



INATECH  
DEPARTMENT OF SUSTAINABLE  
SYSTEMS ENGINEERING

# Integrated Sustainability Assessment and Optimization of Energy Systems

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## 1 Zusammenfassung<sup>1, 2, 3, 4</sup>

### 1.1 Die wichtigsten Ergebnisse

**Einvernehmliche<sup>5</sup> Feststellung: Das gegenwärtige Energiesystem ist nicht nachhaltig**

*Joint statement: The current energy system is not sustainable*

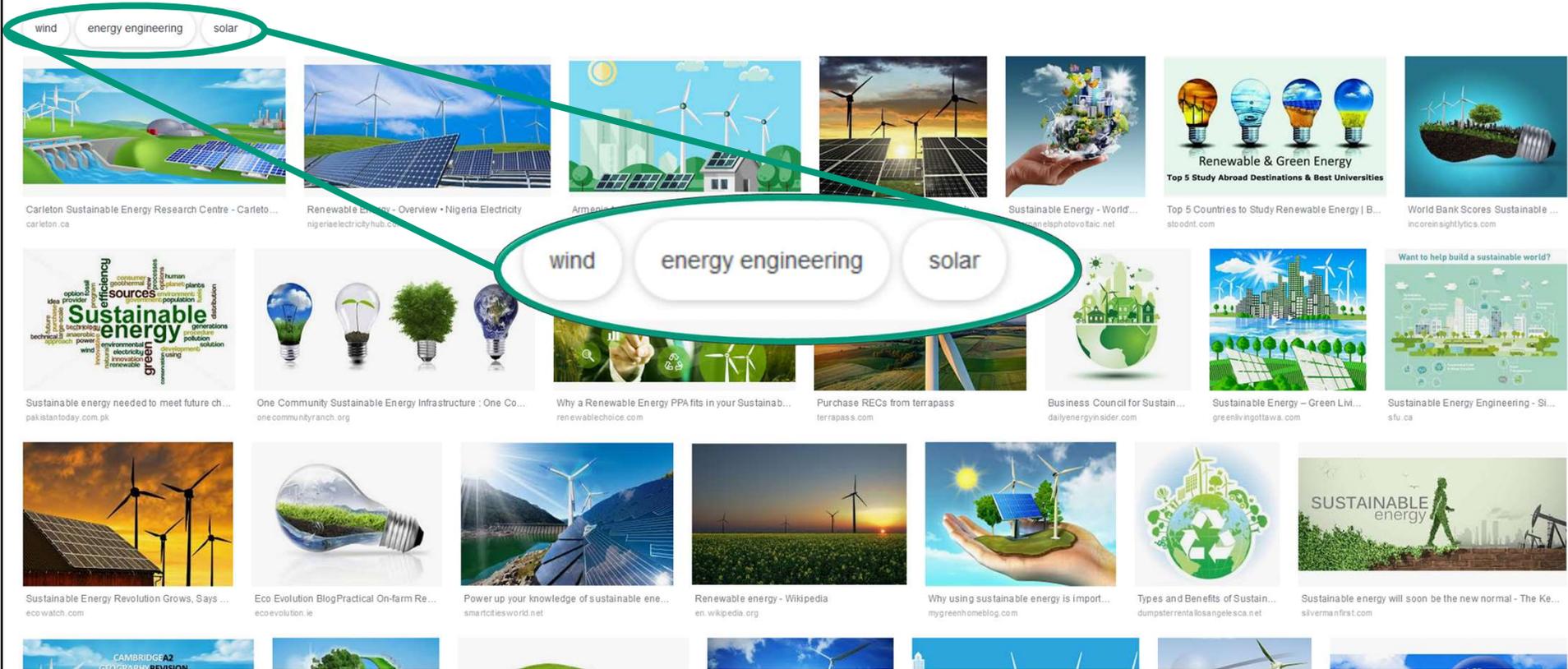
[German Enquête Commission „Sustainable Energy Supply under the Conditions of Globalization and Liberalization“, 2002]

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# The InNOSys Project

- Research project on an *integrated sustainability assessment and optimization of energy systems*
- Jan 2018 – Dec 2020



**Deutsches Zentrum  
für Luft- und Raumfahrt**  
German Aerospace Center  
Institute of Engineering Thermodynamics



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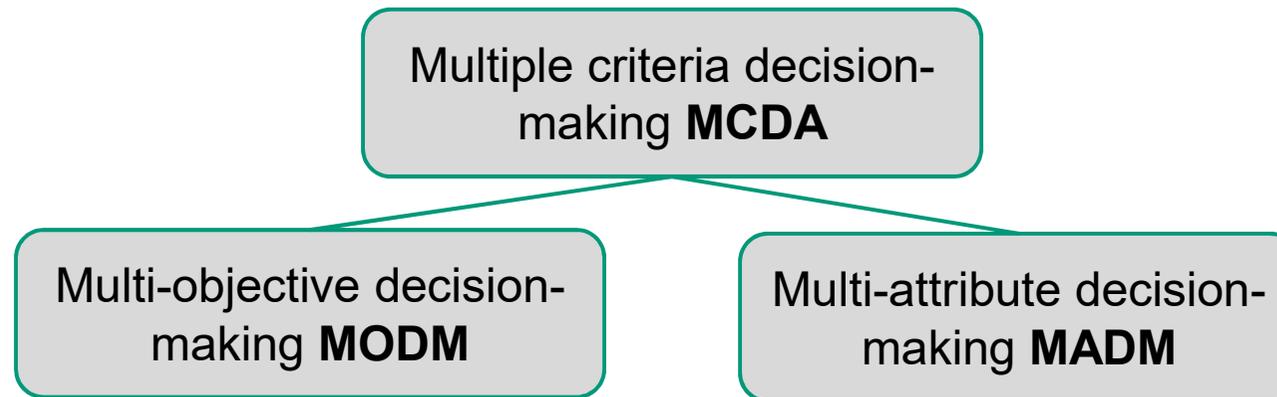


- Object of study: Scenarios for energy system transformation until 2050



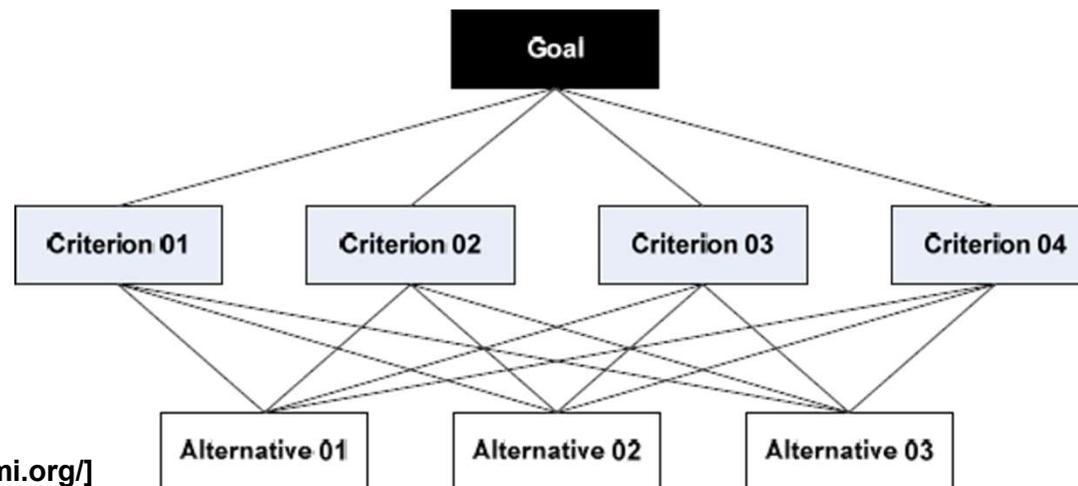
- Objectives:
  - MADM sustainability assessment approaches for energy scenarios
  - MODM methods for deriving optimized pathways of energy systems (in Germany)

- Two sub-classes form the class of MCDA models



- MODM:** multiple, usually conflicting objectives
  - Aim: finding a feasible alternative that yields most preferred / satisfactory set of values for the objective functions
- MADM:** multi-attribute utility functions
  - Aim: make a choice among several alternatives

- Chosen MADM methods
  - Analytic Hierarchy Process  
AHP
  - Technique of Order Preference by Similarity of Ideal Solution  
TOPSIS
  - Preference Ranking Organization Methods for Enrichment of  
Evaluations  
PROMETHEE



[<https://www.pmi.org/>]

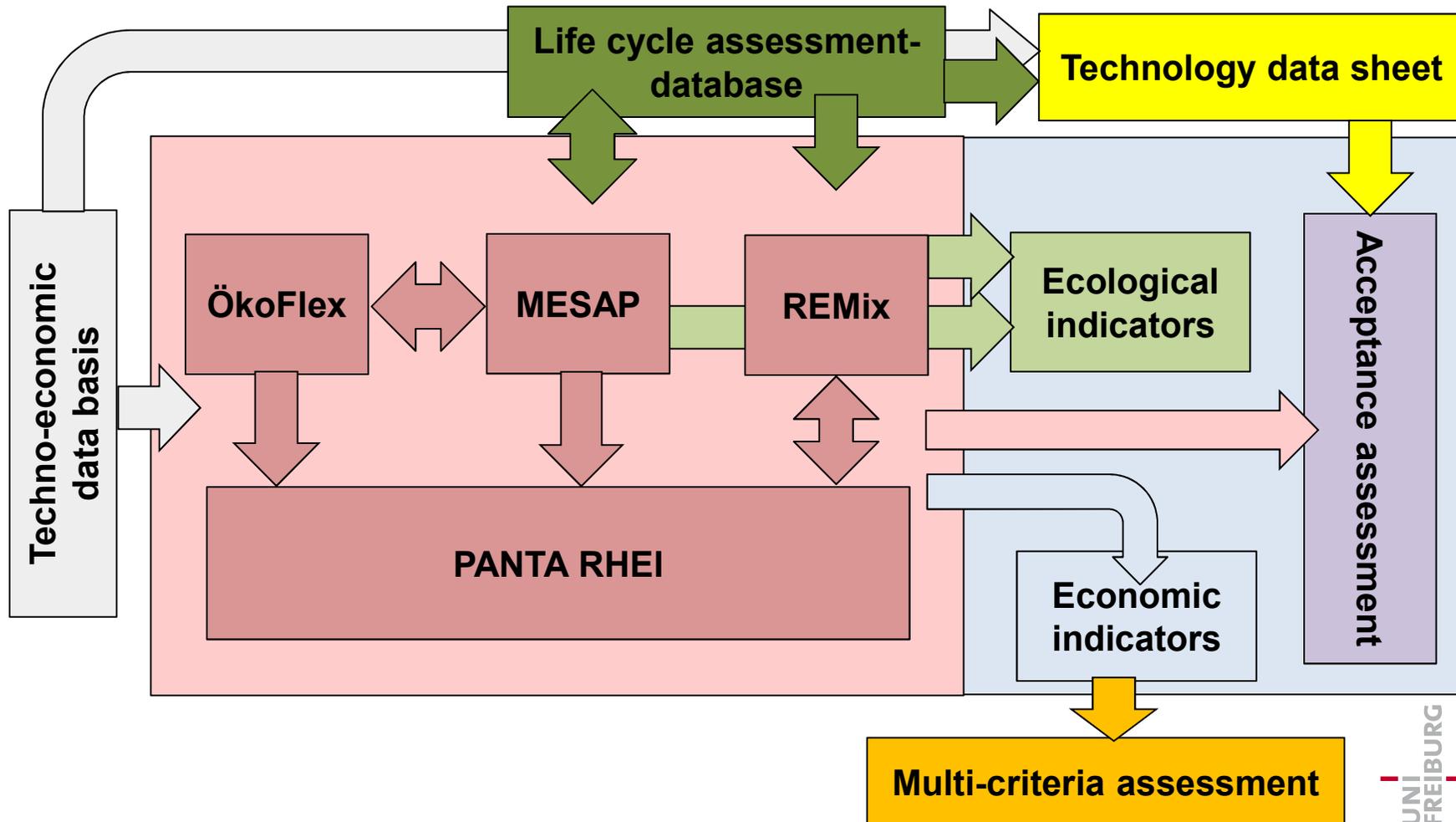
# Indicator (Pre-)Selection

- (Aggregated) indicators selected for focus groups

- Social
  - Quality of living
  - Distributional justice
  - Intergenerational justice
- Socio-economic
  - Employment effects installation
  - Employment effects O&M
- Economic
  - Levelized cost of electricity
  - Security of supply
- Ecological
  - CO<sub>2</sub> emissions
  - Land consumption
  - Respirable dust
  - Ecological toxicity
  - Resource consumption

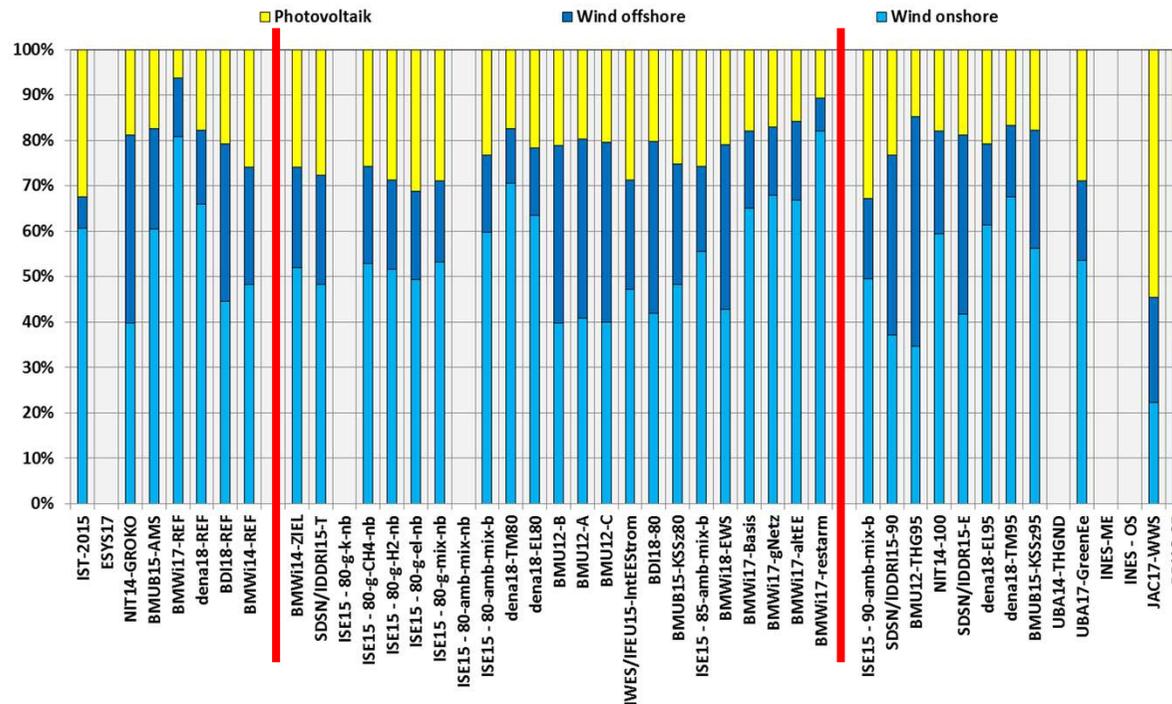
Energy-Trans-Indikatoren
energiebezogene Feinstaub-Emissionen
energiebezogene Kadmium-Emissionen
energiebezogene Quecksilber-Emissionen
Anteil erneuerbarer Energien am Bruttoendenergieverbrauch
Primärenergieverbrauch
Endenergieverbrauch im Verkehrssektor
Modal Split im Verkehrssektor
Anzahl an Elektrofahrzeugen
Endenergieproduktivität der deutschen Wirtschaft
energiebezogene Treibhausgasemissionen
Volumen öffentlicher Darlehen für energiebezogene Investitionen
Energieimportabhängigkeit
Verhältnis von EE-Beschäftigten zu Beschäftigten insgesamt
Pro-Kopf-Endenergieverbrauch privater Haushalte
Endenergieverbrauch der Industrie
Endenergieverbrauch von GHD
Wertschöpfung durch den Erneuerbare-Energien-Sektor
monatliche Energieausgaben von Haushalten mit einem Netto-Monatseinkommen unter 1300 Euro
Endenergieverbrauch privater Haushalte zum Heizen (temperaturbereinigt)
installierte Kapazität regenerativer Kraftwerke
Anteil der Haushalte, die EE-Strom produzieren
Anbaufläche für Energiepflanzen
Internalisierungsgrad von energiebezogenen externen Kosten
energiebezogene Emissionen von säurebildenden Gasen
energiebezogene schädliche Feststoffabfälle
Menge an hochradioaktiven Abfällen, die noch nicht zu einem sicheren Endlager gebracht wurden
zusätzliche Indikatoren
Staatsdefizit
Schuldenstand
NO <sub>x</sub> -Emissionen
NO <sub>2</sub> -Emissionen
NM <sub>VOC</sub> -Emissionen
Anteil EE-Strom an der Bruttostromerzeugung
Anstieg der Siedlungs- und Verkehrsfläche
Rohstoffproduktivität
Erwerbstätigenquote
Energieverbrauch pro Kopf
Energieverbrauch pro Wohnfläche
Verhältnis der Bruttoanlageinvestitionen zum BIP
BIP/Kopf
Energieverbrauch des Konsums
CO <sub>2</sub> -Emissionen des Konsums
Nachhaltigkeitsstrategie für Deutschland (Basis SDGs)
Landwirtschaft: In unseren Kulturlandschaften umweltverträglich produzieren
2.1a Stickstoff-Überschuss
2.1b Ökologischer Landbau
Luftbelastung: Gesunde Umwelt erhalten
3.2a Emissionen von Luftschadstoffen (Index der nationalen Emissionen der Luftschadstoffe SO <sub>2</sub> , NO <sub>x</sub> , NH <sub>3</sub> )

- Model used for analysis



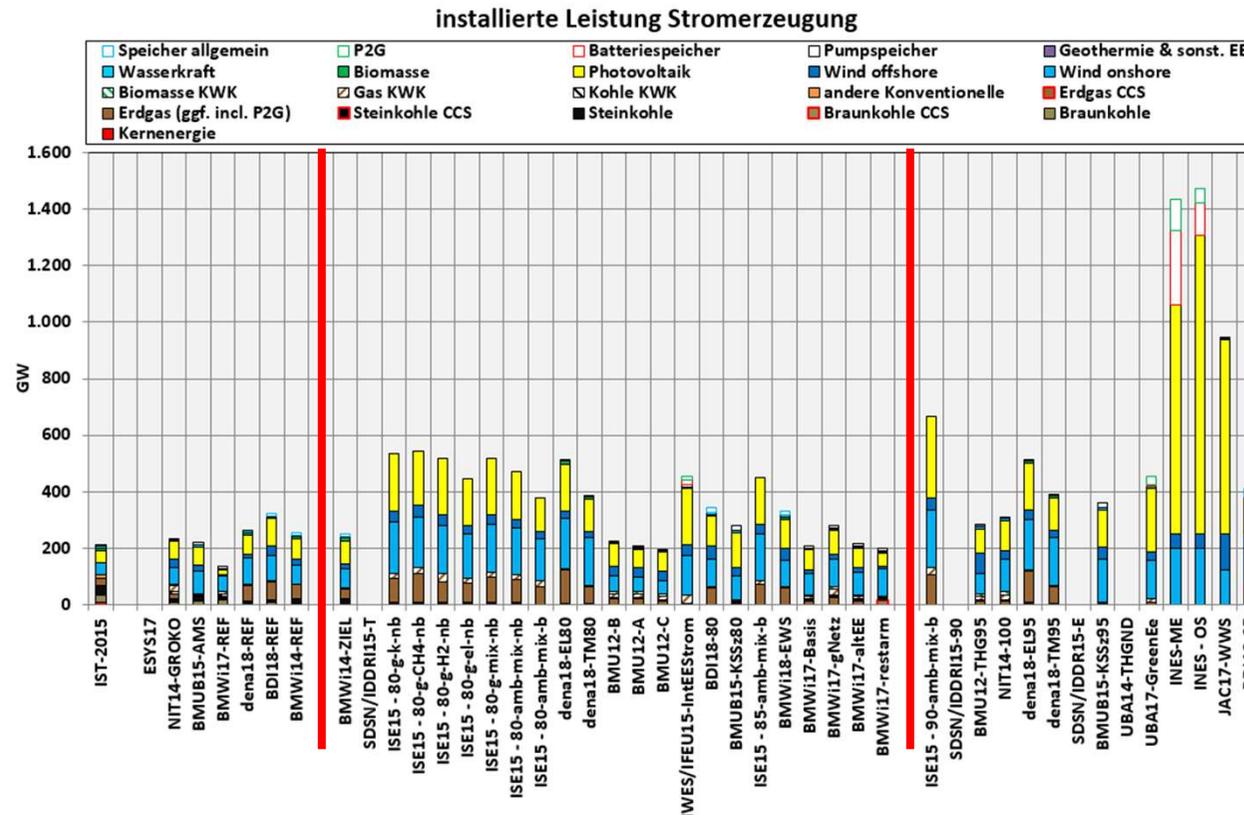
# Scenario Classification

- Scenario sets: 80–90 % & 95 % CO<sub>2</sub> emission reduction target
- Average shares of generation capacity in the scenarios
  - 80–90 %: 54 % wind onshore, 23 % wind offshore, 23 % PV
  - 95 %: 48 % wind onshore, 29 % wind offshore, 23 % PV



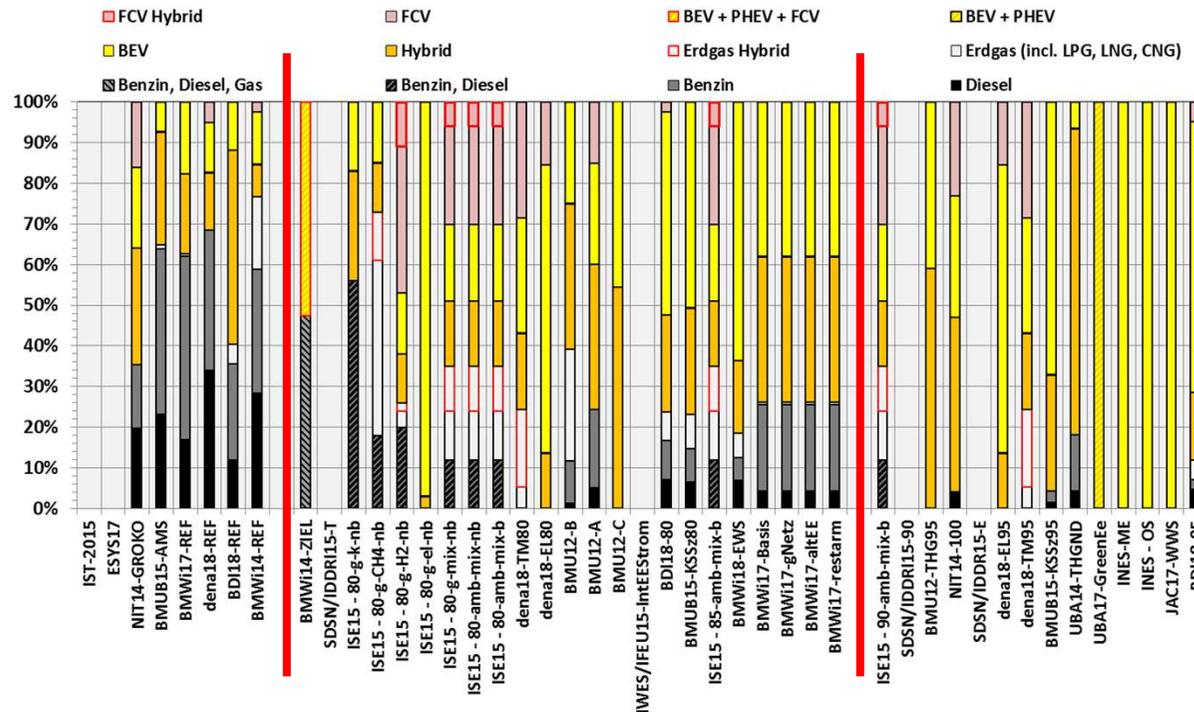
# Differences in Scenarios

- Large differences in installed capacity across scenarios
  - 80–90 %: < 400 GW (all technologies)
  - 95 %: 400 – 1400 GW (all technologies)



# Differences in Scenarios

- Individual mobility
  - 80–90 %: electric vehicles, hybrid vehicles s with biofuels, fuel cell vehicles, natural gas engines
  - 95 %: electric vehicles, hybrid vehicles with synthetic fuels, fuel cell vehicles





- Ten scenarios will be re-calculated for comparable results
  - Harmonized driving factors
  - Harmonized energy intensities
- Criteria weighting facilitated by focus groups
- MADM studies based on weights and selected indicators
- Optimized energy scenarios based on MODM method