötz, Anders Bennehag and Frances Sprei. “**A Model for Public Fast Charging Infrastructure Needs**”. In Proceedings to EVS29 Montréal, Canada, June 19-22, 2016.

Battery electric vehicle (BEV)



- No tailpipe emissions!
- Expensive to buy
- Cheap to drive
- Range limited



Data sets

Driving Data	Location	Collection Method	Sample Size	Average Observation period	Extra Information	In Publication:
SCMD1	Sweden	GPS	429	58 days		1, 2
SCMD2	Sweden	GPS	130	74 days	Contain 65 two-car households with both cars measured.	3
SCMD3	Sweden	GPS	20	106 days	Subset of SCMD2, one car replaced by a BEV in each of 10 households.	3
MoP	Germany	Survey	6339	7 days		1, 2
PSRC	USA	GPS	484	251 days		2
Winnipeg data	Canada	GPS	72	216 days		2
Charging Data	Location	Number of 50 kW Chargers	Average Number of Charging Events	In Publication:		
Charging data	Sweden	43	812	4		

Days Requiring Adaptation (DRA)

- DRA: A day with total driving distance above the range limitation.

Calculated by:

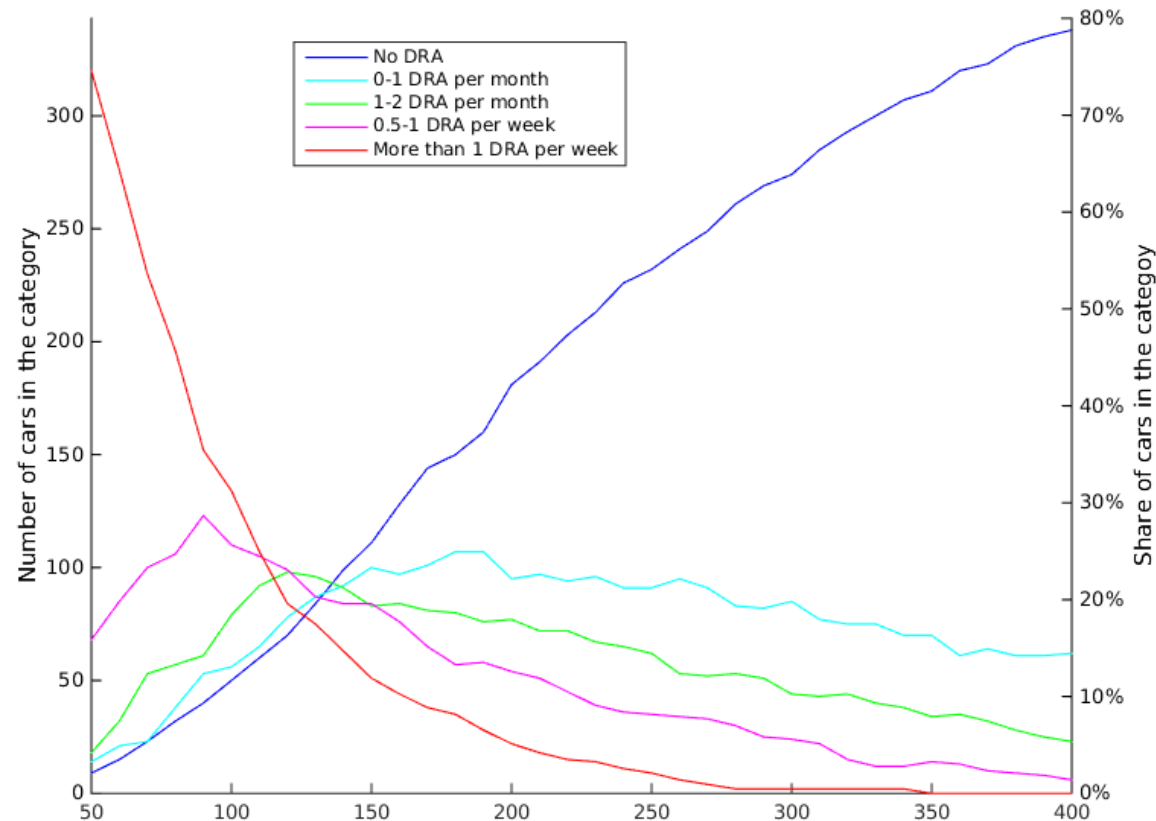
–Method 1: Direct extrapolation

- Counting the number of DRA and scaling this to a yearly basis.

–Method 2: Probability distribution

- Estimating a log-normal distribution of daily driving distances and from this obtain the share of driving days above the range limit.

Days Requiring Adaptation (DRA)



- 230 km range needed for half the cars to fulfill all driving
- 400 km range needed for 80% of cars to fulfill all driving

Multi-Car Households and Infrastructure

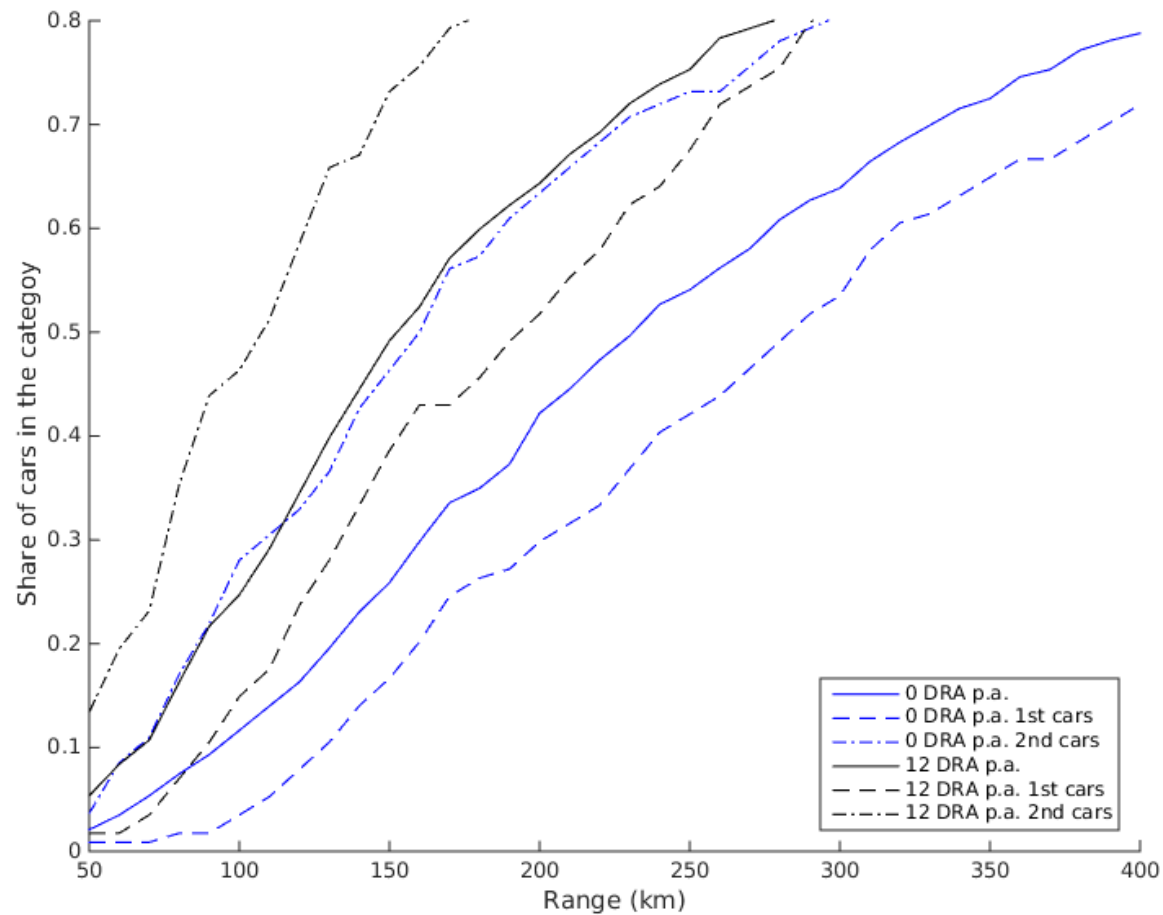
Multi-Car Households

- Two arguments for multi-car households:
 - A household has a 'first' car that is used for long distance trips, and a second car that is used for short everyday trips.
 - A household could optimize the use of a BEV so that it takes more short trips, and the conventional car more long trips.
- **Definition:** First car = the car with the highest annual driving distance in a household.

Multi-Car Households

- Two arguments for multi-car households:
 - A household has a 'first' car that is used for long distance trips, and a second car that is used for shorter everyday trips.
- Do second cars have a more suitable driving pattern for being replaced by BEVs?
- Are they economical as BEVs considering total cost of ownership?

DRA for first and second cars



Total cost of ownership (TCO)

- TCO for an electric/conventional car given the driving pattern.

Important Parameters

Attribute	Value
Battery price [EUR/kWh]	333
Rental car cost [EUR/Day]	60 + Gasoline cost
Investment horizon [Years]	8
Discount rate	5%
Electric range [km]	Variable

Attribute	Sweden	Germany
Electricity price [EUR/kWh]	0.14	0.244
Gasoline price [EUR/l]	1.39	1.29
Diesel price [EUR/l]	1.33	1.2
BEV subsidy [EUR]	4400	-
VAT	25%	19%

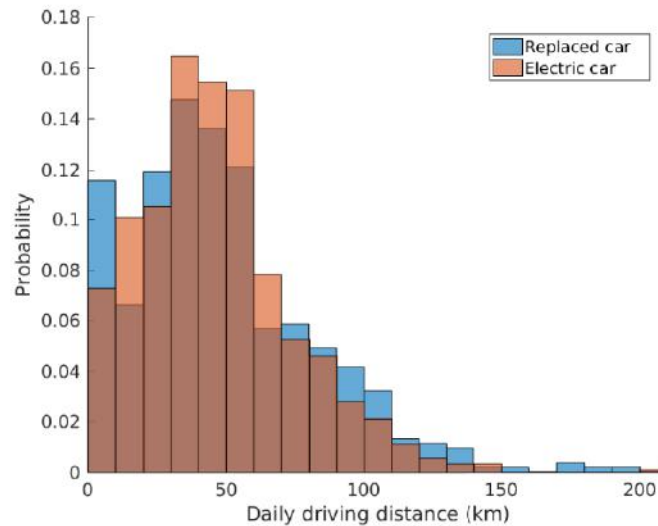
Multi-Car Households

- Two arguments for multi-car households:
 - A household has a 'first' car that is the preferred choice for long distance trips, and a second car that is mainly used for shorter everyday trips.
 - A household could optimize the use of a BEV so that it takes more short trips, and the conventional car more long trips.

Share of driving on BEV and replaced car

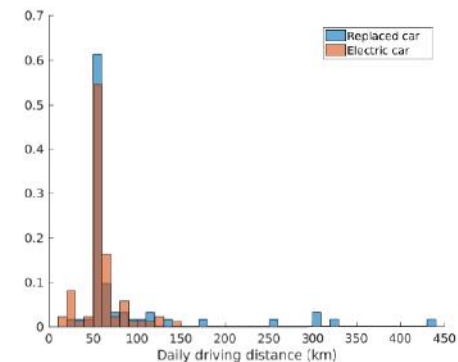
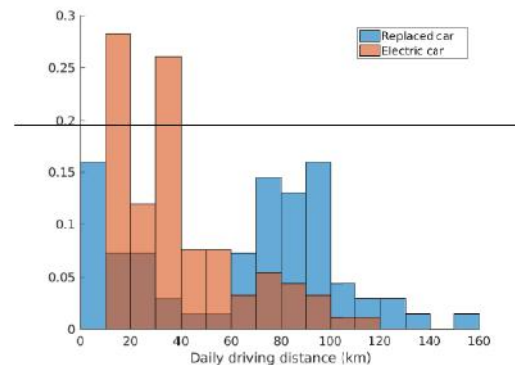
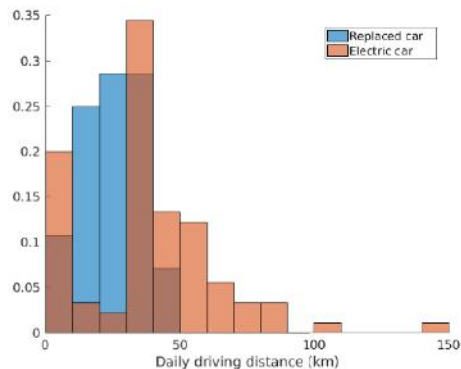
Household	BEV	Replaced car	Increase
1	65%	63%	2%
2	32%	29%	12%
3	52%	20%	160%
4	59%	59%	-1%
5	45%	47%	-4%
6	45%	42%	7%
7	50%	48%	3%
8	35%	34%	4%
9	58%	52%	12%
10	57%	63%	-8%

Distribution of daily driving distances



On Average:

- Long daily driving distances are reduced.
- Short daily driving distances are reduced.
- Distances congregate at 40-70 km.



Fast Charging Infrastructure

Fast Charging Infrastructure

- A model to estimate needed number of charging points in Germany in 2030.
 - Prediction of number of BEVs in 2030
 - Driving patterns from German Data
 - Queueing at the stations and varying charging power
 - Assumptions of exponentially distributed service time and inter-arrival time.
- My Part: Verification of assumptions.

Verification of assumptions

Distribution of service Time



Distribution of inter-arrival time



Model output: 10 Chargers per 1000 BEVs.
Swedish case: 36 Chargers per 1000 BEVs.

On the distributions of daily driving distances

On the distribution of daily driving distances

- Which is the overall best distribution?
- What is the consequence of distribution choice on DRA and electric drive fraction for BEVs, and PHEVs?

On the distribution of daily driving distances

- Log-Normal, Weibull, Gamma distributions

- Goodness of Fit:** RMSE, χ^2 , MAPE, AIC

- Data sets:** SCMD1, MoP, PSRC, Winnipeg

Overall best distribution

		Mobility Panel			Winnipeg			Sweden			Seattle	
Goodness-of-fit	$\ln N$	Weib.	Γ	$\ln N$	Weib.	Γ	$\ln N$	Weib.	Γ	$\ln N$	Weib.	Γ
AIC	32,3%	59,9%	7,8%	40%	35%	25%	34,7%	39,2%	26,1%	16,0%	71,6%	12,4%
RMSE	74,0%	12,5%	13,5%	36%	35%	29%	43,6%	37,3%	19,1%	36,8%	35,7%	27,5%
χ^2	88,2%	9,1%	2,7%	17%	41%	41%	29,6%	33,8%	36,6%	68,9%	18,3%	12,8%
MAPE	75,2%	21,9%	2,9%	9%	51%	40%	19,8%	44,5%	35,7%	65,0%	24,0%	11,0%

- Gamma best in 2/16 cases.
- Weibull best in 6/16 cases.
- Log-Normal best in 9/16 cases.

Estimating DRA

Swedish data

	Range (km)	ln N	Weib.	Γ	Empirical
Mean DRA	100	52.7	48.4	48.9	45.3
	150	32.4	22.6	23.2	22.4
	200	22.4	11.9	12.1	12.8
Median DRA	100	49.6	35.4	37.5	29.0
	150	27.3	11.2	12.2	12.2
	200	17.4	3.8	4.1	6.0

•Log-Normal predict higher number of DRA than the other cases.

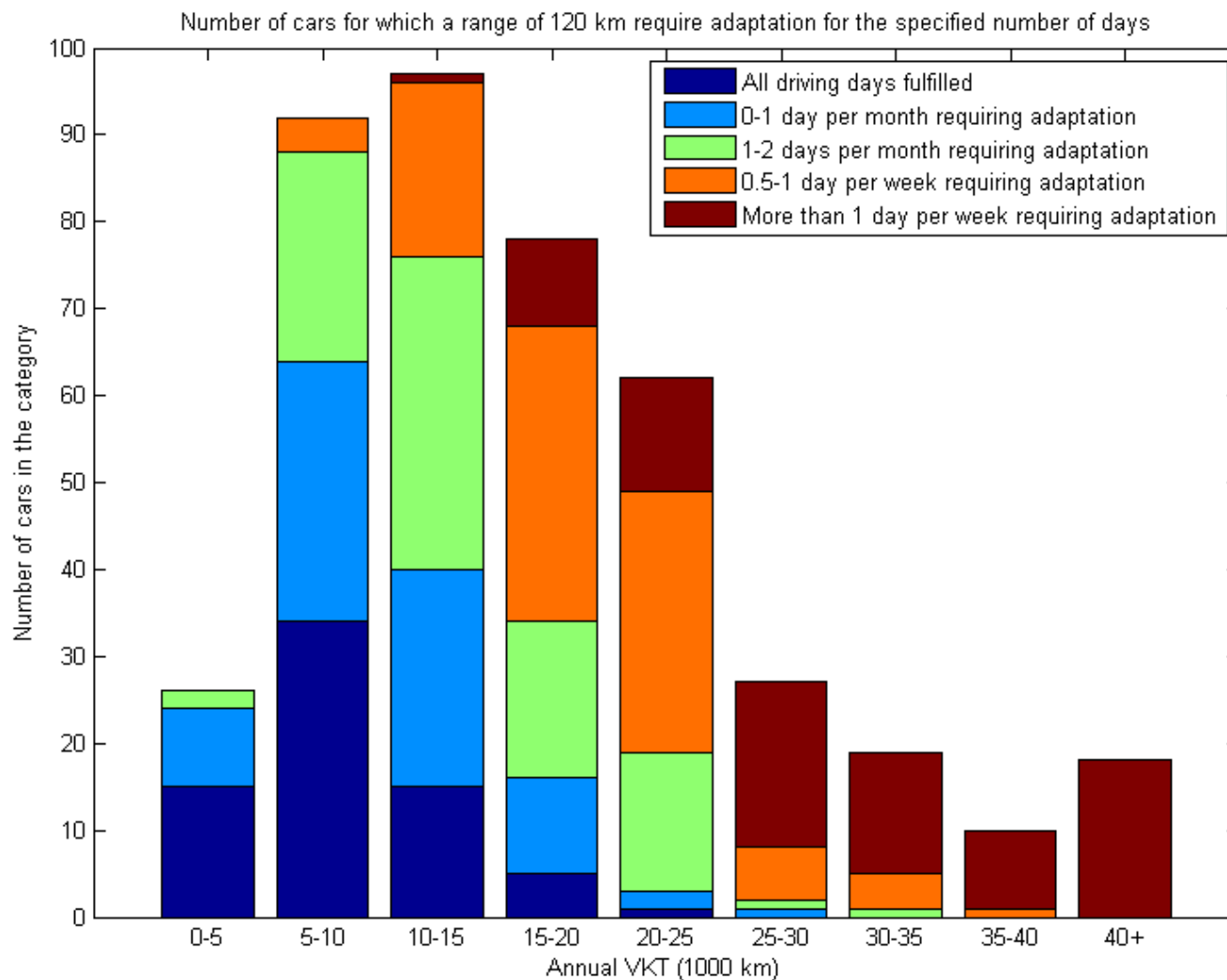
Estimating electric drive fraction

Swedish data

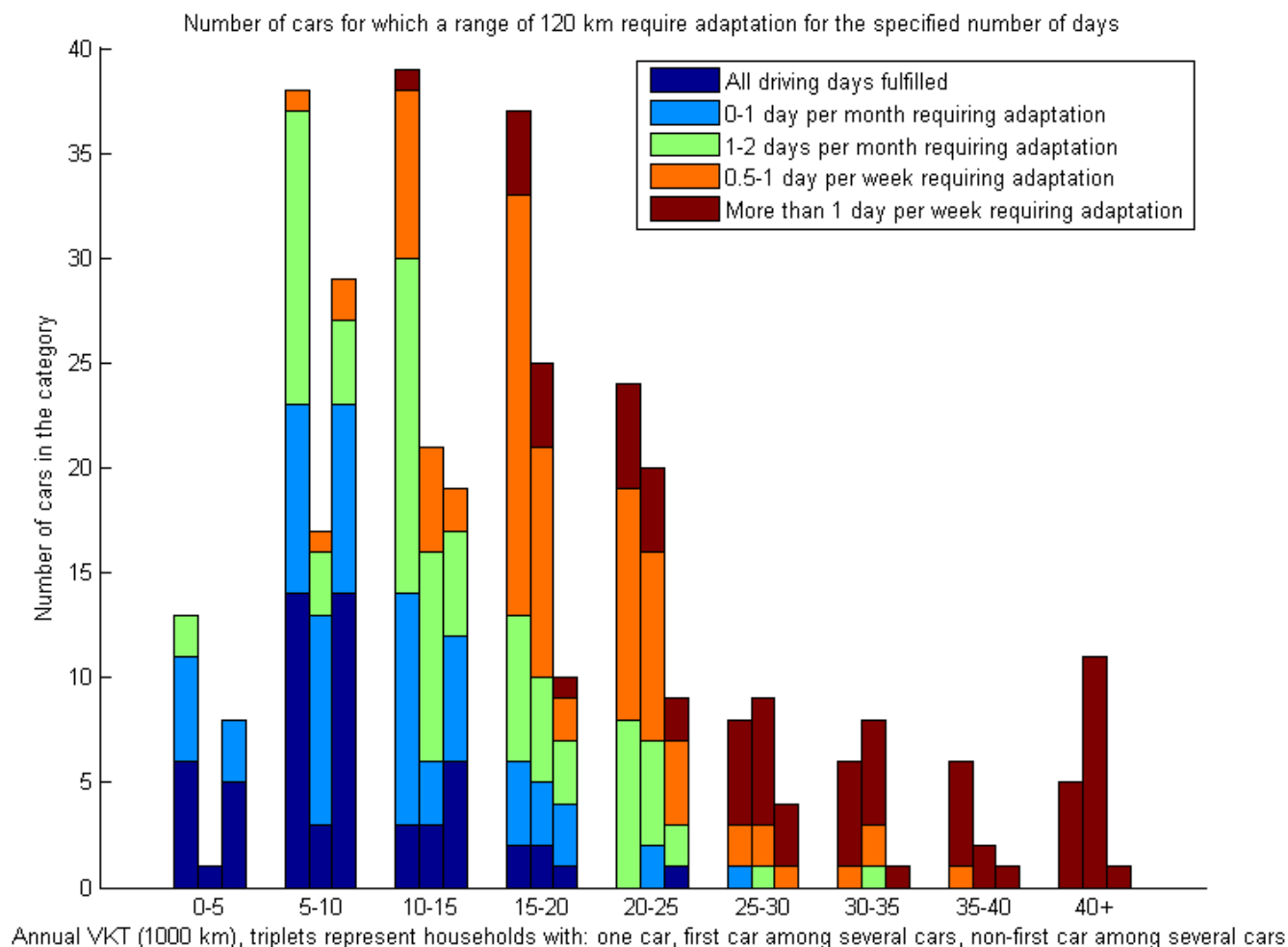
	Range (km)	$\ln N$	Weib.	Γ	Empirical
Mean [%]	25	33.2	41.9	42.2	42.1
	50	49.3	64.3	64.5	63.6
	75	58.6	76.9	77.1	75.5
Median [%]	25	29.4	39.1	39.7	39.4
	50	47.9	63.3	64.0	62.4
	75	59.6	78.9	79.0	76.9

- Log-Normal predict lower electric drive fraction than the other cases.

Days requiring adaptation (DRA)



DRA for three household categories



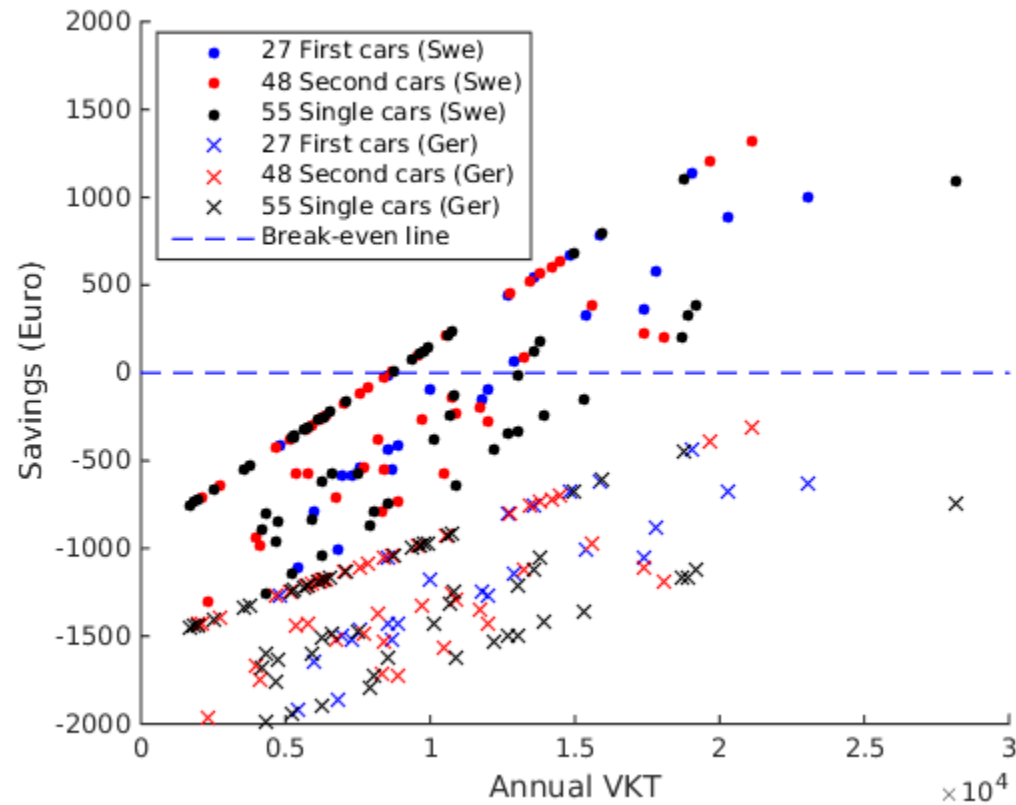
Estimating DRA

	Range (km)	MoP	MoP	MoP	MoP	SCMD	SCMD	SCMD	SCMD	Wpg.	Wpg.	Wpg.	Wpg.
		$\ln N$	Weib.	Γ	Empirical	$\ln N$	Weib.	Γ	Empirical	$\ln N$	Weib.	Γ	Empirical
Mean DRA	150	25.5	21.1±1.0	22.2	22.0	32.4	22.6	23.2	22.4	7.2	3.2	3.2	5
Median DRA	150	9.4	0.4±0.1	1.3	-	27.3	11.2	12.2	12.2	4.2	0.2	0.5	1

Results related to driving needs

- The share of second cars viable as BEVs are approximately 20 percentage units higher than first cars both for varying behavioral change as well as for varying ranges.
- When both accepting some behavioral change and focusing on second cars, current ranges give high possible market share of BEVs.
- This is both because second cars have a lower annual VKT, but also because they have fewer long distance driving days.

Size of savings of using a BEV



Conclusions

- The second car is more easily replaced by a BEV compared to a first car or a car belonging to a one car household from a driving need fulfillment perspective in both data sets.
- There are still many second cars who cannot directly be replaced by a BEV.
- When taking economics into consideration the second car is still replaceable more often than a first car in Sweden, but the difference is reduced. In Germany, the result is similar, but with much smaller market shares due to the economic conditions.

