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Multidimensional Assessment of Passenger Cars: Comparison of Electric Vehicles with Internal Combustion Engine Vehicles

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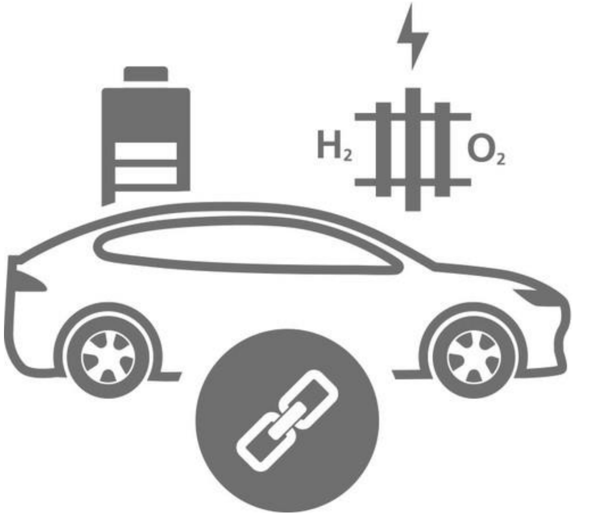
Goal

Goal: Multidimensional assessment of the sustainability of passenger cars



Source: DLR-VE

- **Multidimensional Assessment**
  - Combination of different (life cycle) assessment methods and multicriteria decision making methods (MCDM)
- **Sustainability**
  - Environmental, economic and social aspects
- **Passenger cars**
  - **Battery electric vehicles (BEV)**
    - European energy mix (BEV_EU-mix), Wind energy (BEV_wind), Photovoltaics (BEV_pv)
  - **Fuel Cell electric vehicles (FCEV)**
    - European energy mix (FCEV_EU-mix), Wind energy (FCEV_wind), Photovoltaics (FCEV_pv)
  - **Internal combustion engine vehicles (ICEV)**
    - Gasoline (ICEV_gas), diesel (ICEV_diesel)

Method

Selection of criteria

- Relevant Stakeholder: Society, User
- Combined Top-Down and Bottom-Up approach
- 13 criteria selected

Application of criteria

- Use of already existing studies if possible, supplement with own data if necessary
- Environmental → Life Cycle Assessment [Bauer et al. 2015]
- Economic/technical→ Manufacturer data, statistics, other literature, own calculations

Calculate ranking

- Multi criteria decision making (MCDM) method: PROMETHEE
- Ranking of alternatives based on criteria values, preference functions, and criteria weights
- 9 Preference scenarios & 6 weighting scenarios → 54 scenarios

Used Sustainability Dimensions and Criteria

Sustainability dimensions / Stakeholder and respective criteria	Abbreviation	Parameter
Environment & human health		
Global warming potential	GWP	g CO2 eq/km
Terrestrial acidification potential	TAP	g SO2 eq/km
Metal depletion potential	MDP	g Fe eq/km
Fossil resources depletion potential	FRDP	g oil eq/km
Photochemical oxidant formation potential	POFP	g NMVOC/km
Particulate matter formation potential	PMFP	g PM10 eq/km
Human toxicity potential	HTP	g 1,4-DB eq/km

Criteria Weighting Scenarios

- 6 Weighting Scenarios
  - S1: Equal weights
  - S2: Intragenerational justice
  - S3: Intergenerational justice
  - S4: Functionality with ecological criteria
  - S5: Functionality without ecological criteria
  - S6: Ecological criteria

- 3 different weighting options
  - Very Important → Factor 2
  - Important → Factor 1
  - Not important → Factor 0

		S1	S2	S3	S4	S5	S6
		Equal weights	Intra-generational justice	Inter-generational justice	Functionality with ecological criteria	Funtionality without ecological criteria	Ecological criteria
Global warming potential	GWP	7,69%	6,67%	20,00%	5,26%	0,00%	14,29%
Particulate matter formation potential	PFMP	7,69%	13,33%	10,00%	5,26%	0,00%	14,29%
Photochemical oxidant formation potential	POTP	7,69%	13,33%	10,00%	5,26%	0,00%	14,29%
Terrestrial acidification potential	TAP	7,69%	13,33%	10,00%	5,26%	0,00%	14,29%
Human toxicity potential	HTP	7,69%	13,33%	10,00%	5,26%	0,00%	14,29%
Metal depletion potential	MDP	7,69%	6,67%	20,00%	5,26%	0,00%	14,29%
Fossil resources depletion potential	FRDP	7,69%	6,67%	20,00%	5,26%	0,00%	14,29%
Total costs of ownership	TCO	7,69%	6,67%	0,00%	10,53%	16,67%	0,00%
Capital expenditure	CAPEX	7,69%	13,33%	0,00%	10,53%	16,67%	0,00%
Operational expenditure	OPEX	7,69%	6,67%	0,00%	10,53%	16,67%	0,00%
Fueling/charging time	FT	7,69%	0,00%	0,00%	10,53%	16,67%	0,00%
Fueling/charging points	FP	7,69%	0,00%	0,00%	10,53%	16,67%	0,00%
Driving range	RNG	7,69%	0,00%	0,00%	10,53%	16,67%	0,00%

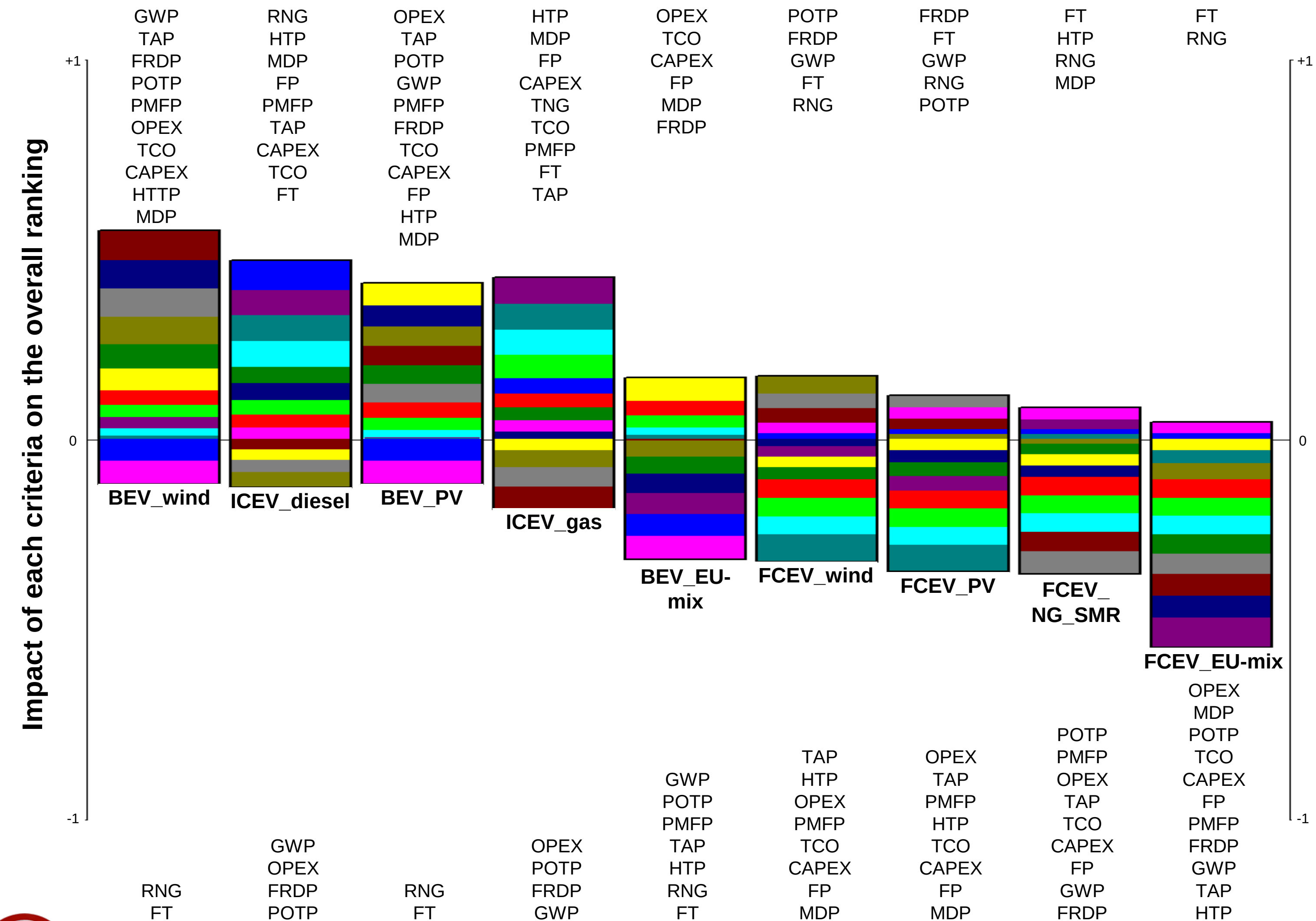
Rank distribution based on all scenarios

	Alternatives								
Rank	**BEV_wind**	**BEV_PV**	**ICEV_diesel**	**ICEV_gas**	**FCEV_wind**	**FCEV_PV**	**BEV_EU-mix**	**FCEV_NG-SMR**	**FCEV_EU-mix**
1	71,11%	-	28,89%	-	-	-	-	-	-
2	13,33%	62,22%	8,89%	15,56%	-	-	-	-	-
3	15,56%	6,67%	57,78%	15,56%	4,44%	-	-	-	-
4	-	31,11%	-	51,11%	13,33%	4,44%	-	-	-
5	-	-	4,44%	13,33%	57,78%	-	24,44%	-	-
6	-	-	-	4,44%	24,44%	48,89%	13,33%	8,89%	-
7	-	-	-	-	-	31,11%	26,67%	42,22%	-
8	-	-	-	-	-	15,56%	35,56%	48,89%	-
9	-	-	-	-	-	-	-	-	100,00%

Results

- Results vary between scenarios, but tendencies are still shown
- BEV appear more sustainable than ICEV if charged with renewable energy
- Current FCEV are less sustainable than ICEV and BEV, regardless of electricity mix

Ranking with individual criteria impacts



GWP	Global warming potential
TAP	Terrestrial acidification potential
MDP	Metal depletion potential
FRDP	Fossil resources depletion potential
POFP	Photochemical oxidant formation potential
PMFP	Particulate matter formation potential
HTP	Human toxicity potential
CAPEX	Capital expenditure
OPEX	Operational expenditure
TCO	Total cost of ownership
FT	Fueling/charging time
FP	Fueling/charging points
RNG	Driving range

Conclusion & Outlook

- Scenarios enable to take various stakeholder perspectives simultaneously into account
  - ➢ More elaborated weighting scenarios could enhance the assessment
  - ➢ Integrate stakeholder directly into the assessment

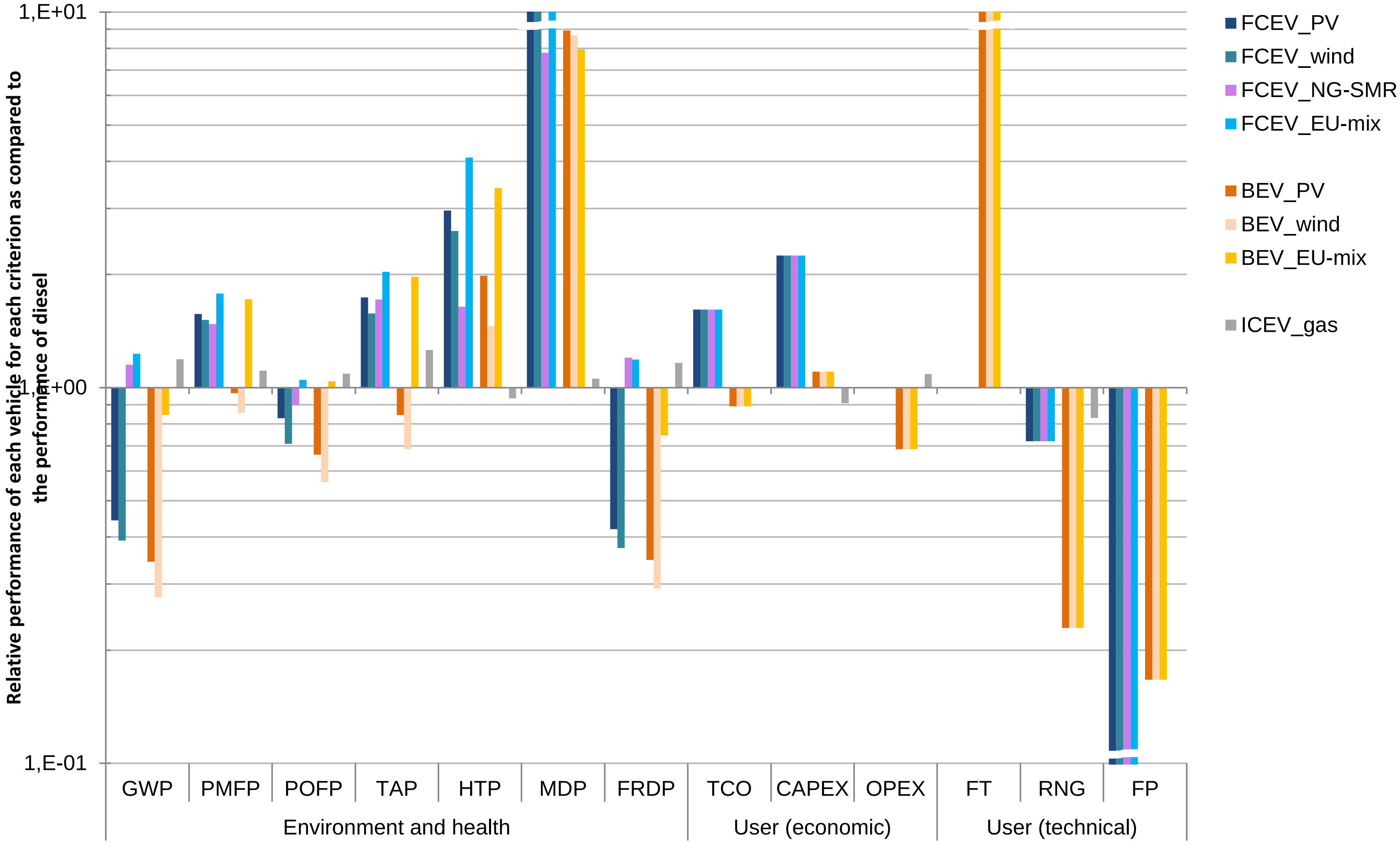
- The applied method allowed to rank the alternatives while taking different dimensions into account
  - ➢ More criteria necessary to reach holistic assessment, especially regarding the social and economic dimension

- Approach showed a way to incorporate already existing studies, which only looked at one dimension into a holistic assessment
  - ➢ Incorporate more studies into the assessment as input data

Assumptions

- Lifetime:
  - 240.000 km
  - 17 years of service
  - WLTP driving cycle
- Vehicles: compact car class
  - VW Golf (gasoline, diesel)
  - VW e-Golf (BEV)
  - Hyundai NEXO (FCEV)

Perfomance of each alternative compared to ICEV-diesel in all criteria



Sources: [1]-[17]

Preference Scenarios and Value Functions

Preference scenario	Preference function	Indifference threshold q	Preference threshold p
P1	Usual Criterion	-	-
P2	Linear Criterion with Indifference area	1%	10%
P3	Linear Criterion with Indifference area	10%	20%
P4	Linear Criterion with Indifference area	10%	50%
P5	Linear Criterion with Indifference area	10%	80%
P6	Linear Criterion with Indifference area	10%	100%
P7	Linear Criterion with Indifference area	25%	50%
P8	Linear Criterion with Indifference area	Standard deviation	Distance between minimum and mximum
P ILCD	Linear Criterion with Indifference area	10 % / 30 %	30 % / 50 %