EV research projects in the Netherlands and

Zero-emission Energy & Mobility simulating the transition from the bottom up

Einhoven May 18 2018

Auke Hoekstra
Senior Advisor Electric Mobility TU/e
Founder ZEnMo Simulations
a.e.hoekstra@tue.nl @aukehoekstra

ZEnMo
zero emission energy and mobility
simulations

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Faculties:
Electrical Engineering; Industrial Engineering & Innovation Sciences; Mathematics and Computer Science

Expertise:
Energy modelling, charging technology, agent based modelling

Projects (present)
- **EV powertrain system design**
- **Power matching for large EV fleets**
- **3Ccar** (Integrated Components for Complexity Control in affordable electrified cars (ECSEL)
- EVERLASTING (Electric Vehicle Enhanced Range, Lifetime and Safety Through INGenious battery management)
- **AUTODRIVE** (Advancing fail-aware, fail-safe, and fail-operational electronic components, systems, and architectures for fully automated driving to make future mobility safer, affordable, and end-user acceptable), ECSEL
- **SMARTER**: Realizing the Smart grid: Aligning consumer behaviour with Technological opportunities (NWO together with UU and RuG)
- **Locating electric vehicle charging stations**: A multi-agent based dynamic simulation
- **Periodicity analysis of charging behavior of electric car drivers**: Latent class hazard models
- **Agent-based Buying Charging Driving** (ABCD) model
- **FlexPower simulation model**

Technische Universiteit Eindhoven University of Technology

DELFT UNIVERSITY OF TECHNOLOGY

Faculties:
Technology, Policy and Management; Radiation Science & Technology; Electrical Engineering, Mathematics and Computer Science

Expertise fields:
Energy modelling, charging technology, energy networks, policy analysis, simulation, engineering

Projects (past/present):

- Dynamic Powering of EV's using **Inductive Power Transfer**
- Economic Viability Study of an **On-Road Wireless Charging** System with a Generic Driving Range Estimation Method
- Electric Vehicle supported **PV Smart Grid** (CT-design)
- **Solar E-bike station**
- Design and development of the **E-Hub** – charging station of the future(BM)
- **Planning under Uncertainty** for Aggregated Electric Vehicle Charging using Markov Decision Processes
- Benefits of Coordinating Plug-In Electric Vehicles in Electric Power Systems: Through Market Prices and Use-of-System Network Charges

Solar E-bike station project:

WHAT ARE ACADEMICS ACTUALLY DOING?

UNIVERSITY OF TWENTE

Faculties:
Engineering Technology; Bahavioural, Management and Social Sciences

Expertise:
Energy modelling, system engineering

Projects (past):
- Robust peak-shaving for a neighborhood with electric vehicles (2016)
- Electric mobility and charging: systems of systems and infrastructure systems (2015)
- Optimization of charging strategies for electric vehicles in PowerMatcher-driven smart energy grids (2015)
- Optimal scheduling of electrical vehicle charging under two types of steering signals (2014)
- POPCORN: privacy-preserving charging for eMobility (2013)

POPCORN
Privacy-Preserving ChaRgiNg for eMobility

UNIVERSITY OF GRONINGEN

Faculties
Behavioural and Social Sciences

Expertise
Consumer research, behavior and choice models, adoption models

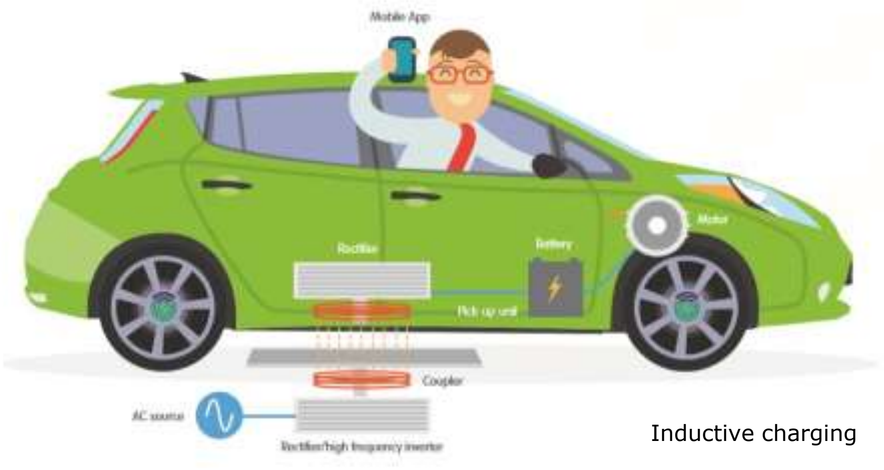
Projects (past/current)
- **Ersas:** develop an efficient energy system integration
- **SMARTER:** realizing the smart grid (collaboration with UU)
- **SMARTEST:** electric vehicle as gateway to smart and sustainable energy (collaboration with TUE)

ERSAS Project

ELAADNL

About
ElaadNL researches and test the possibilities for smart charging

Expertise
Energy markets, business modelling, simulation, regulations and legislation.



Inductive charging

Projects (current)

- **Smart Chain:** smart charging system that takes into account the whole chain.
- **FlexPower:** Flexbile charging when wind and sun energy generate lots of electricity.
- **Social charging:** Facilitate the increase of the throughput of charging EV's by connecting the 'Social Charging' app to the ElaadNL (EVnetNL's) stations.
- **Inductive charging pilot Rotterdam:** The goal of this project is to gain experience with (interoperability matters) of inductive charging.
- **E-clearing.net :** e-mobility roaming.
- **Internationalisation:** a broader standardisation of protocols in the area of smart charging.
- **eFlexibility as a service:** a prototype product / service combination that convinces EV drivers for smart charging
- **Interflex:** demonstrating a local capacity market.

UTRECHT UNIVERSITY

Faculties
Social and Behavioural Sciences, Copernicus Institute

Expertise
Innovation studies, energy markets, energy modelling, behavior models

Projects (current)
- **SMARTER** (in collaboration with UoG)
- **Co-Evolution of Smart Energy Products and Services (CESEP**S): analyzing the role of Evs in smart grid pilots
- **PARticipatory platform for sustainable ENergy managemenT (PARENT):** increasing engagement of individuals in the responsable management of own electricity usage.
- **Smart Solar Charging (SSC):** experimenting with smart solar charging

UNIVERSITY OF AMSTERDAM

Faculties
Economics and Business; Science; Computational Science Department

Expertise
Computational sciences, business economics

Projects (past)
- Market-based coordinated charging of electric vehicles on the low-voltage distribution grid
- Simulation model for charging infrastructure optimization (IDOLaad)

ERASMUS UNIVERSITY

Faculties
Department of Technology and Operations Management (Rotterdam School of Management)

Expertise
Energy markets, pricing models, consumer economics

Projects (past)
- Stable energy: the road ahead for electric cars
- A multiagent approach to variable-rate electric vehicle charging coordination

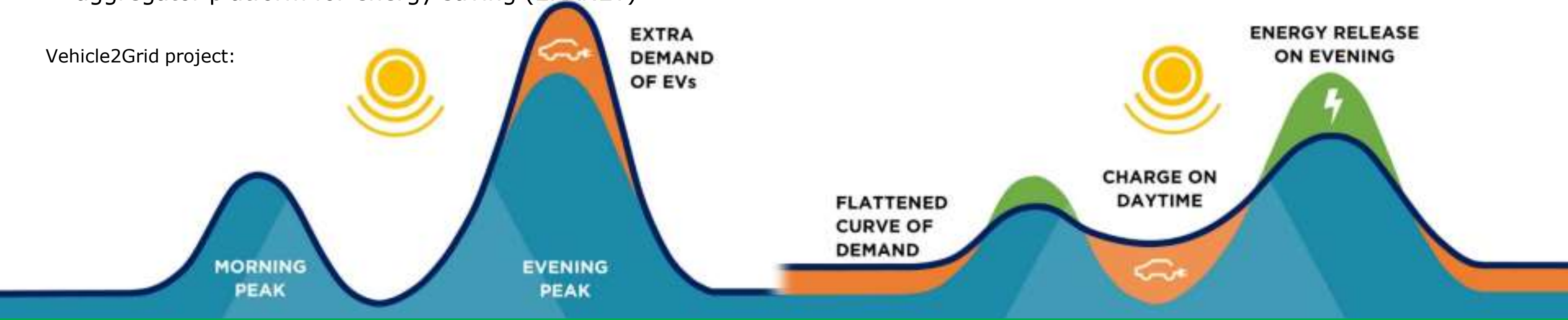
UNIVERSITY OF APPLIED SCIENCES AMSTERDAM

Faculties
Technology

Expertise
Data analytics, engineering, consumer research, business modelling

Projects (current)
- **IDO-laad**: research on the roll-out of a cost-efficient and effective use of charging infrastructure (RAAK).
- **Me2**: Development of a an energy-marketplace and aggregator platform for energy saving (ERANET).
- **U-SMILE**: research into effects of incentives, particularly in taxi sector (collab. with RUG, TUD and VUA) (SURF)
- **Seev4-City**: demonstrations of Vehicle2Grid on different aggregation levels (v2house, v2street, v2neighbordhood, v2stadium) (INTERREG)
- **Vehicle2Grid**: use of EV battery to temporary store electricity (TKI)

Vehicle2Grid project:



WHAT ARE ACADEMICS ACTUALLY DOING?

HOGESCHOOL ROTTERDAM

Faculties
Automotive, Logistiek en Bedrijfskunde

Expertise
Emobility technology, battery and drive train

Projects (current)

- **Zero Emission Stadslogistiek 010**: deployment of electric truck and charging infrastructure
- **Surf STAD**: researching automated and autonomous driving
- **Sia Raak INTRALOG**: Intelligent Truck Applications in Logistics (in collab. with HAN)
- **Monitoring e-Busz**: researches performances of electric and fuell cell electric busses in Rotterdam

Monitoring e-Busz project

HAN UNIVERSITY OF APPLIED SCIENCES

Faculties
Technologie en Samenleving

Expertise
Drive train technology, battery, fuel cells

Projects (current)

- **Electric Power Train**: increasing knowledge about electric power train and charging technology

Electric power train

WHAT ARE ACADEMICS ACTUALLY DOING?

TNO

Expertise
Emobility technology, policy analysis, consumer analysis

Projects (past)
- Economic viability study of an **on-road wireless charging system** with a generic driving range estimation method (2016)
- Generic methodology for **driving range estimation of electric vehicle with on-road charging** (2015)
- Fuel-electricity mix and efficiency in Dutch plug-in and range-extender vehicles on the road (2013)
- Constrained capacity management and cost minimisation of **EV-charging in a parking garage** (2013)

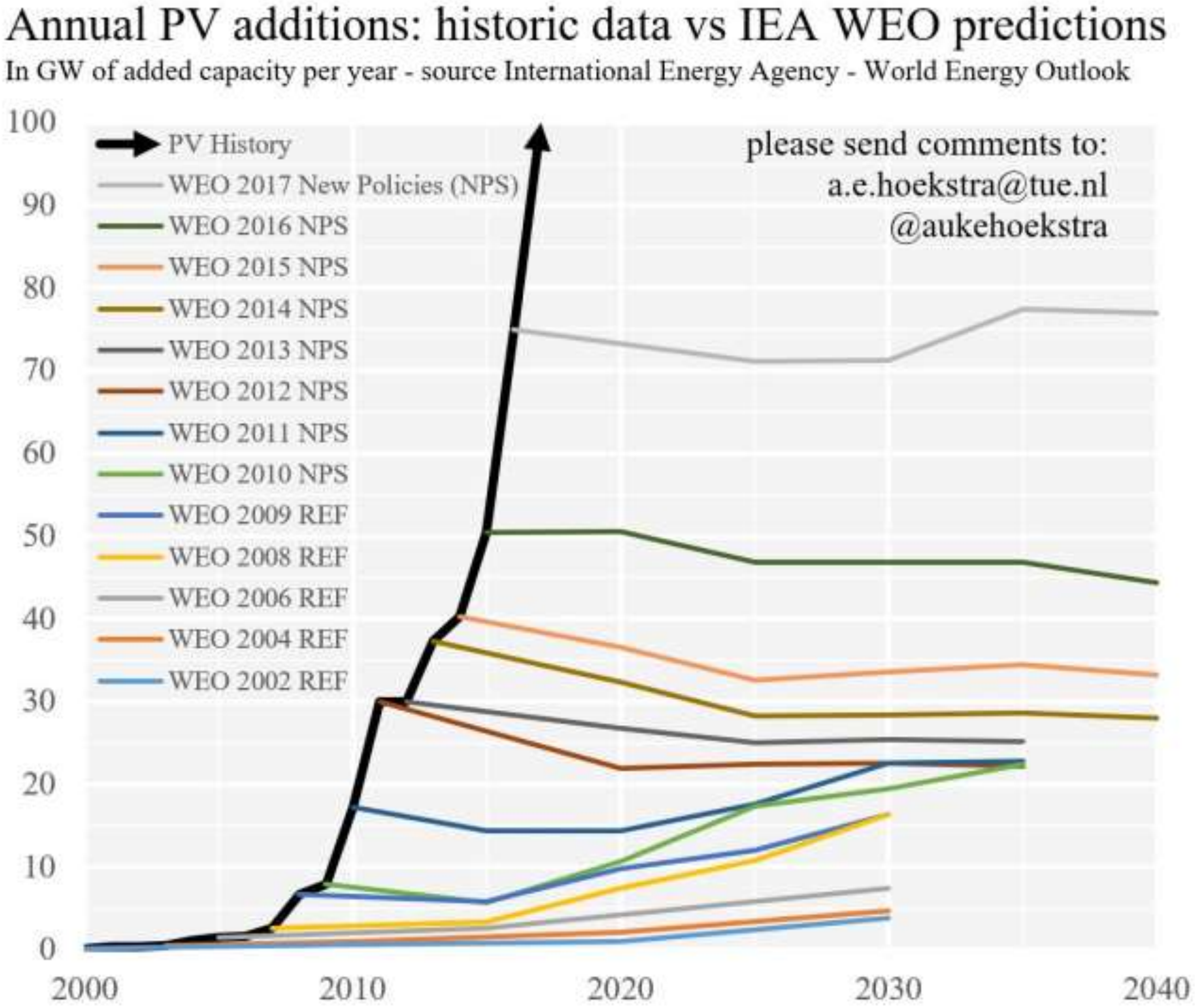
TNO innovation for life

ECN

Expertise
Emobility technology, policy analysis, consumer analysis

Projects (past/current)
- **Policies and good practices** to foster electromobility roll-out at the local, national and European level (2015)
- **Policy recommendations** and stakeholder actions towards effective integration of EVs in the EU (2015)
- **User preferences** for charging locations and charging schemes – a survey in eight EU countries (2011)

ECN



Conventional predictions are often really really bad

Annual additions of PV

Thick black line:
Reality

Colored lines:
12 predictions of the International Energy Agency through the years

(see my pinned tweet for more info)

Technische Universiteit Eindhoven University of Technology

Hindawi
Complexity
Volume 2017, Article ID 1967645, 23 pages
https://doi.org/10.1155/2017/1967645

WILEY | Hindawi

Review Article

Creating Agent-Based Energy Transition Management Models That Can Uncover Profitable Pathways to Climate Change Mitigation

Auke Hoekstra, Maarten Steinbuch, and Geert Verbong

Eindhoven University of Technology, Eindhoven, Netherlands

Correspondence should be addressed to Auke Hoekstra; a.e.hoekstra@tue.nl

Received 6 June 2017; Revised 17 October 2017; Accepted 12 November 2017; Published 28 December 2017

Academic Editor: Ettore Bompard

ZEnMo
zero emission energy and mobility
simulations

http://bit.ly/ETModels

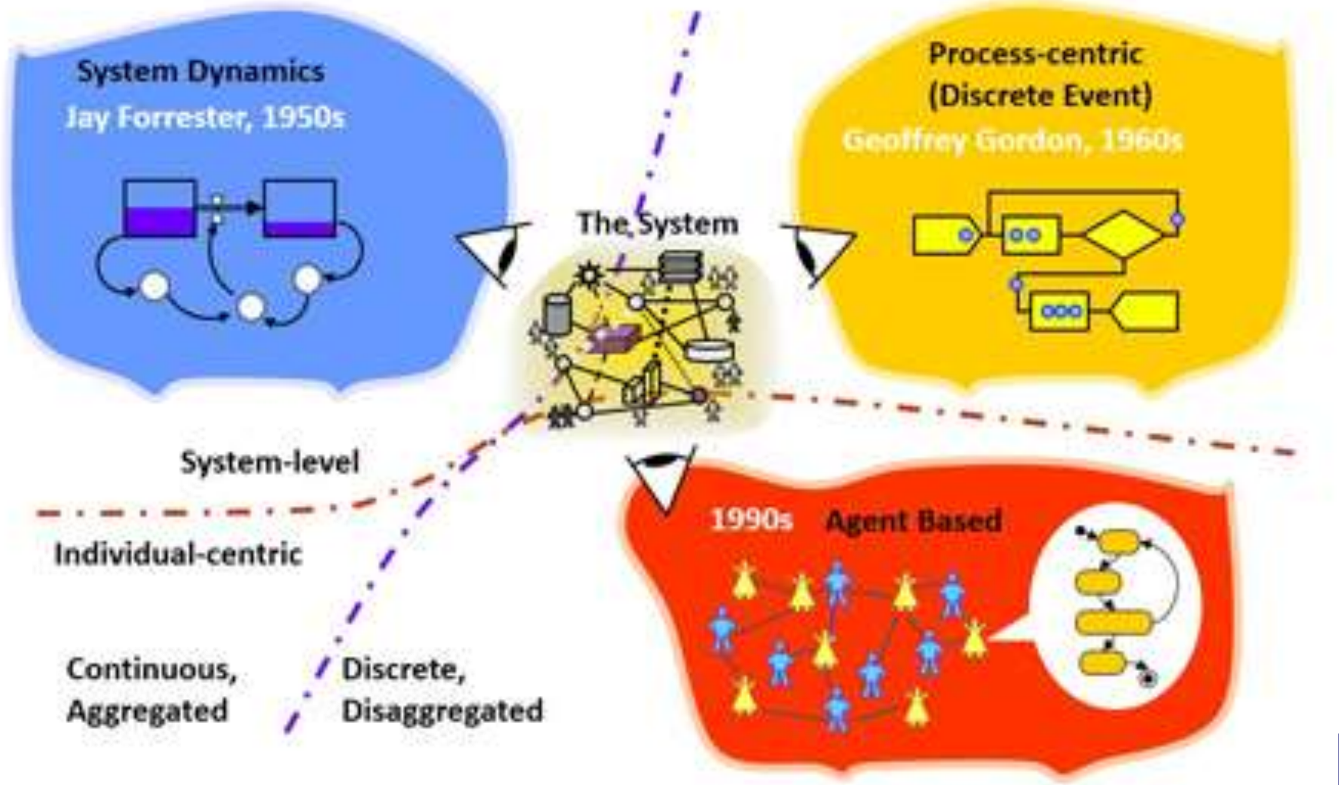
Technische Universiteit Eindhoven University of Technology

Agent-based modelling can change this

Bottom-up

Discrete and disaggregated

Higher complexity with simpler math



ZEnMo
zero emission energy and mobility
simulations

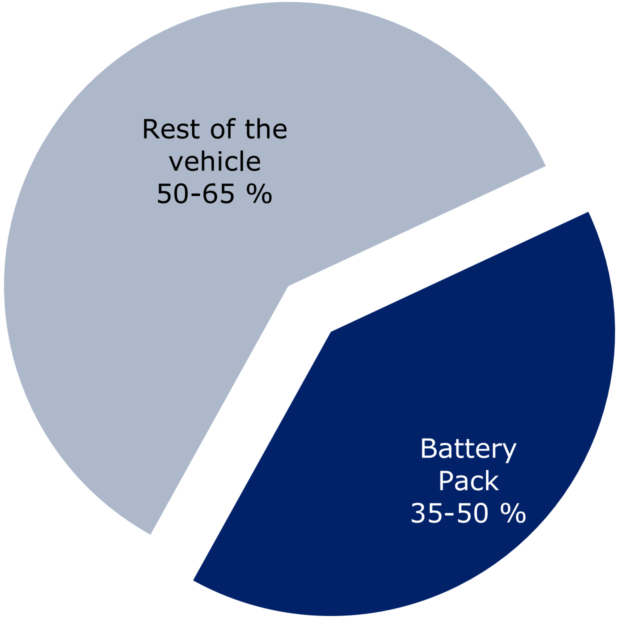
SparkCity agents live in an environment based on real maps
Crucial for interaction with experts in different domains
Crucial for connecting multiple systems: road, grid, buildings, etc.

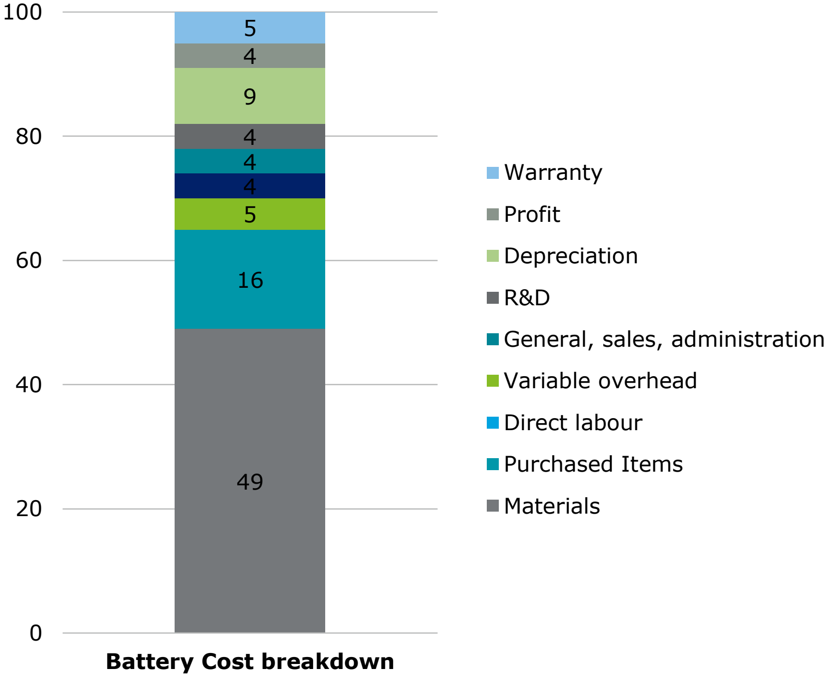
SparkCity can use GIS maps of actual physical infrastructure (buildings, electricity grid, parking places, charge points etc.) and inhabitants with specific demographics and behavior. On this canvas you can play out complex and integral scenarios with realistic interactions.

ZEnMo zero emission energy and mobility simulations

TU/e Technische Universiteit Eindhoven University of Technology

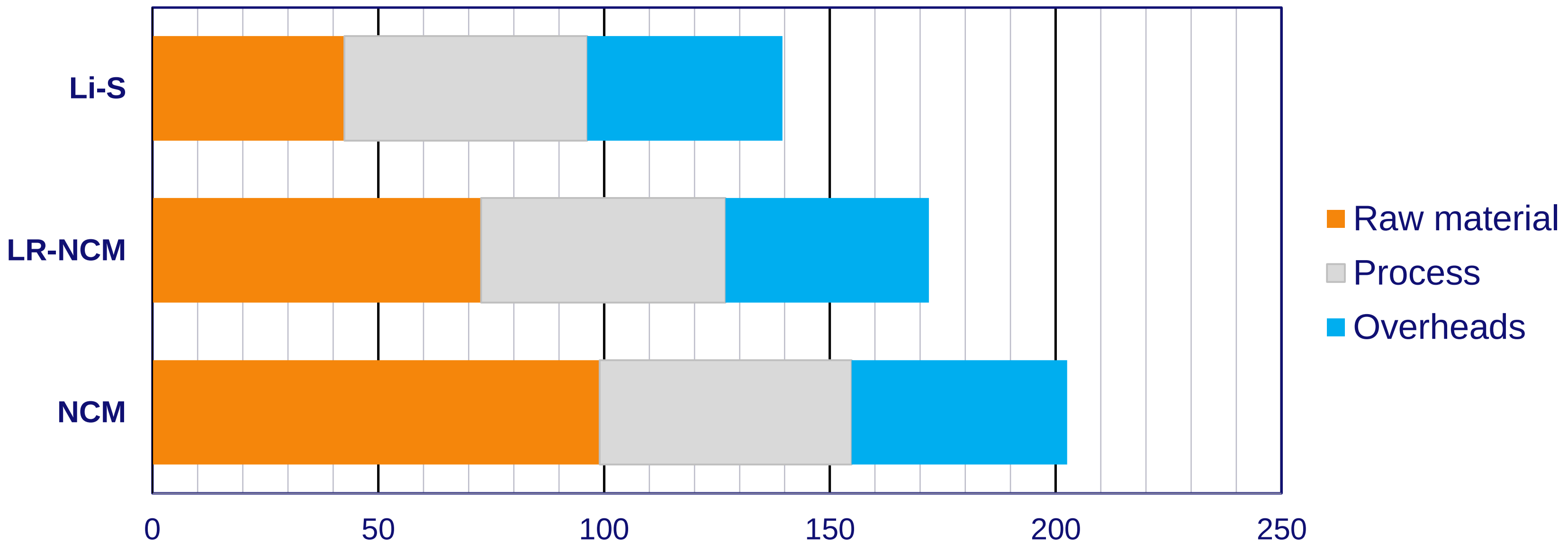
Not only using extrapolation but also by using bottom up analysis of raw materials and processes used.





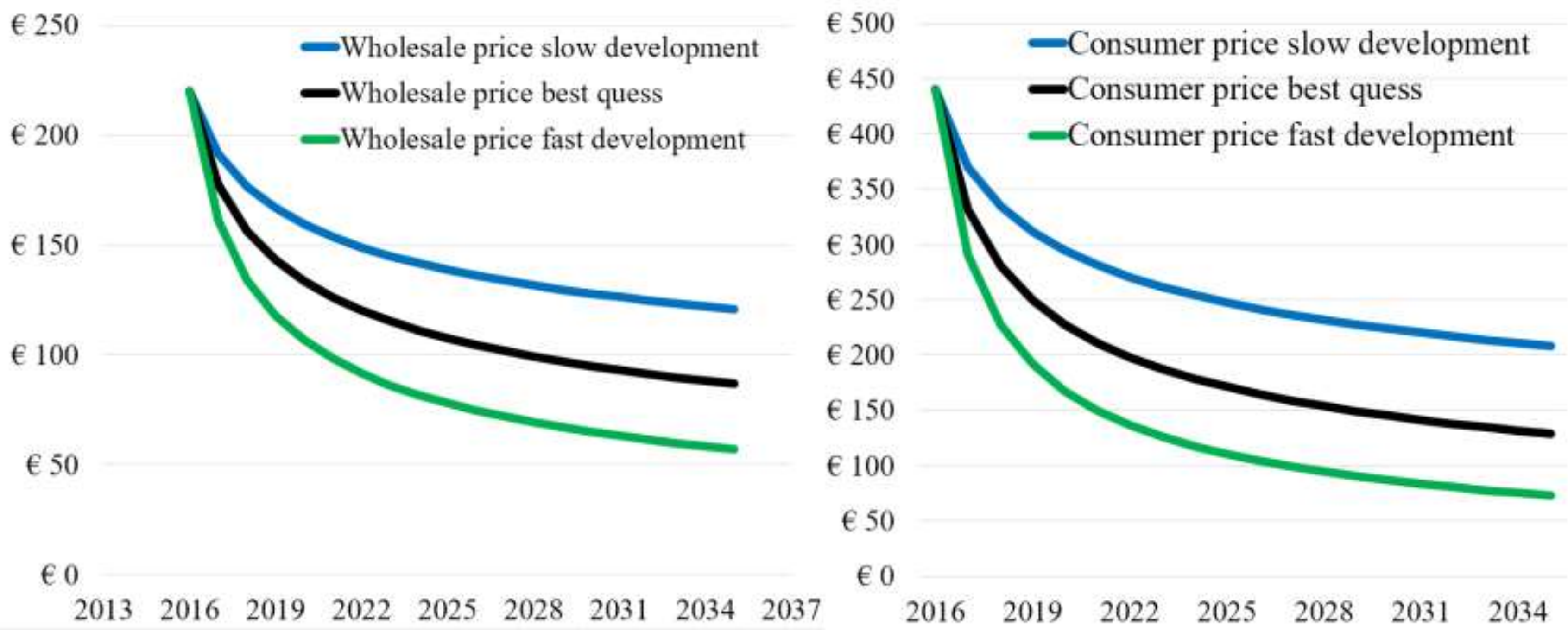
Source: R. Kochhan, et. Al., "An Overview of Costs for Vehicle Components, Fuels and Greenhouse Gas Emissions," *Publ. Www.Res. Net, Feb, 2014.*

It 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



ZEnMo zero emission energy and mobility simulations

TU/e Technische Universiteit Eindhoven University of Technology

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.

We create virtual cars in a virtual showroom

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

ZEnMo zero emission energy and mobility simulations

Technische Universiteit Eindhoven University of Technology

Everything evolves over time
Here the example of charging

Energy source	Perc. 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

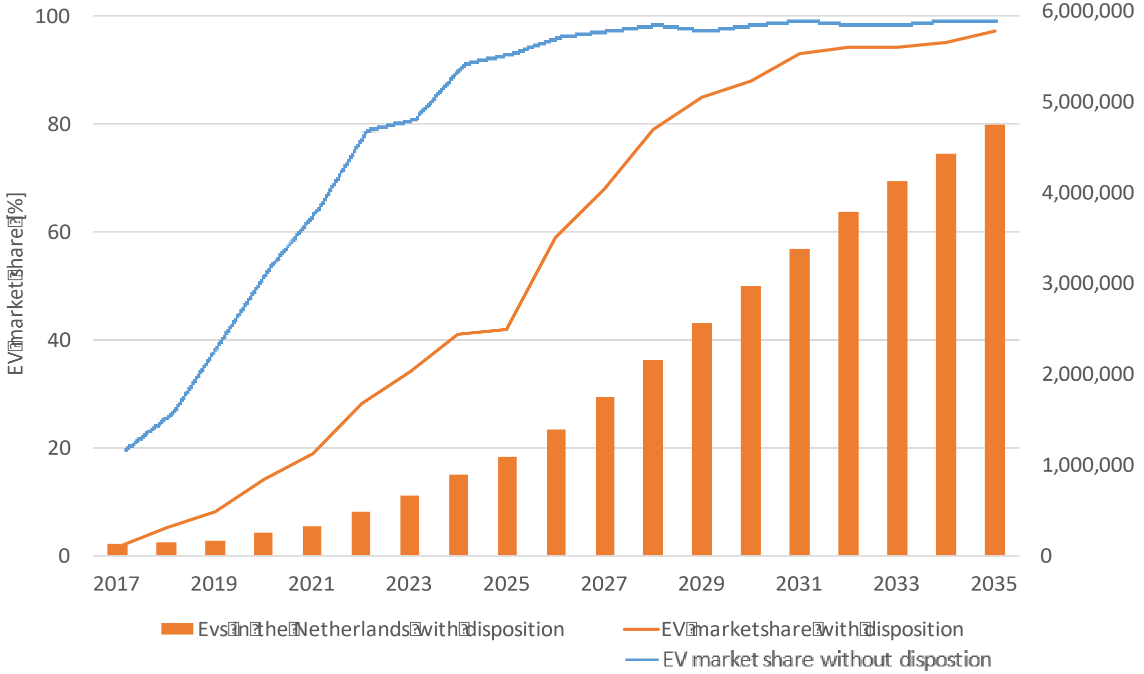
Using agent-based modelling, SparkCity can model thousands of unique agents

For each agent the factors that determine e.g. financial attractiveness of EVs are different
These are just some examples of the variables that have been taken into account.

Fuel costs	**Maintenance costs**	**Vehicle class**	**Residual value**
Fuel efficiency	**Purchase subsidies**	**Luxury level**	**Battery capacity**
Yearly mileage	**Tax rebates**	**Vehicle power**	**Battery pack costs**
Income	**Lease or private**	**Discount rate**	**Ownership period**

Total Cost of Ownership (TCO)

SparkCity can predict behavior like EV buying in a fine grained and realistic way



Difference between blue and red line takes non-financial reasoning in car purchases into account through a disposition factor. E.g.:

1. Limited model choices for EVs
2. Limited EV stock/production
3. Psychological factors (brand and drive-train preferences)
4. Limitations of EVs (range, charging infra)

Validity can be improved through market research into such factors.

ZEnMo zero emission energy and mobility simulations

TU/e Technische Universiteit Eindhoven University of Technology

Takeaways for achieving 100% EV market share in 2030

1. By 2027 all EVs have lower TCO than their ICE counterparts → policies should focus on non-financial factors such as raising awareness, placement of charging infrastructure, ICE bans and stimulating EV production

2. 80% of E-class EVs already financially more attractive → financial incentives might not be as effective for E-class vehicles

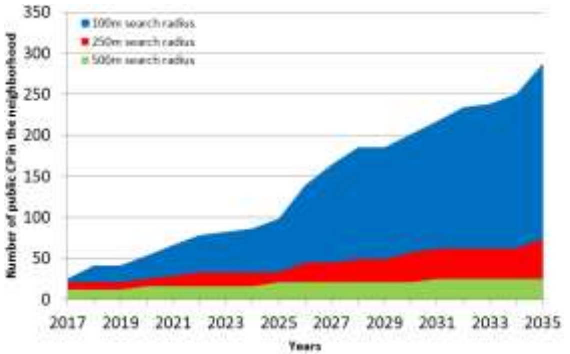
3. The smaller the vehicle class the lower the TCO differences (ICE vs EV) → financial incentives are likely to be more effective for smaller vehicle classes such as A, B and C.

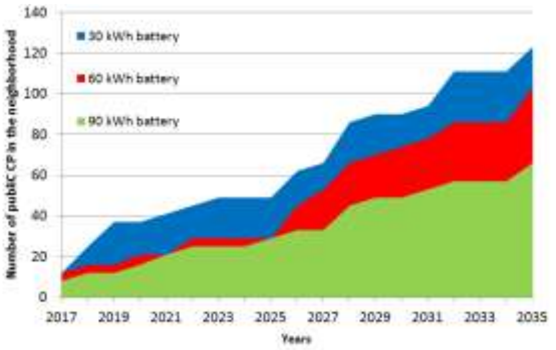
4. Smaller vehicle classes are the last to reach cost-parity → financial incentives for A class may significantly speed up adoption

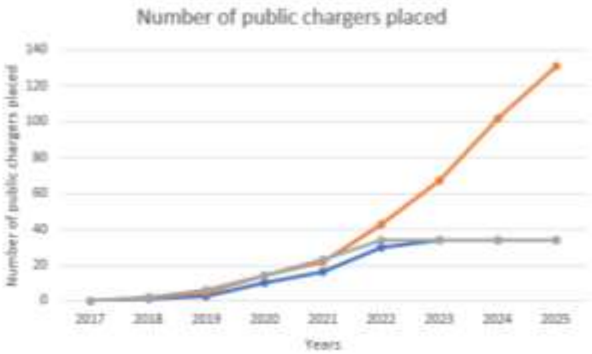
Planned SparkCity EV research (Help wanted!)

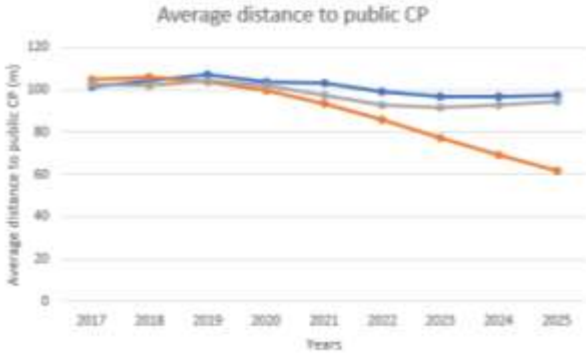
1. Social research for better disposition factor
2. 2nd hand EV flow between neighborhoods
3. OEM EV production limits
4. Multiple car ownership of households
5. Autonomous driving and car sharing

SparkCity can predict the number of charge points and their usage
Each charge point is monitored separately (e.g. every 15 minutes)









We can include battery state of charge in the charging behavior and monitor how often users are disappointed and how far they had to walk to home or work. There are big impacts of search radius (from the viewpoint of the municipality), battery size, neighborhood and placement strategy.

ZEnMo zero emission energy and mobility simulations

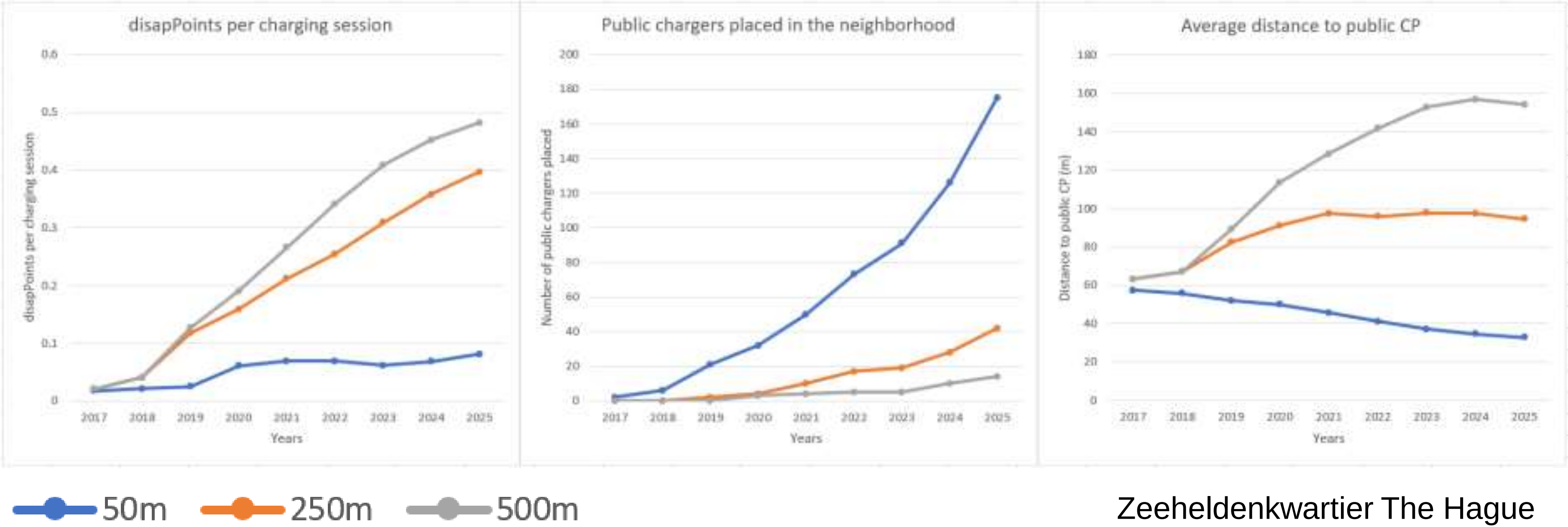
TU/e Technische Universiteit Eindhoven University of Technology

Big differences between neighborhoods

ZEnMo zero emission energy and mobility simulations

Technische Universiteit Eindhoven University of Technology

Optimizing search radius has big effects

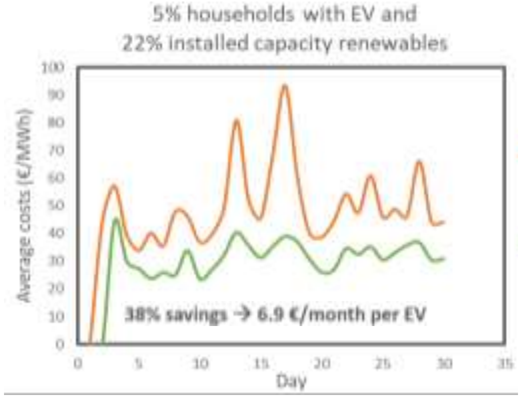


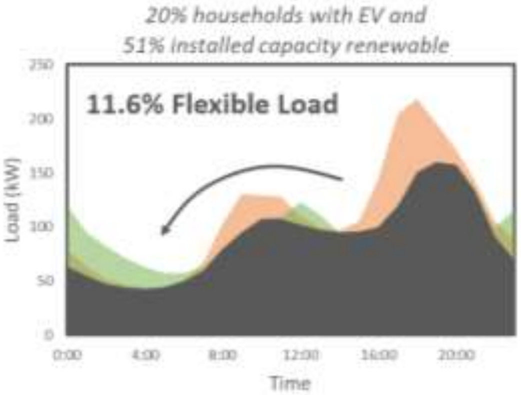
Zeeheldenkwartier The Hague

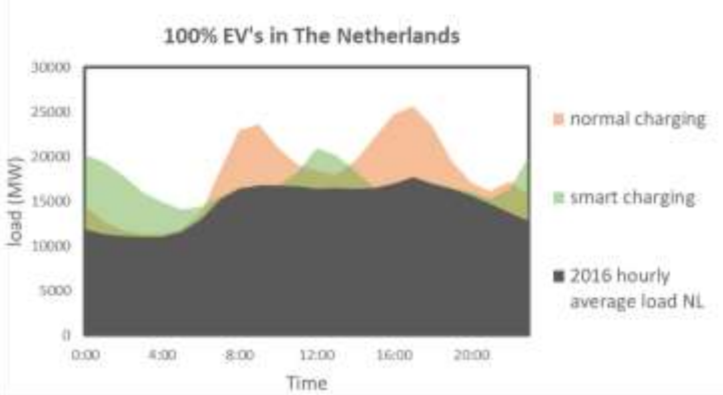
ZEnMo zero emission energy and mobility simulations

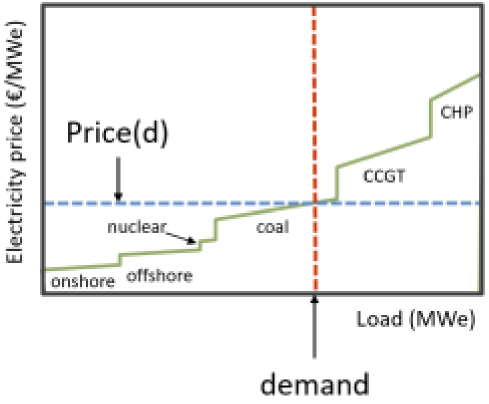
TU/e Technische Universiteit Eindhoven University of Technology

Impact on energy supply and grid can be modelled in detail Including energy markets, individual grid elements et cetera







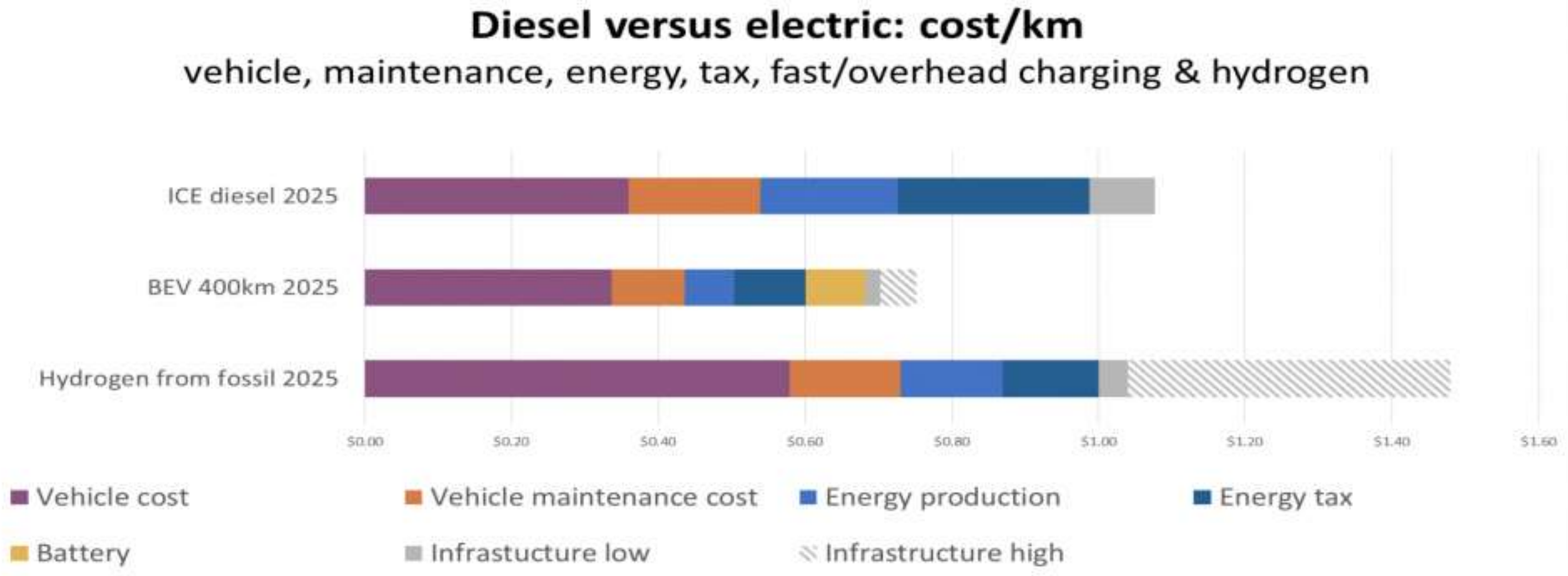


- = Electricity price
- = Supply curve
- = Demand curve

ZEnMo
zero emission energy and mobility
simulations

TU/e Technische Universiteit Eindhoven University of Technology

Now expanding to long haul trucks



ZEnMo zero emission energy and mobility simulations

Technische Universiteit Eindhoven University of Technology

I got a lot of skepticism but Tesla semi is better

ABM and EV have a bright future ahead!

ZEnMo
zero emission energy and mobility
simulations

TU/e Technische Universiteit Eindhoven University of Technology