



Universiteit Utrecht



EVCONSULT  
experts in sustainable mobility



# Modelling the Total Cost of Ownership of Electric Vehicles in the Netherlands

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Provincie Noord-Brabant



Technische Universiteit  
Eindhoven  
University of Technology

Where innovation starts

# Co-authors and collaborators



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Lead writer and initiator



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Eindhoven University  
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Drive train modelling

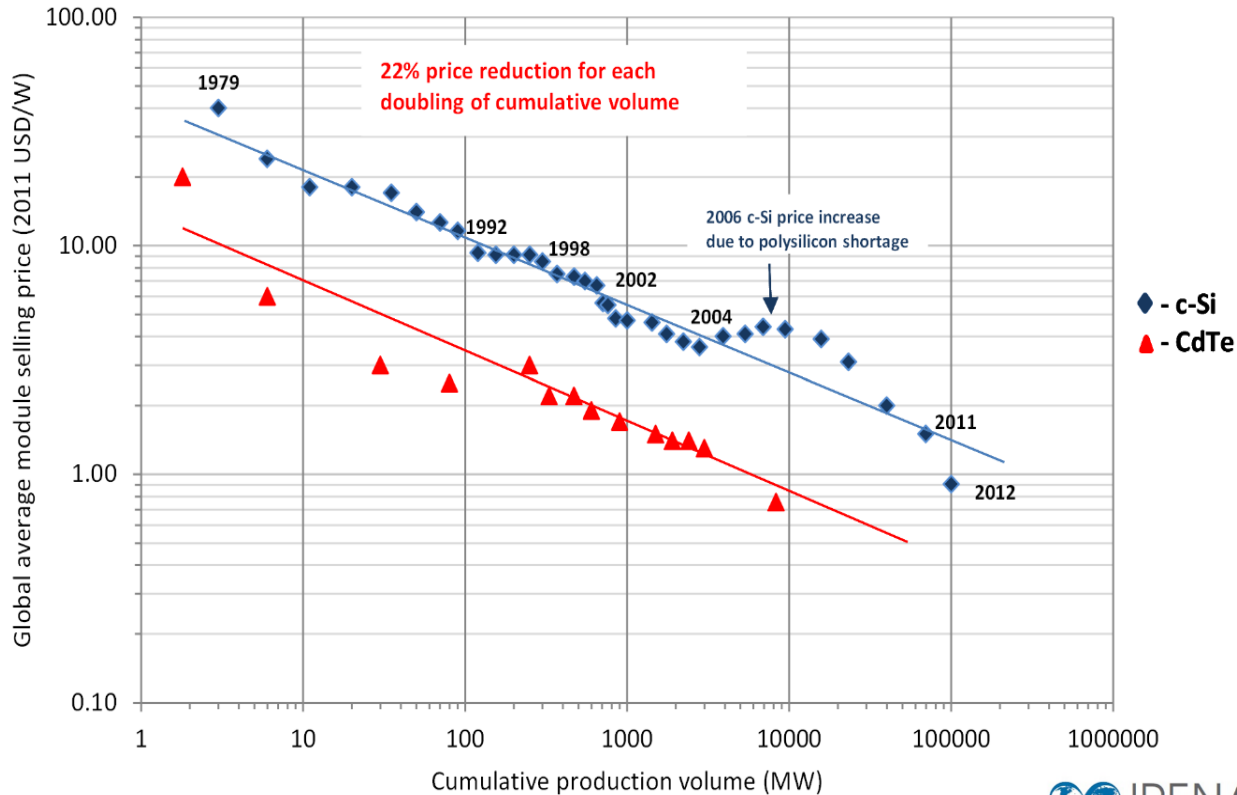


## **Vedant Linesh Sundrani**

Integration Engineer  
Vanderlande  
Battery modelling

# It's all about learning curves

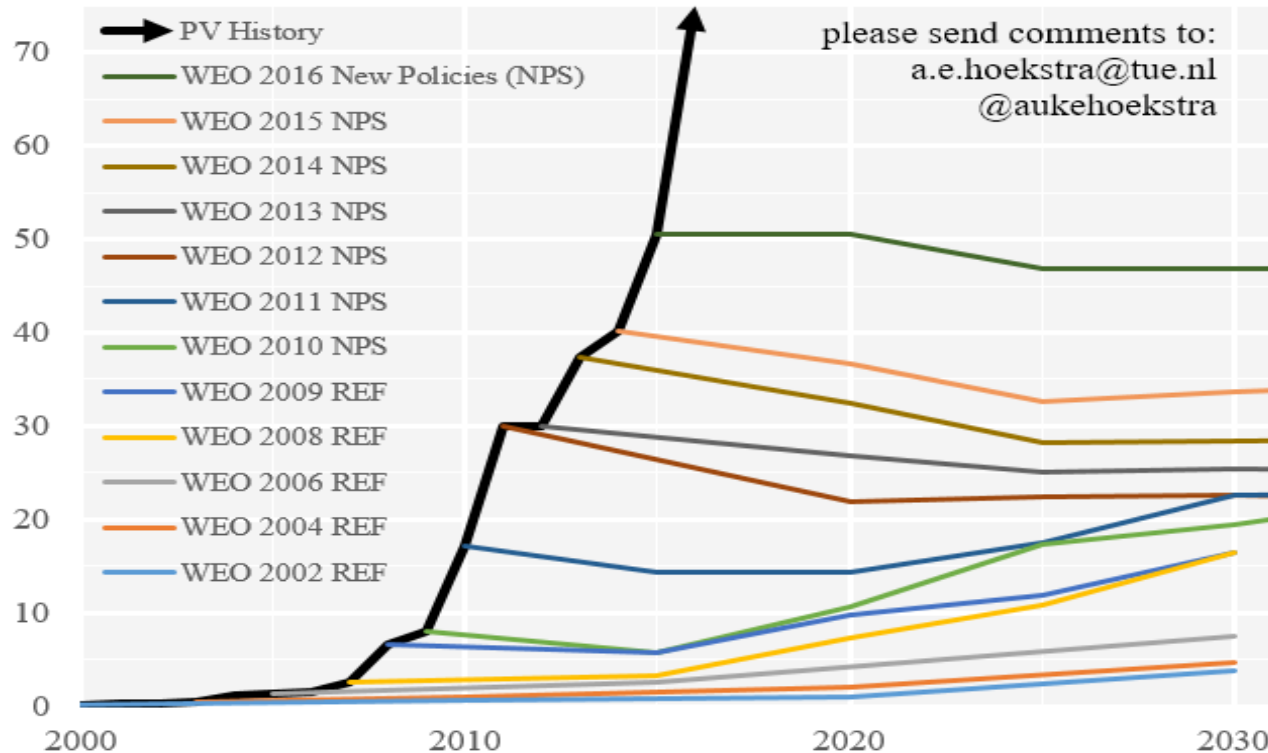
## Solar cells are the famous example in Energy



# Combining learning curves with adoption through feedback loops creates acceleration

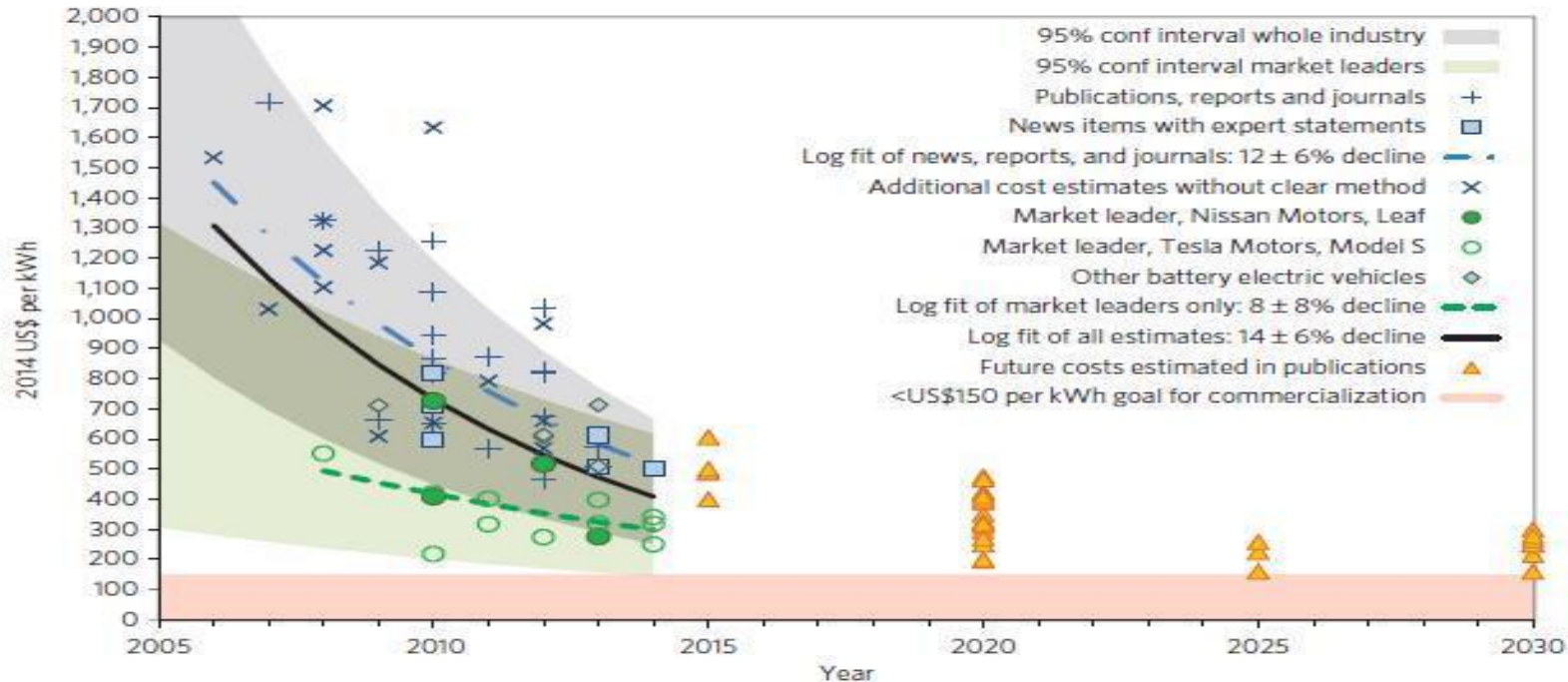
## Annual PV additions: historic data vs IEA WEO predictions

In GW of added capacity per year - source International Energy Agency - World Energy Outlook



Many modellers seem to overlook learning curves and/or feedback loops.

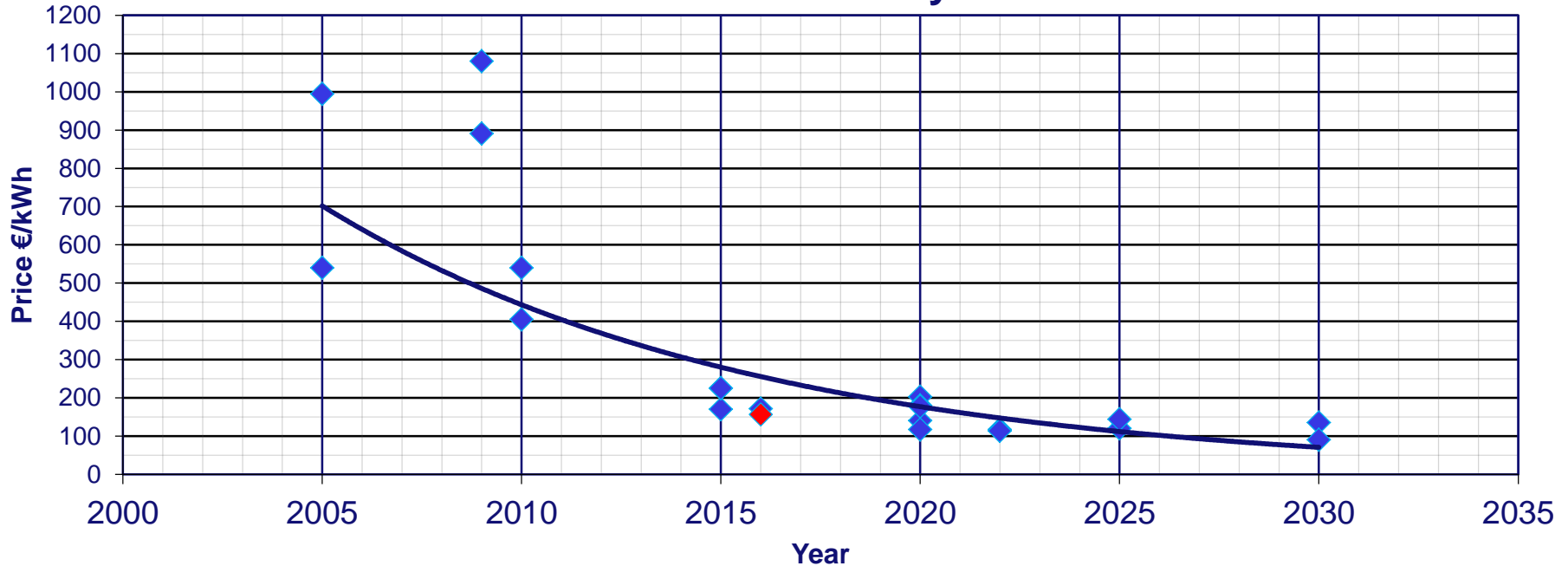
# Battery price developments



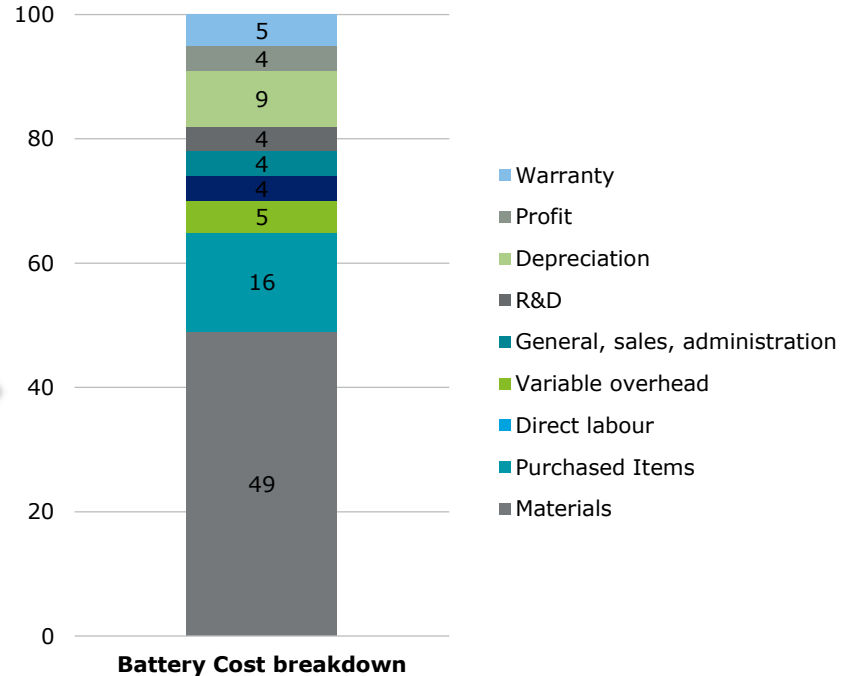
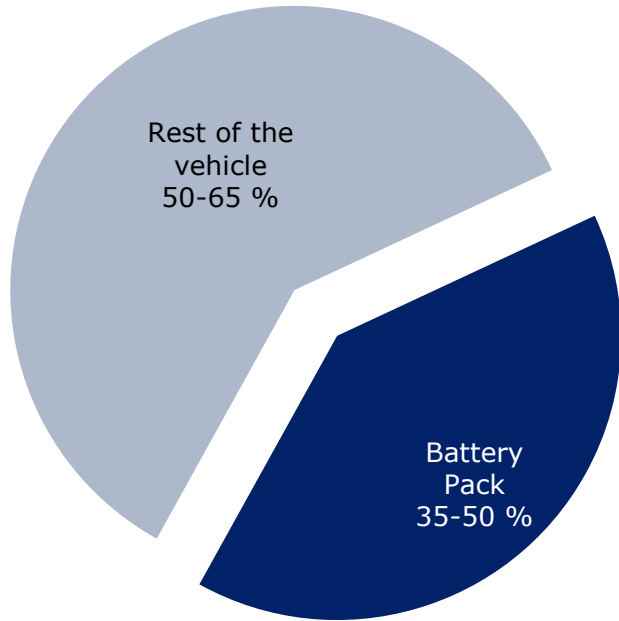
Source: "Rapidly falling costs of battery packs for electric vehicles" by Björn Nykvist and Mans Nilsson, Nature Climate Change, March 2015

# We have researched this intensively

## Predicted Battery Price

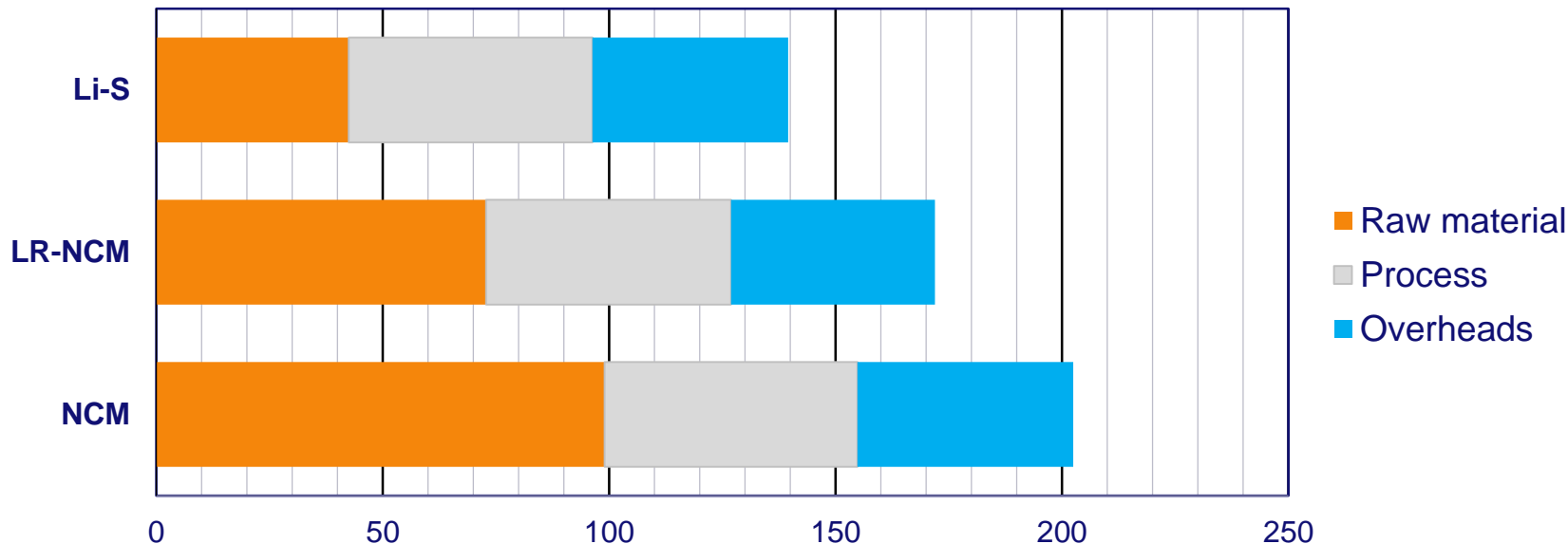


# Not only using extrapolation but also by using bottom up analysis of raw materials and processes used.



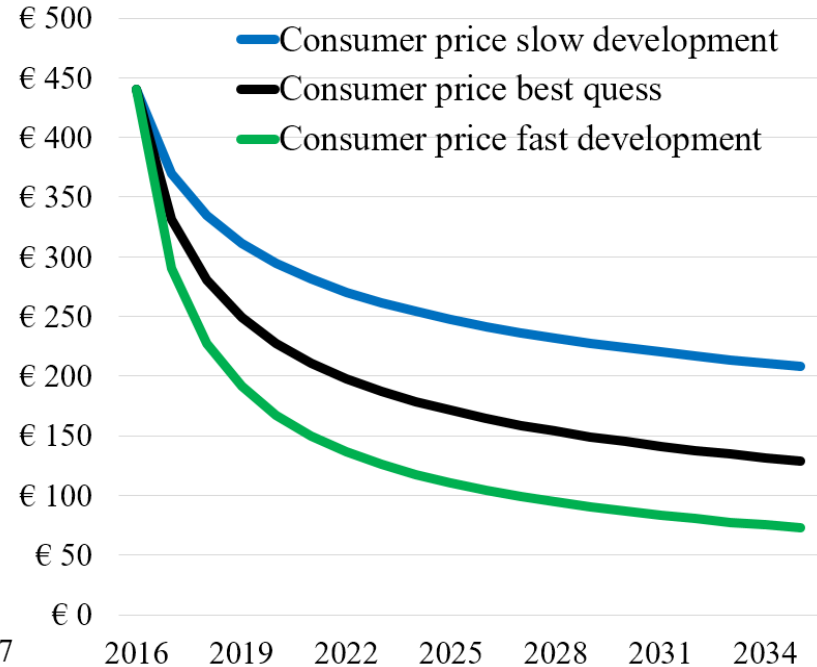
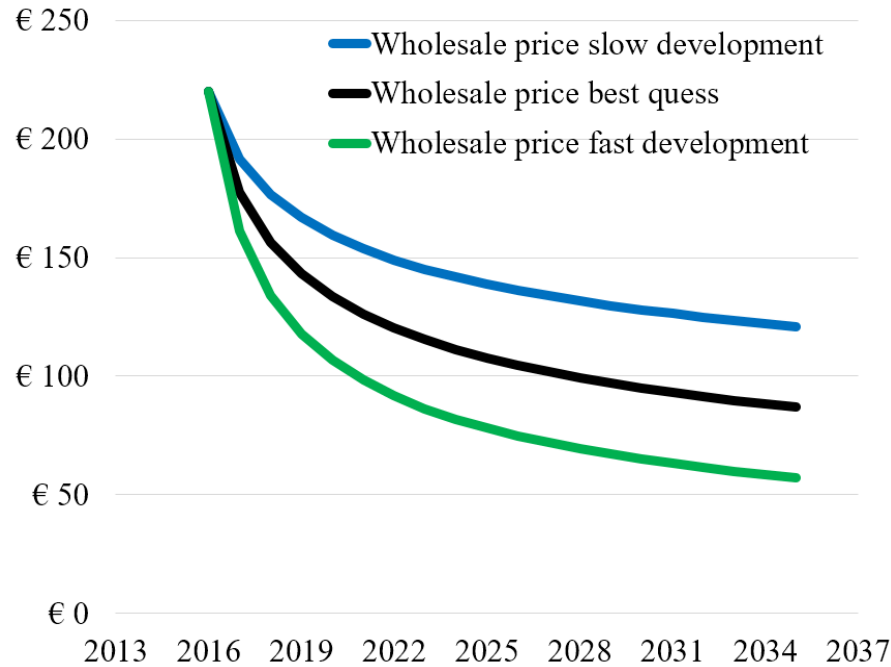
Source: R. Kochhan, et. Al., "An Overview of Costs for Vehicle Components, Fuels and Greenhouse Gas Emissions," *Publ. Www Res. Net*, Feb, 2014.

Analysis shows that even current day batteries can become 5-10 times cheaper (\$50-\$100 in 2050). If solid state batteries or metal air batteries break through things will become even more interesting.



Source: Adapted from "Rechargeable Batteries: Grasping for the Limits of Chemistry" by Petr Novak, Journal of Electrochemical Society, October 2015

# Battery price developments



# Drive train cost developments

Electric Vehicle Drivetrain	2010	2035
DC motor / kW peak	8	4.5
AC motor / kW peak	5	2.7
Power electronics / kW peak	15	1.6
DC-DC converter	300	300
On-board charger	600	600

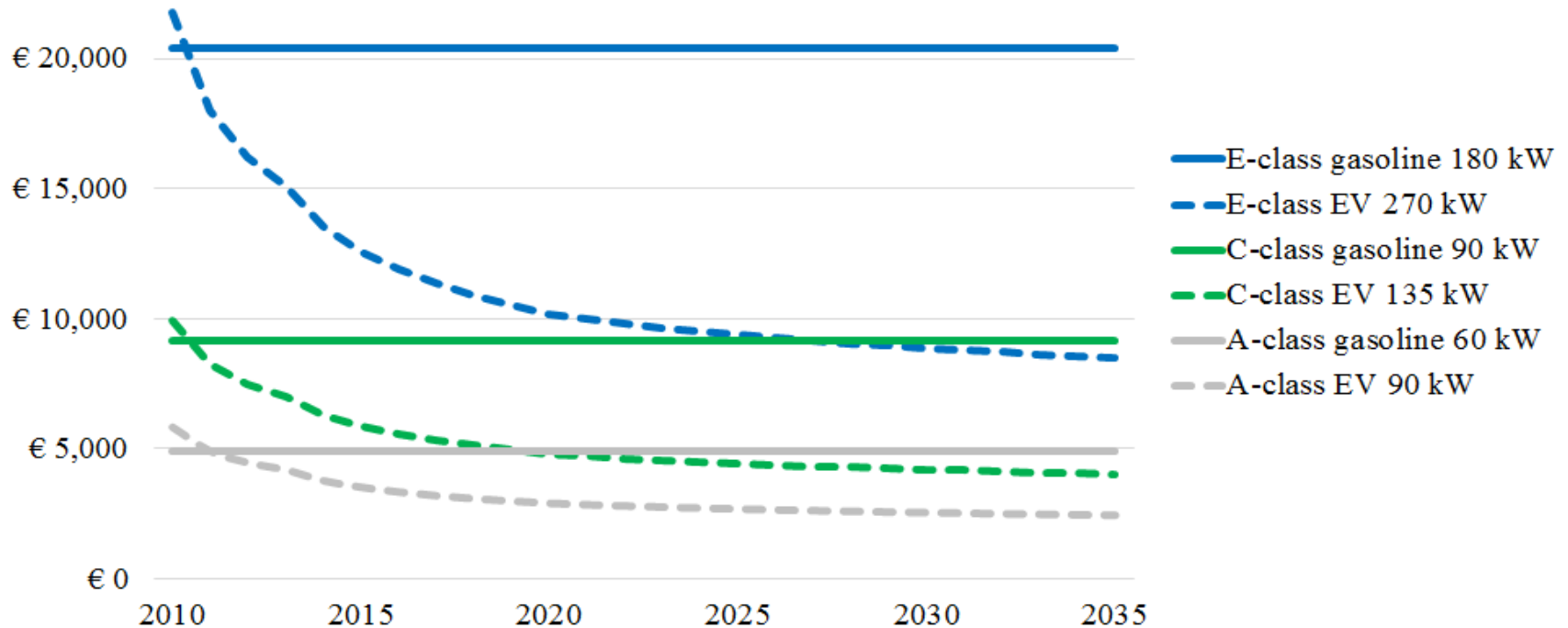
Gasoline and Diesel drivetrain	Gasoline	Diesel
Motor incl. transmission / kW peak	35	50
Stop & go system + exhaust treatment	500	1000

We had to adjust findings to observed market cost. So again double analysis: bottom-up from parts and top down from market prices.

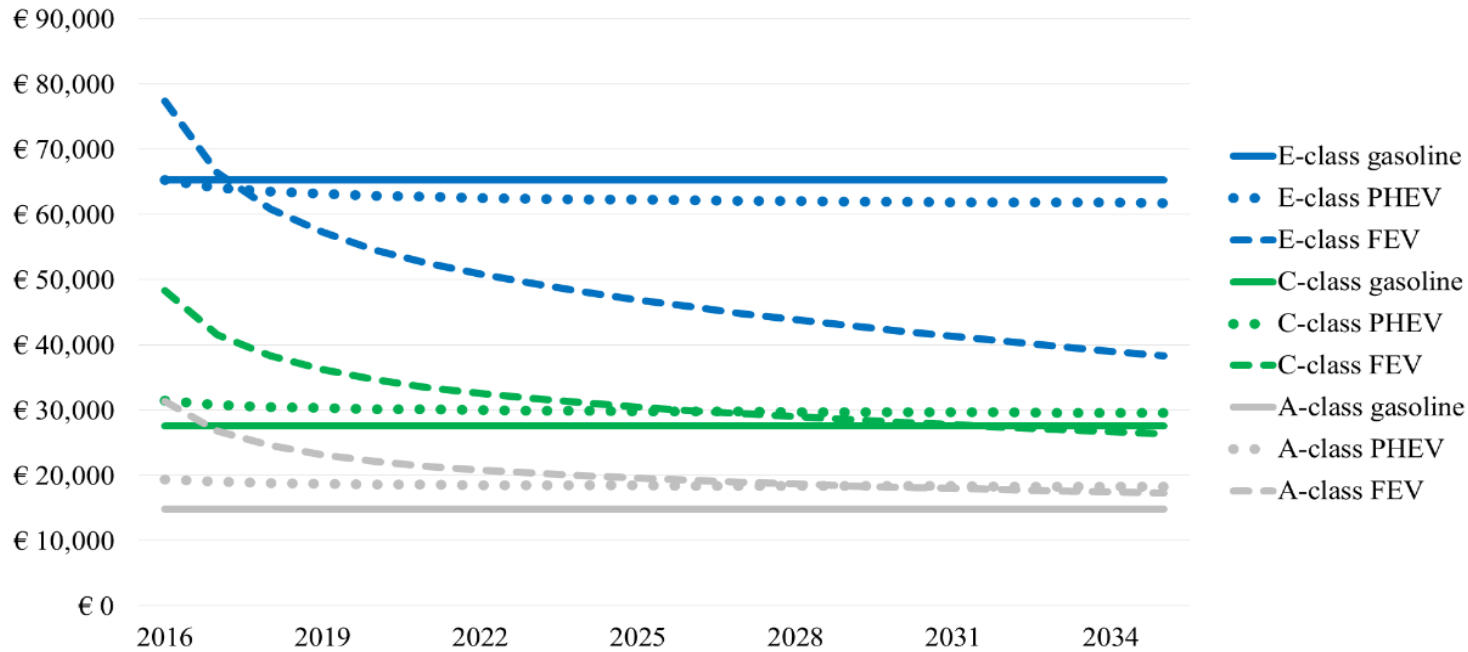
# Construct virtual cars to choose from

Car type	Price excl. drivetrain	Motor kW	On board energy use kWh/km	Tires per km	Maintenance per km	EV range km
A-class gasoline	10847	60	0.5	€ 0.008	€ 0.036	
A-class PHEV	10847	60	0.3	€ 0.008	€ 0.025	25
A-class FEV	10847	90	0.14	€ 0.008	€ 0.011	300
C-class gasoline	15830	90	0.7	€ 0.010	€ 0.047	
C-class PHEV	15830	90	0.45	€ 0.010	€ 0.032	40
C-class FEV	15830	135	0.15	€ 0.010	€ 0.014	400
E-class gasoline	18831	180	1.1	€ 0.017	€ 0.075	
E-class PHEV	18831	180	0.6	€ 0.017	€ 0.053	60
E-class FEV	18831	270	0.19	€ 0.020	€ 0.021	500

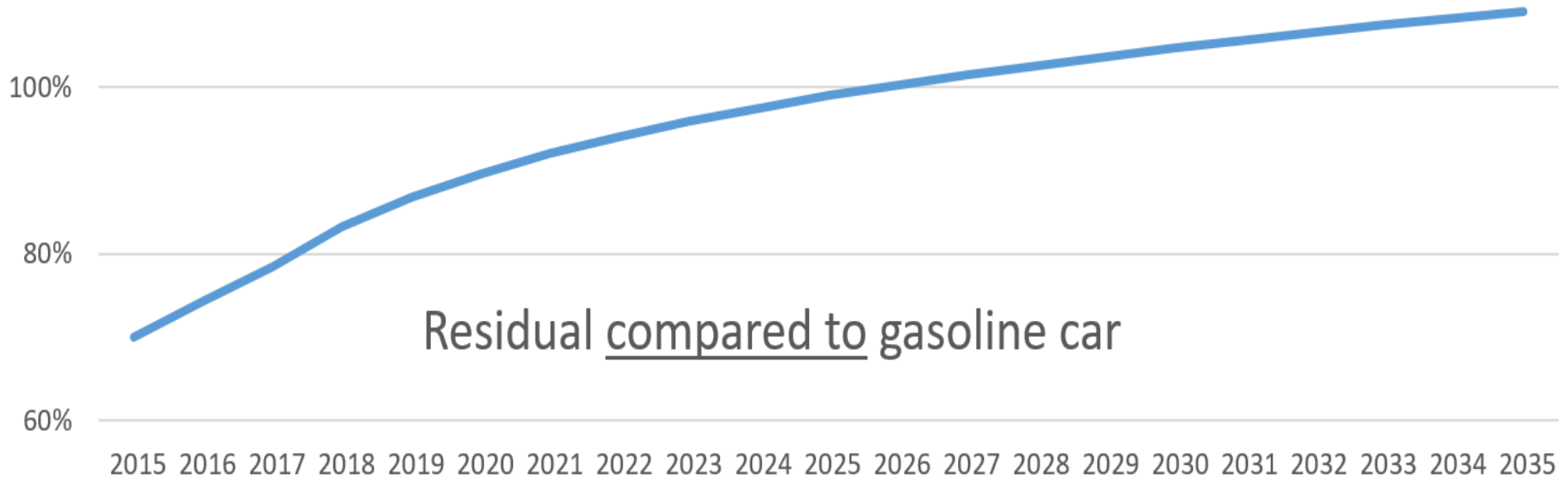
# Drivetrain costs: gasoline vs EV



# Sticker price: gasoline vs EV



# Residual value



# Discount rate

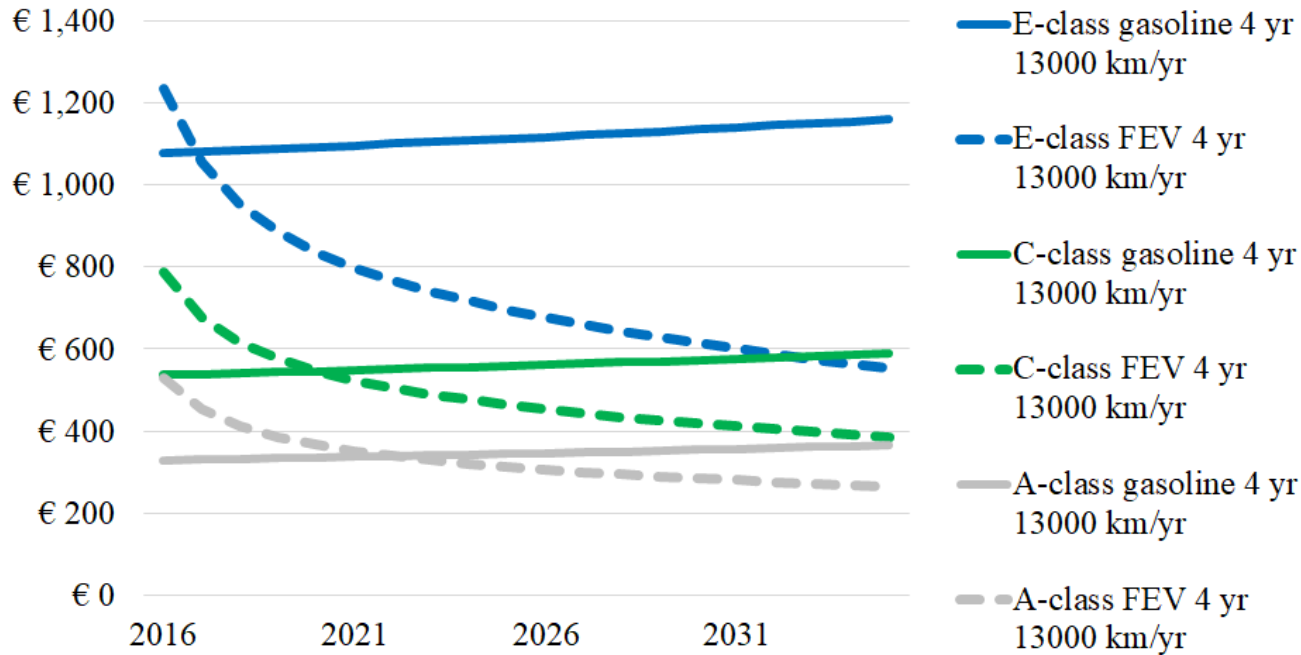
- **We chose a discount rate of 5%**
- **However, even a discount rate of 10% moves the break even point by less than a year in most scenarios**

# Energy and maintenance cost

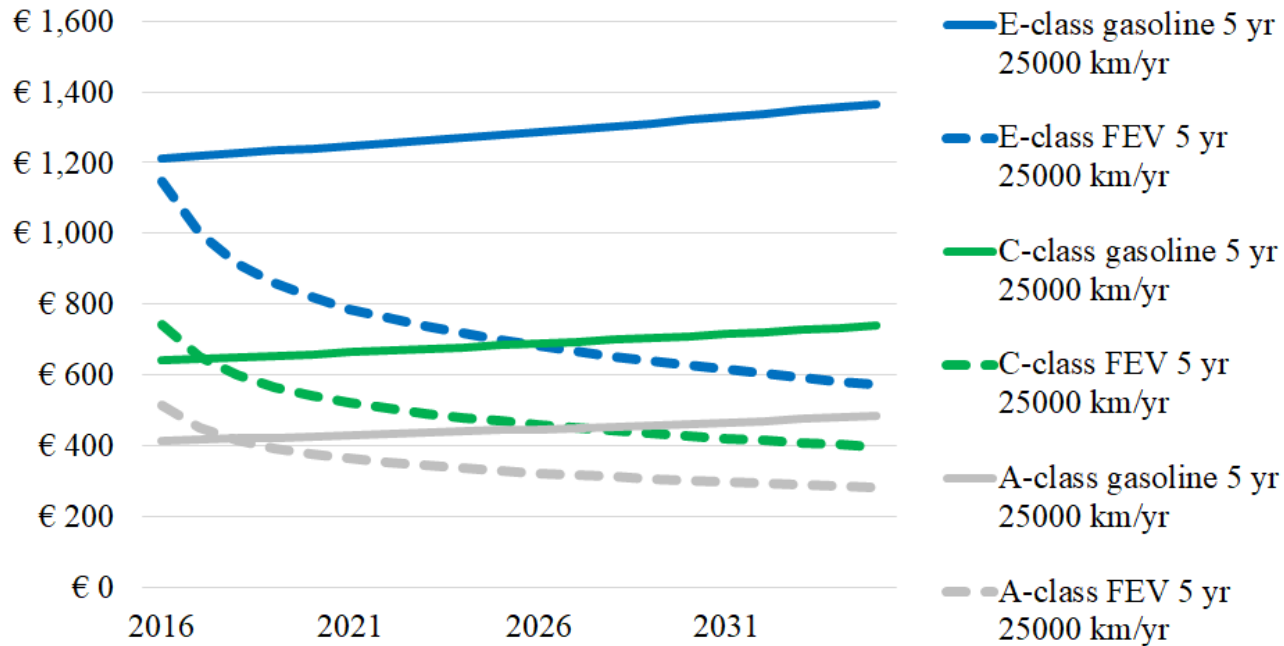
Energy source	<u>Perc.</u> Energy	2015	2020	2025	2030	2035
Diesel	100%	€ 0.12	€ 0.13	€ 0.15	€ 0.16	€ 0.19
Gasoline	100%	€ 0.17	€ 0.18	€ 0.20	€ 0.22	€ 0.24
Flex value		€ 0.00	€ 0.02	€ 0.03	€ 0.03	€ 0.04
Home charging	35%	€ 0.22	€ 0.21	€ 0.20	€ 0.19	€ 0.18
Work charging	25%	€ 0.18	€ 0.17	€ 0.16	€ 0.14	€ 0.13
Street charging	25%	€ 0.35	€ 0.32	€ 0.29	€ 0.26	€ 0.24
Fast charging	15%	€ 0.35	€ 0.30	€ 0.24	€ 0.20	€ 0.16

Very roughly put: energy and maintenance are both 1/3

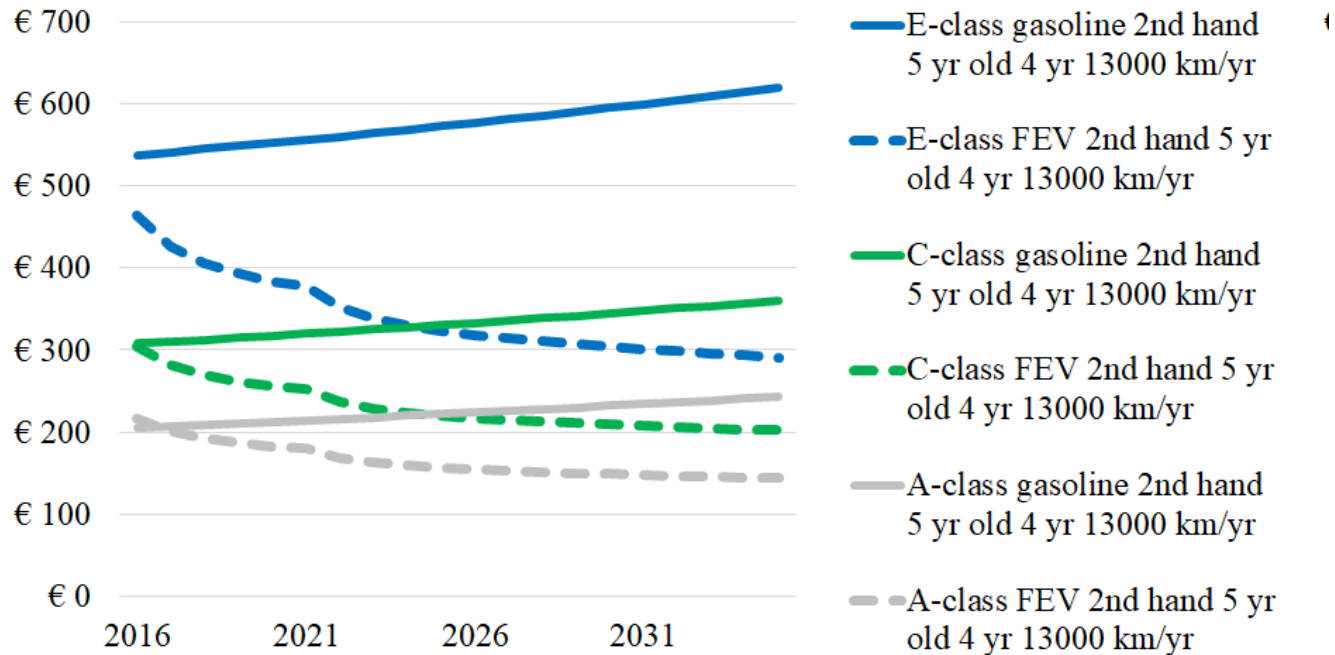
# With 13.000 km per year (Dutch average)



# With 25.000 km per year (new car buyers)

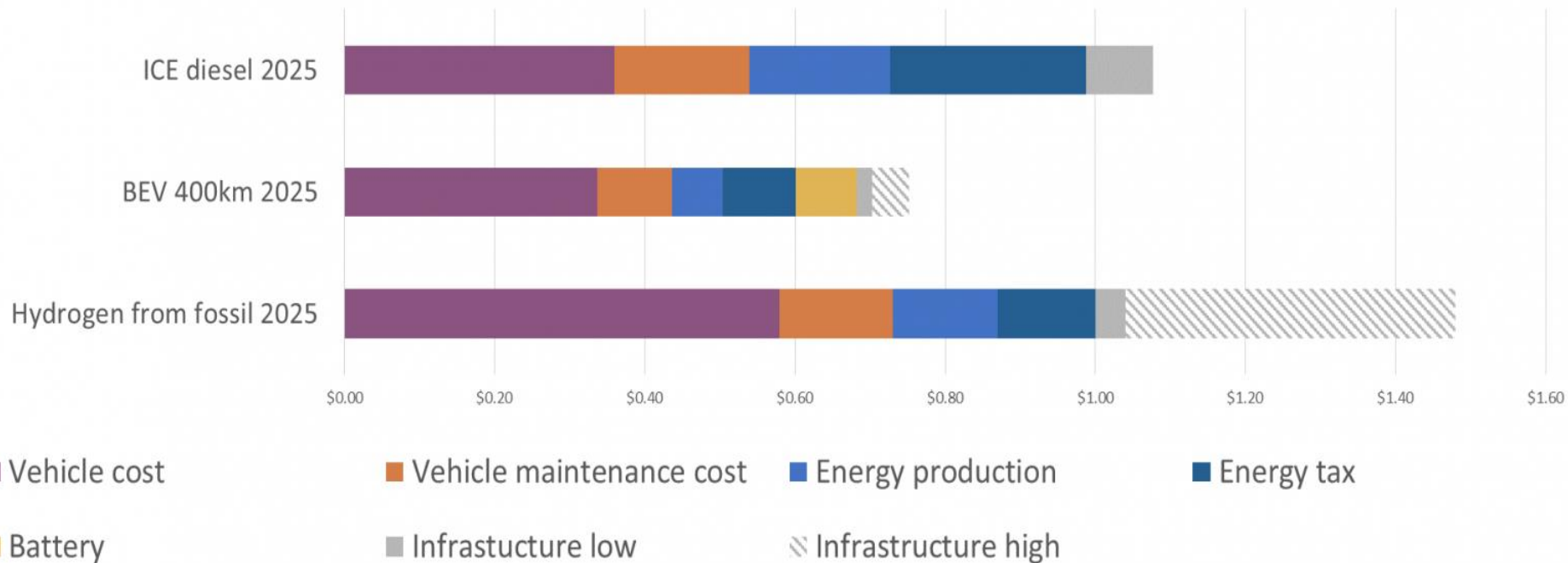


# Second hand market with 13.000 km/yr



# Electric long haul trucks?

## Cost per km shows it's far from impossible



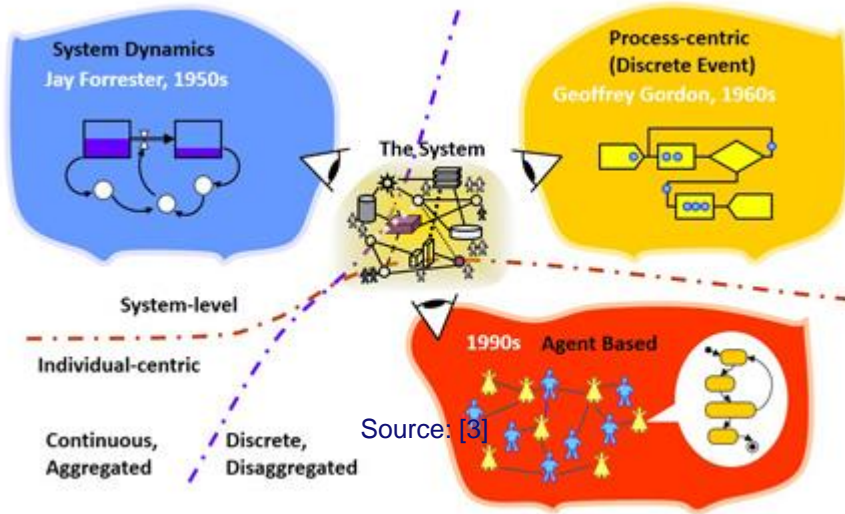
Extra FEV scenario for IEA study “The Future of Trucks”  
<https://www.livinglabsmartcharging.nl/nl/Auteurs/auke-hoekstra>

# Future work: better interaction with neighborhood

## An example neighborhood in the ABCD model.



# Heterogeneous actors by using agent-based modelling: “play out” the real life system in the computer.



- **Bottom-up modelling:** system not defined in advance.
- **Every agent is unique and you can have many thousands of them.**
- **De-facto standard for socio-technical systems [4].**
- **Agents can be people but also institutions, machines or buildings.**

[3] <https://www.anylogic.com/use-of-simulation/agent-based-modeling/>

[4] K. H. Van Dam, “Capturing socio-technical systems with agent-based modelling,” PhD Thesis, TU Delft, Delft University of Technology, 2009.

# Ambitions for next gen model (Agent-based Buying Charging Driving model) we are working on now (poster presentation)

- 1. Extrapolate (non-linear) techno trends as learning curves.  
*E.g. Moores Law, wind, PV, batteries and chemical storage.***
- 2. Incorporate exponential growth using feedback loops.  
*E.g. Internet, PV and EV.***
- 3. Interaction with build environment is crucial so use GIS files.  
*E.g. neighborhoods with buildings, roads, electricity grid and charge points.***
- 4. Radical innovation (like renewables and EV) lead to new roles that you will only see if you model heterogenous actors with individual choices that create the system bottom-up.  
*E.g. buyers/users of PCs and EVs.***

# Results of next gen model (Agent-based Buying Charging Driving model) we are working on now (poster presentation)

- **Result of taking bottom up actions and infrastructure into account is that the model becomes more accurate.**
- **It also becomes simple to determine impact of EVs on electricity grid and prices of renewables, with and without smart charging.**
- **Many what-if scenarios can be run.**

# Final conclusions

- **FEVs have higher battery price but as batteries get cheaper the TCO becomes lower than PHEVS because of cheaper drivetrain, lower maintenance costs and lower energy costs**
- **New cars (25000 km/y) will become profitable without subsidies before 2020 in the Netherlands**
- **2<sup>nd</sup> hand EVs have a lower TCO relative to gasoline than new ones**
- **Adoption speed will be driven by awareness of TCO, availability of charging infrastructure, and availability of cars**
- **New types of models can more accurately predict adoption, impact on (renewable) electricity grid and optimal interventions**