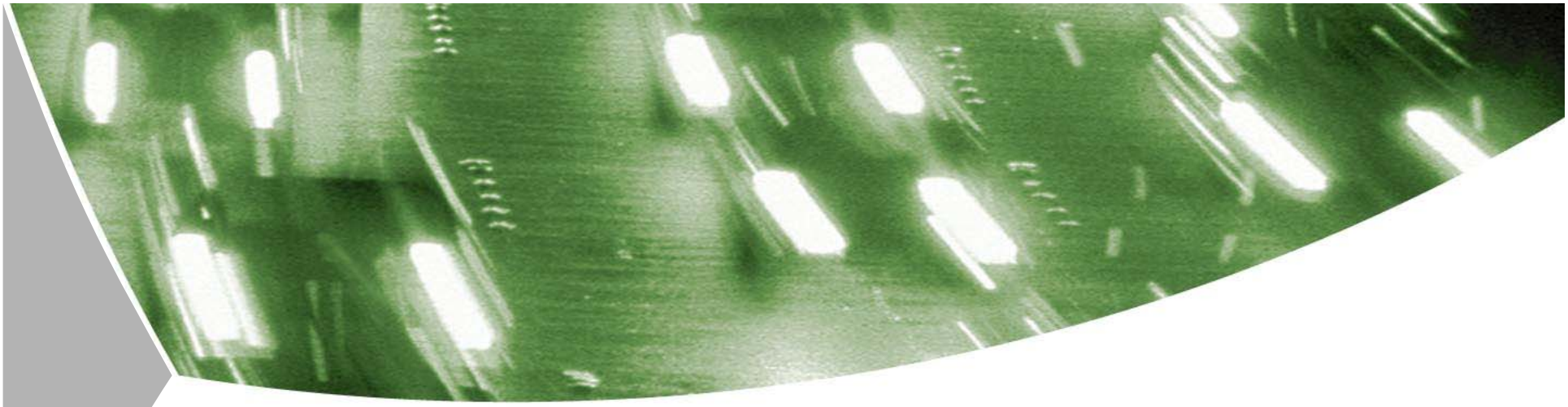


Peter Mock
German Aerospace Center (DLR), Institute of Vehicle Concepts

Market Prospects of Electric Passenger Vehicles and Their Effect on CO_2 Emissions up to 2030 (*VECTOR21*)

PHEV'09 – Plug-In Hybrid and Electric Vehicles
Montreal, Sept. 29, 2009

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

PHEV'09 Plug-In Hybrid and Electric Vehicles
September 28 to 30, 2009 – Montreal
Véhicules électriques et hybrides rechargeables
28 au 30 septembre, 2009 – Montréal

Introduction
German Aerospace Center (DLR)

- 5.700 employees at 29 research institutes and facilities in 13 locations
- Offices in Brussels, Paris and Washington D.C.
- 4 main research fields:
  - Aeronautics
  - Space
  - Transport
  - Energy

Introduction
Motivation and framework

What are the vehicle technologies and fuels of the future?

- complex system of concurrency / prospects of success unknown
- to be taken into account:
  - technology costs
  - energy prices
  - taxation
  - customer decision process, …
- new computer model for market scenarios up to 2030: ***VECTOR21***

Overview
3-step approach

1. **Set up a technology database**
2. **Develop a model to reflect the market**
3. **Apply the model to get to scenarios of the future**

Technology cost and energy consumption assessment
Vehicle types currently included in the analysis

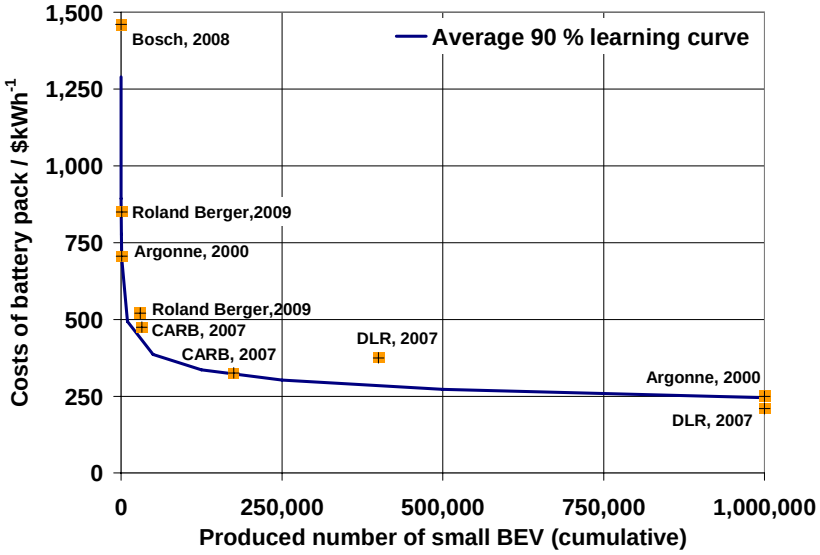
- conventional gasoline and gasoline hybrid electric (HEV) vehicles
- conventional diesel and diesel HEV vehicles
- conventional compressed natural gas (CNG) and CNG HEV vehicles
- extended range electric vehicles (EREV)
- battery electric vehicles (BEV)
- fuel cell hybrid electric vehicles (FCHEV)

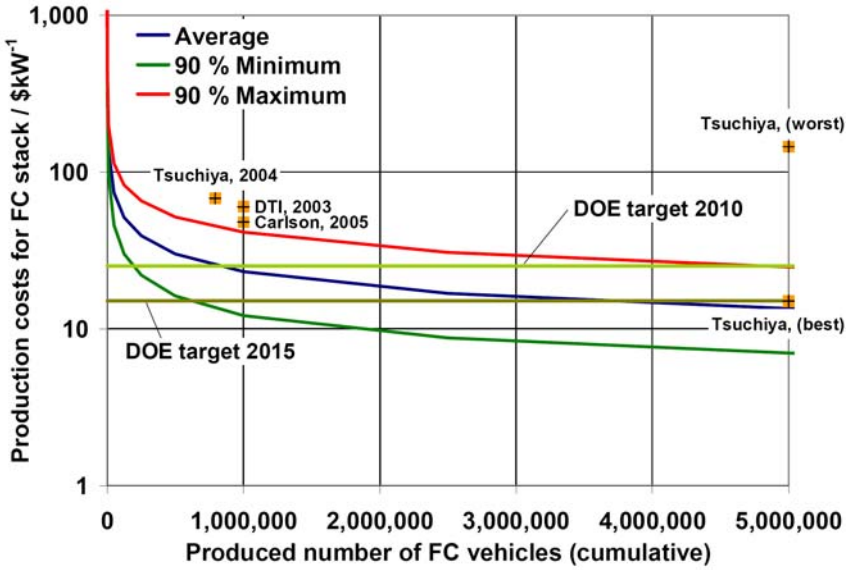
Technology cost and energy consumption assessment
Example medium size gasoline vehicle

				Packages					Energy Cons.	Costs / Price: Start		
		Start	End							Production	Markup	Retail
PARTS	BaselineGasolineVehicle	1994	---							9.350 €	35%	15.021 €
	G_EURO5 (Euro 5 Compliance)	2009	---							50 €	35%	80 €
	G_EURO6 (Euro 6 Compliance)	2014	---							50 €	35%	80 €
	SUM	**2008**	---						**2,65 MJ/km**	**9.450 €**	**35%**	**15.181 €**
									=> 0,74 kWh/km	=> 8,2 l/100 km		
ADDONS	Reduced engine friction losses	2009	---	X	X	X	X	X	-3,0%	70 €	35%	112 €
	Direct injection: homogeneous charge	2010	---		X	X	X		-2,0%	150 €	35%	241 €
	Direct injection: stratified charge	2013	---					X	-8,0%	700 €	35%	1.125 €
	Medium Downsizing with turbocharging	2010	---		X	X			-5,0%	200 €	35%	321 €
	Strong Downsizing with turbocharging (twin charger)	2011	---				X	X	-8,0%	450 €	35%	723 €
	Variable Valve Timing	2010	---			X			-3,0%	150 €	35%	241 €
	Variable Valve Control	2012	---				X	X	-7,0%	350 €	35%	562 €
	Start Stop	2009	---	X	X	X			-4,0%	200 €	35%	321 €
	Start Stop + Regenerative Braking (Micro Hybrid)	2011	---				X	X	-7,0%	600 €	35%	964 €
	Low friction tyres	2009	---	X	X	X	X	X	-2,0%	30 €	35%	48 €
	Optimised cooling circuit, electric water pump	2011	---			X	X	X	-2,0%	120 €	35%	193 €
	Exhaust heat recovery	2012	---				X	X	-1,0%	50 €	35%	80 €
	Improved aerodynamic efficiency	2012	---				X	X	-1,5%	75 €	35%	120 €
	Electrically assisted steering, auxiliary power steering	2010	---		X	X	X	X	-2,0%	100 €	35%	161 €
	Improved transmission (e.g. Dual-Clutch)	2011	---			X	X	X	-4,0%	350 €	35%	562 €
	Weight reduction: package 1 (mild) = 1,5% veh. weight (20 kg)	2010	---		X	X			-1,0%	120 €	35%	193 €
	Weight reduction: package 2 (medium) = 3,5% veh. weight (50 kg)	2011	---				X		-2,0%	300 €	35%	482 €
	Weight reduction: package 3 (strong) = 9,0% veh. weight (120 kg)	2013	---					X	-5,0%	720 €	35%	1.157 €
	G_FE#01	2009	---	X					-8,0%	300 €	35%	482 €
	G_FE#02	2010	---		X				-17,0%	870 €	35%	1.398 €
	G_FE#03	2011	---			X			-24,0%	1.490 €	35%	2.394 €
	G_FE#04	2012	---				X		-34,0%	2.645 €	35%	4.249 €
	G_FE#05	2013	---					X	-40,0%	3.615 €	35%	5.807 €
	Best available vehicle	**2013**	---					X	**1,59 MJ/km**	**13.065 €**	**35%**	**20.989 €**
									=> 0,44 kWh/km	=> 4,9 l/100 km		**+ 38 %**

Technology cost and energy consumption assessment
Learning curve approach for electric vehicles

- **Internal combustion engines**
  - manufacturing costs / retail prices for **baseline vehicles**
  - individual technical measures summarized into **fuel economy packages**
  - **potential for future fuel economy improvements** taken into account
- **Electric vehicles**
  - identification of **learning curves**, costs dependent on production volume





Overview
3-step approach

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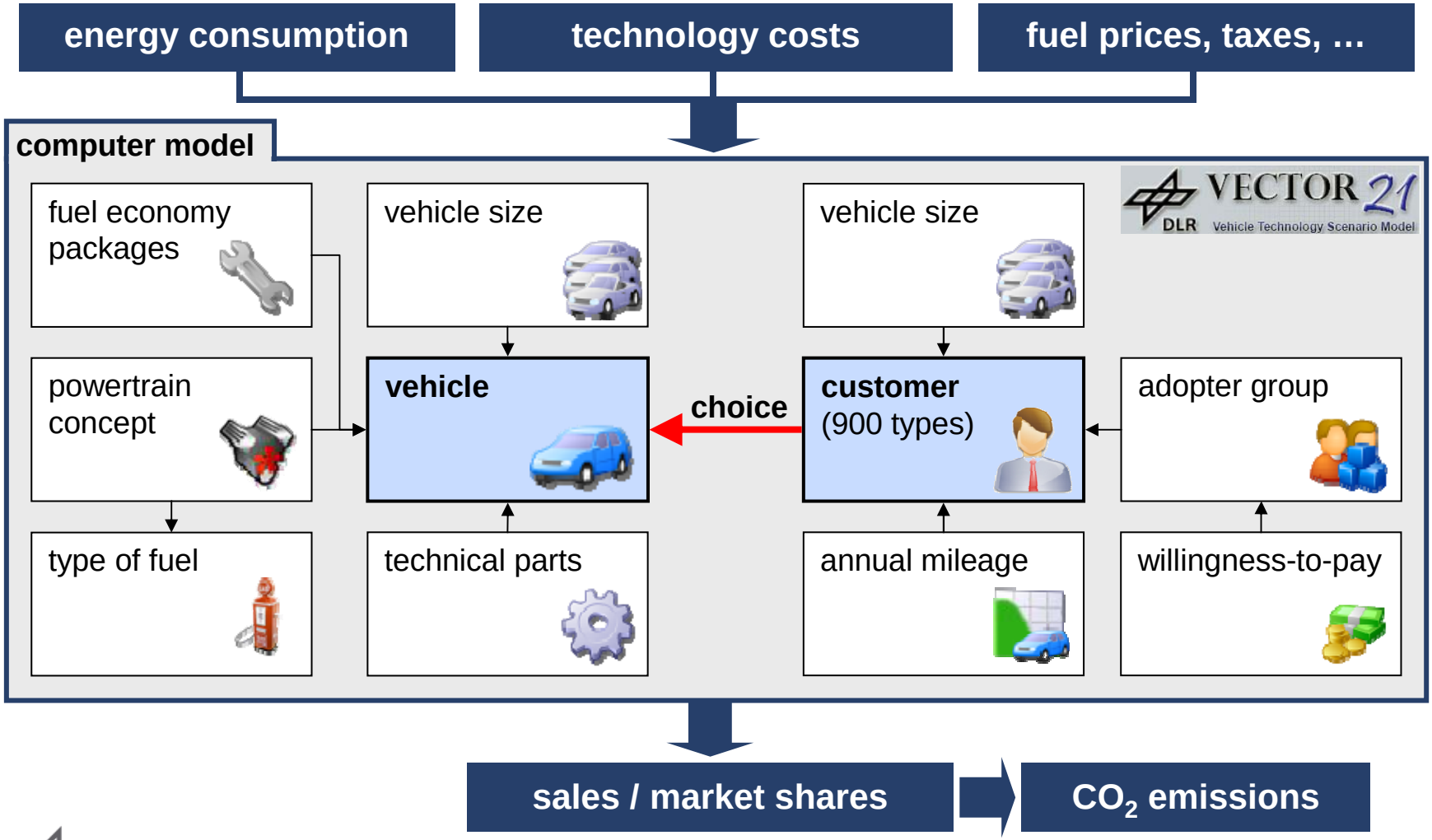
Scenario model (*VECTOR21*)
Modeling technology supply and customer demand



Scenario model (*VECTOR21*)
Relevant cost of ownership as main purchase criteria

Total cost of ownership (TCO) = <u>all</u> costs

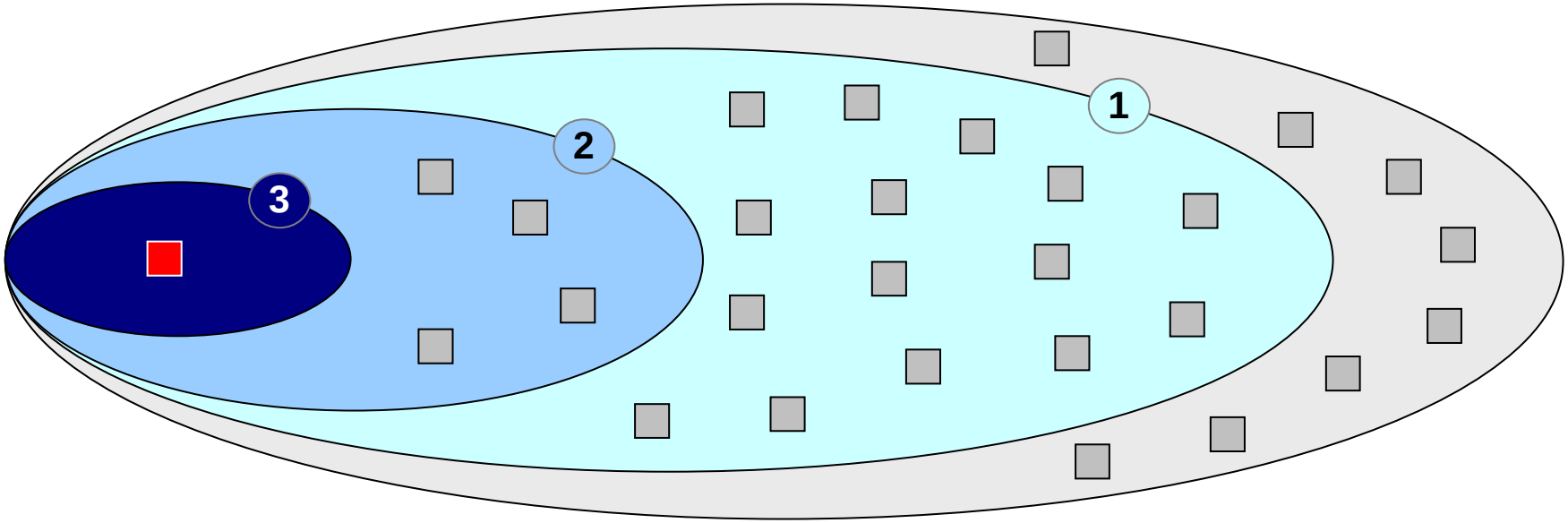
Relevant cost of ownership (RCO):

=	vehicle price	-	subsidies	+	penalties			purchase price
+	vehicle tax	x	time for break-even (4 years)					annual costs
+	fuel costs per km	x	annual mileage	x	time for break-even			mileage depending costs

Innovator	Early Adopter	Early Majority	Late Majority	Laggard
+ 10 %	+ 7 %	+ 3 %	+ 1 %	0 %

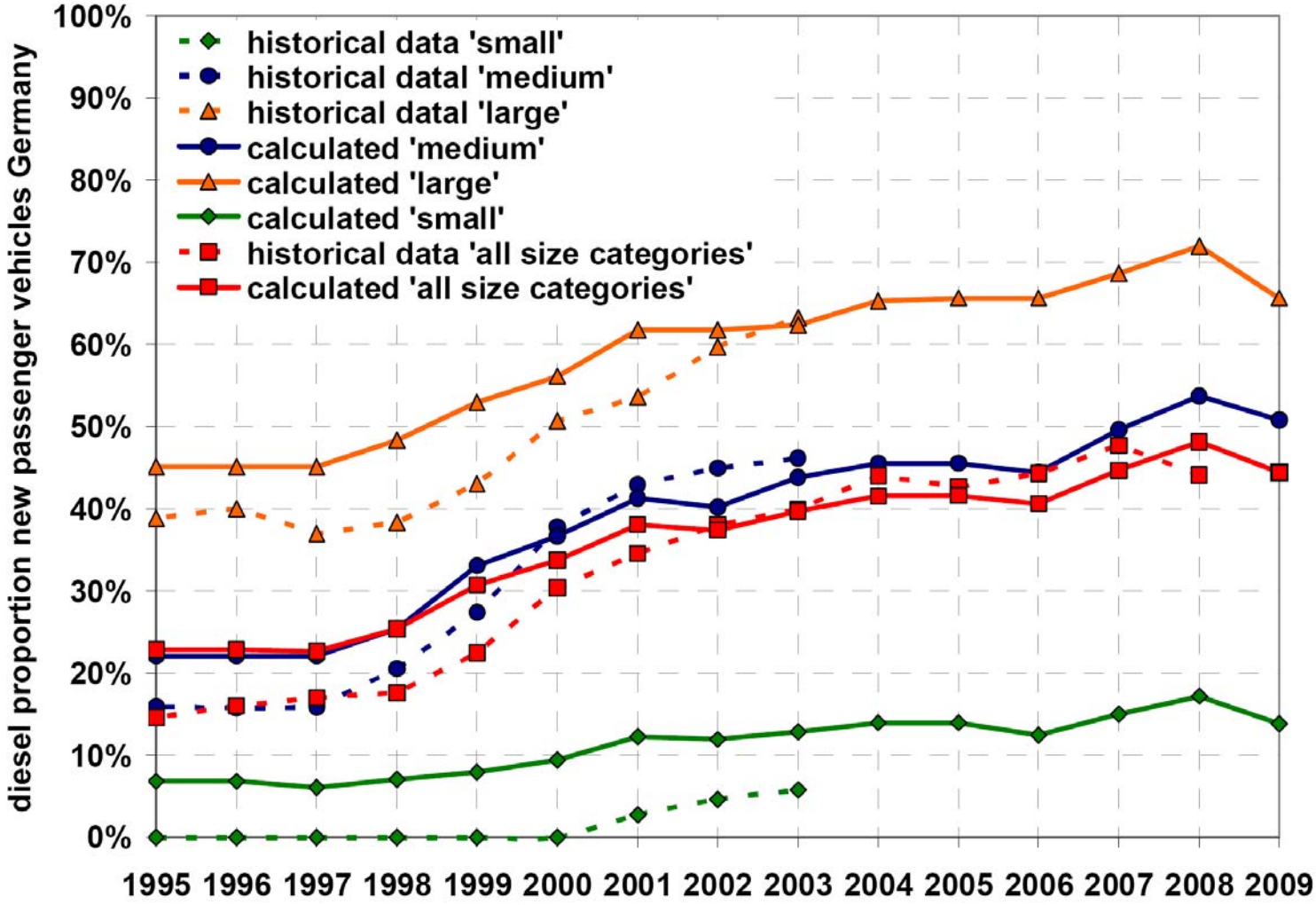
- **assumption: purchase decision <u>within</u> vehicle category rational**
- **basis for decision: relevant cost of ownership (RCO)**
- **additional willingness-to-pay depending on customer type**

Scenario model (*VECTOR21*)
Illustration of selection process



- **vehicle variants** (combination of vehicle technology and fuel)
- **step 1: filter for vehicle size category and general compulsory requirements**
- **step 2: choose lowest Relevant Cost of Ownership (RCO)**
- **step 3: choose lowest well-to-wheel CO_2 emissions**

Scenario model (*VECTOR21*)
Model results vs. real historical developments



Overview
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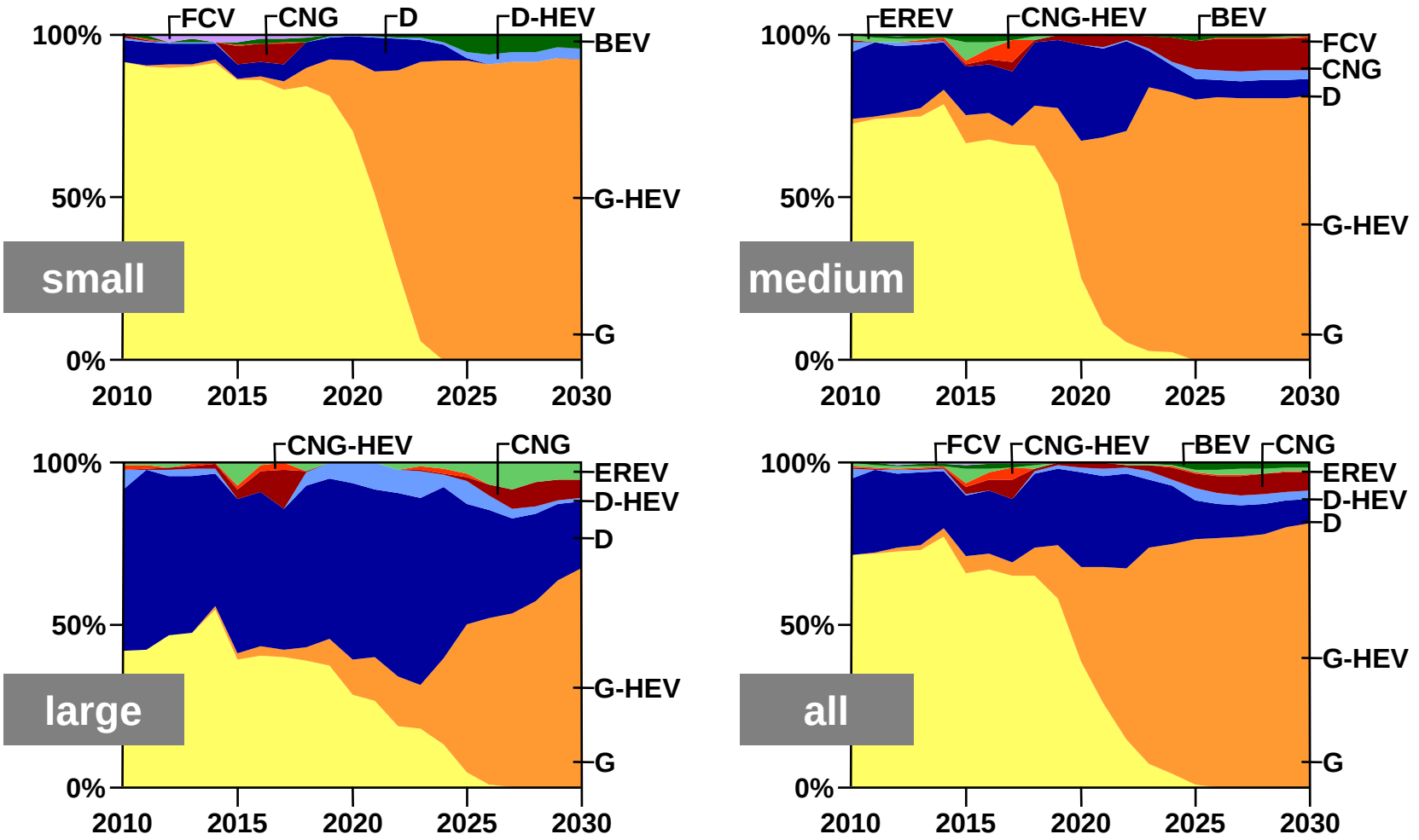
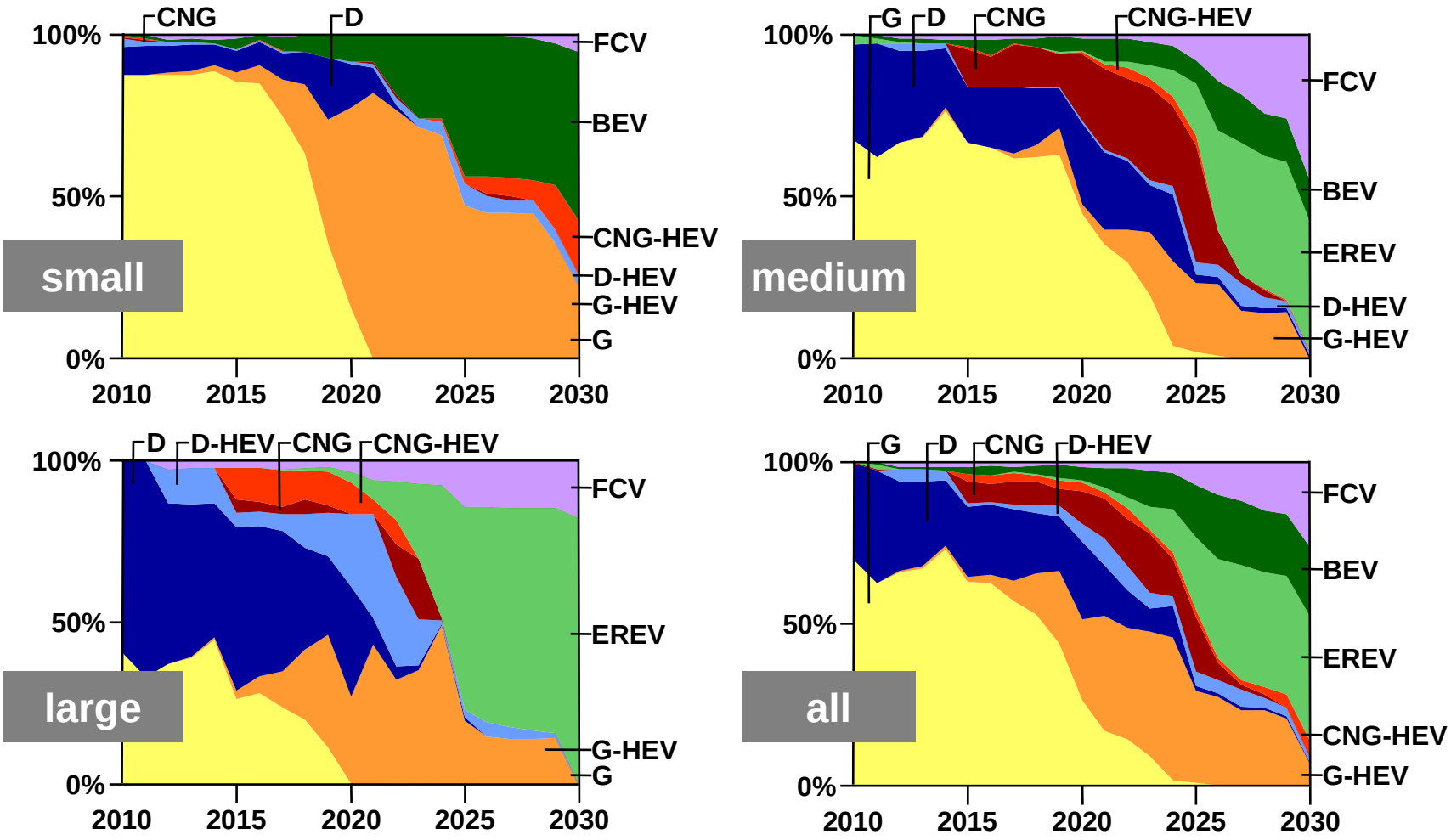
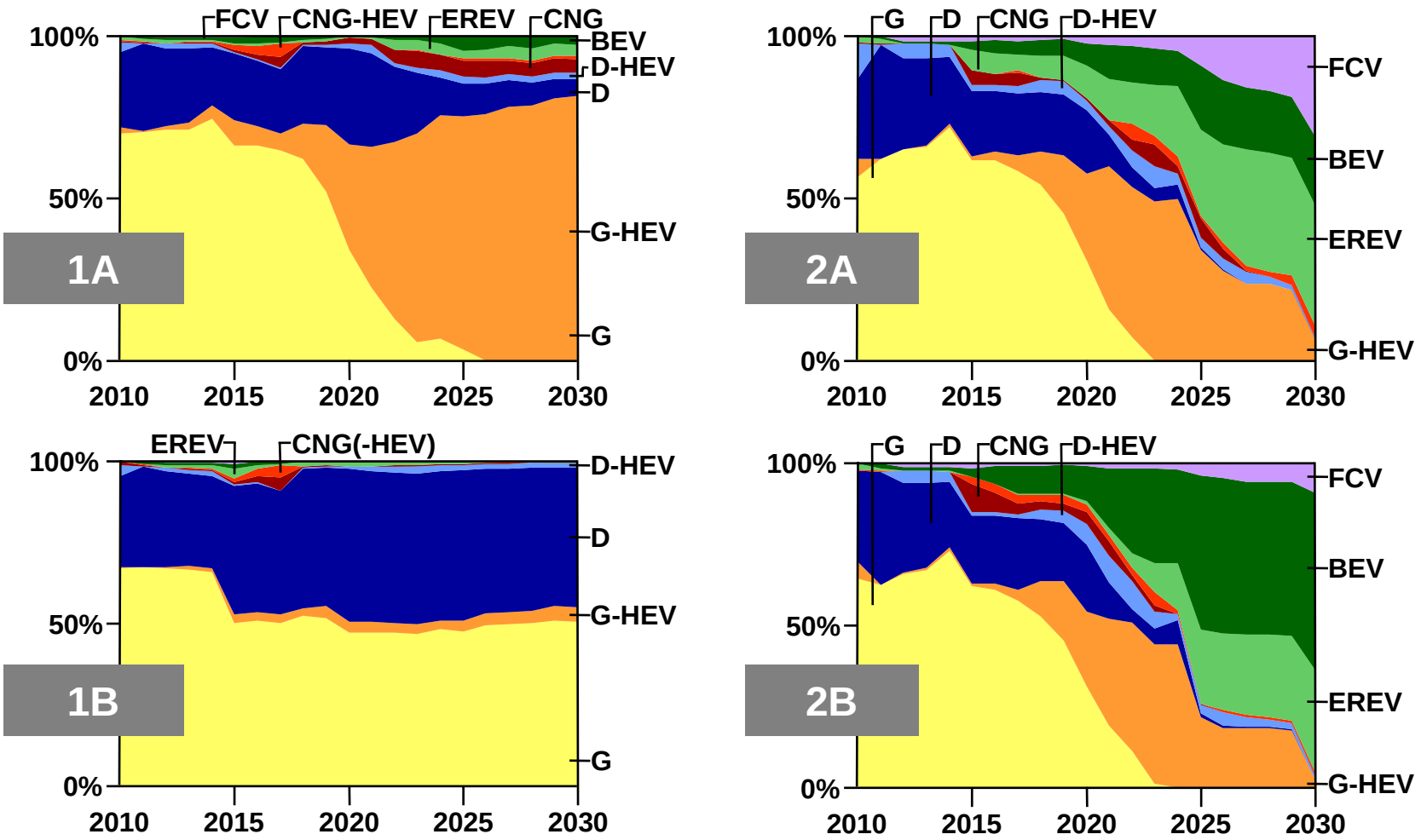
Scenario calculations
Scenario 1 (Baseline) – New vehicle fleet



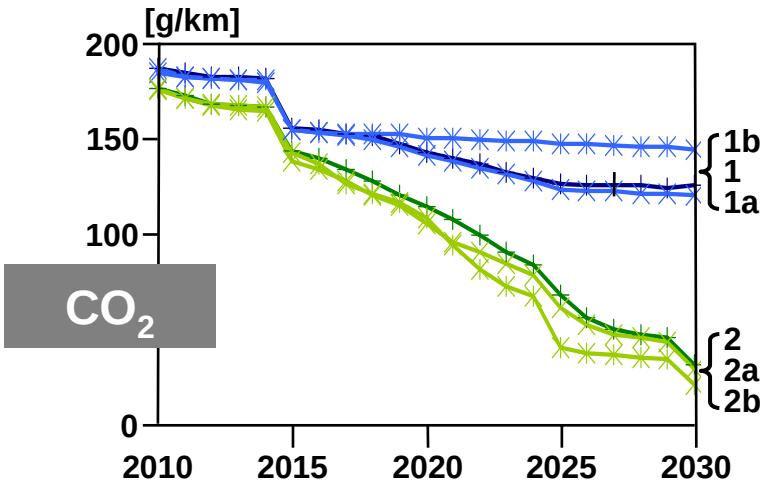
Scenario calculations
Scenario 2 (Climate Protection) – New vehicle fleet

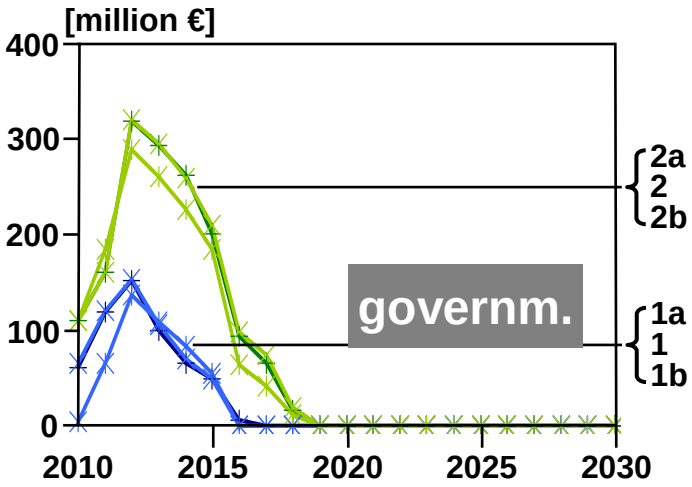


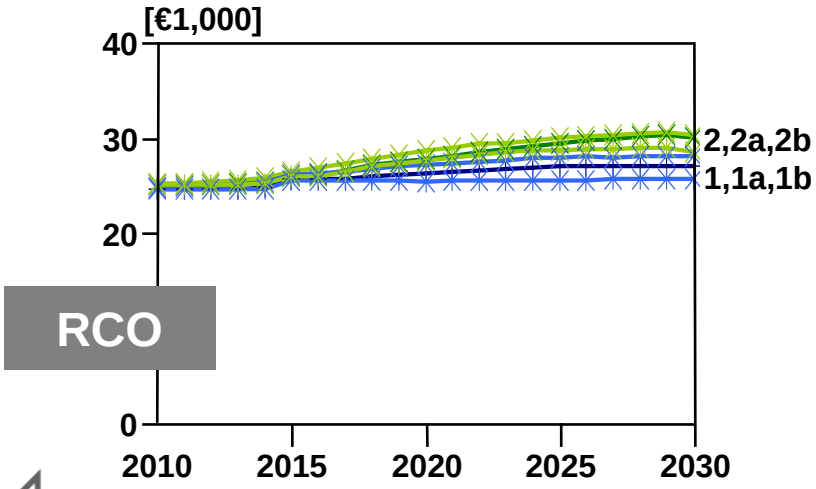
Scenario calculations
Scenarios A&B – New vehicle fleet (all vehicles)

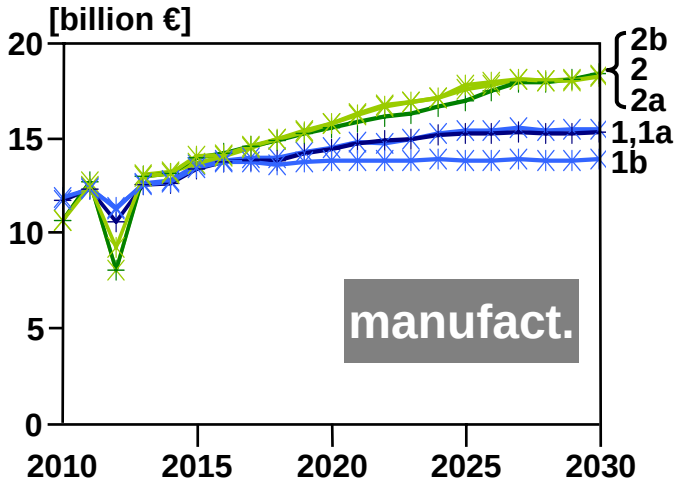


Scenario calculations
All scenarios – New vehicle fleet (all vehicles)







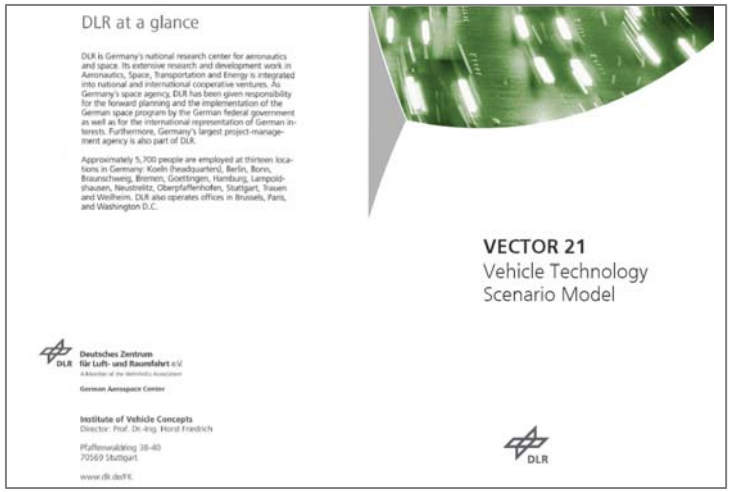


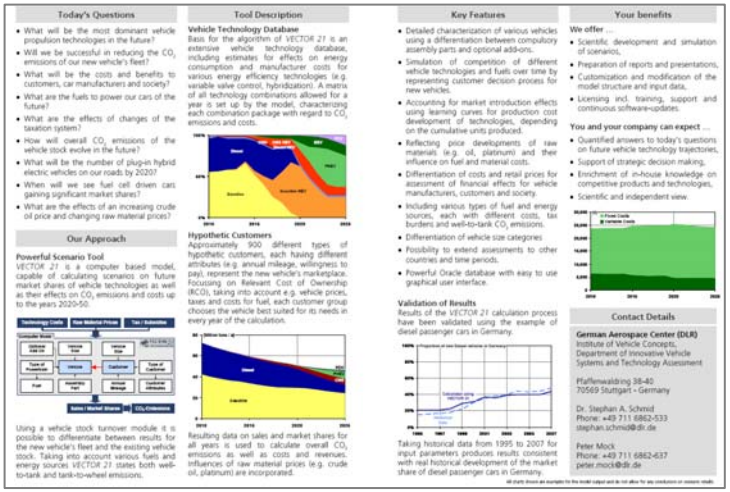
Conclusion / Outlook

- ***VECTOR21*** allows taking into account **many influencing factors**
- Future market shares of electric vehicles strongly **dependent on calculation assumptions**:
  - **CO_2 target values a key factor**
  - **Oil price less significant** for customer decision
  - Electricity and hydrogen from **renewable sources** important for sustainable reduction of CO_2 emissions
- **Recent applications** of *VECTOR21*:
  - analysis carried out for German automotive manufacturer
  - detail analysis carried out for German electricity supplier
  - extended study on behalf of the German Ministry of Economic Affairs
- **Expansion of assessment** planned for other markets (e.g. China, U.S., Europe) and time horizon (2050), depending on funding and data availability

Further information

- **please ask for information brochure on *VECTOR21*:**





- **recent publications:**
  - Mock, P., Huelsebusch, D., et al. (2009). Electric vehicles – A model based assessment of future market prospects and environmental impacts. EVS24 – International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium 2009.
  - Mock, P., and Schmid, S.A. (2009). Fuel cells for automotive powertrains – A techno-economic assessment. Journal of Power Sources, 190(1), 133-140.
  - Mock, P., and Schmid, S.A. (2008). Fuel cell and battery electric vehicles – Hype or trend? VDI-Berichte Nr. 2030 (VDI innovative vehicle propulsions conference 2008), 213-231.

Contact

Peter Mock
peter.mock@dlr.de
+49 711 6862-637

Dr. Stephan Schmid
stephan.schmid@dlr.de
+49 711 6862-533