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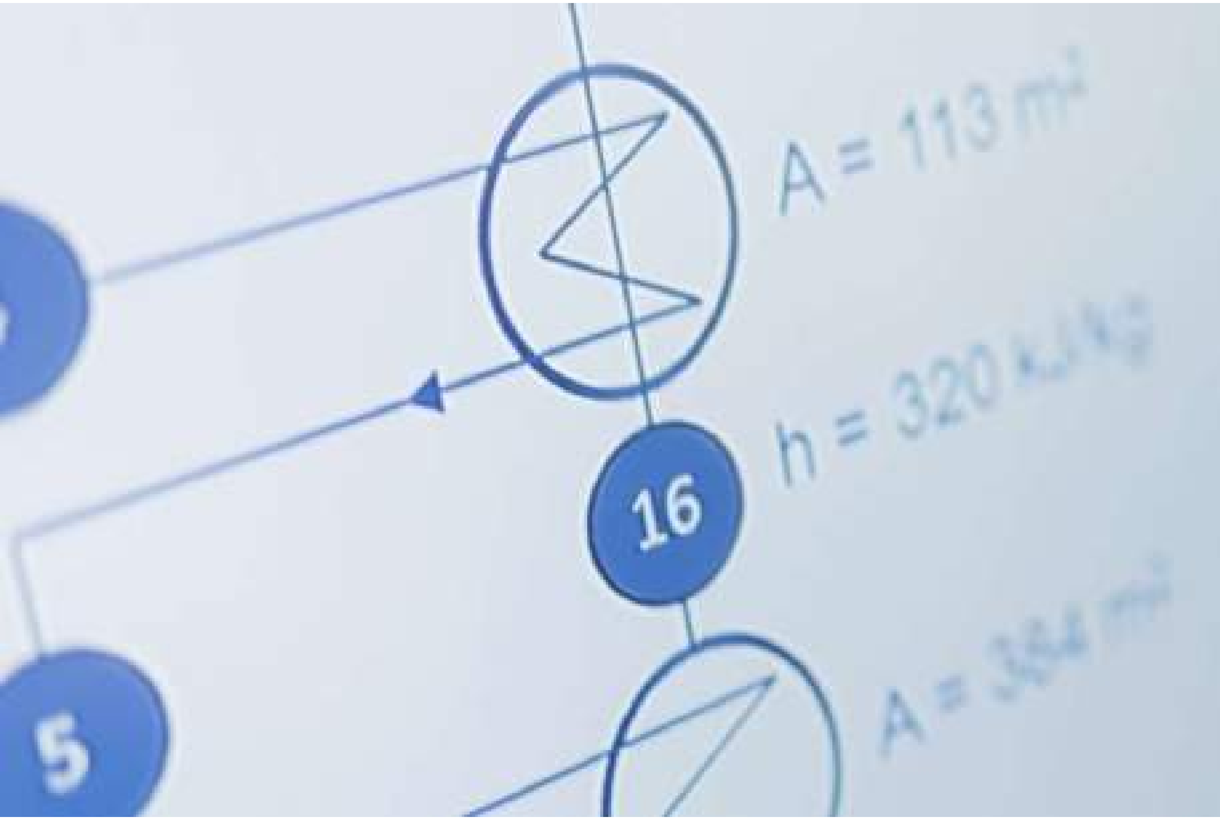

Introduction to Energy System Modelling and the TIMES Modelling Framework

Audrey Dobbins
Isela Bailey
Jithin Jose
Ulrich Fahl

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University of Stuttgart, Institute of Energy Economics and Rational Energy Use,
Hessbruehl Str. 49a, 70565 Stuttgart, Germany
www.ier.uni-stuttgart.de

Course content

Day 1

- Introduction: UrGe4Hy Project, University of Stuttgart, and IER
- Basics of Energy planning and the role of Energy System models
- Showcase: Results and analyses possible with energy system models – overview of insights
- Introduction to the Uruguayan Energy System (Dr. Mariana Corengia)
- Troubleshooting installation issues

Day 2

- Introduction on how to build and use a model
- Hands-on presentations and exercises

Day 3

- Hands-on presentations and exercises
- Future/further applications of modelling
- Evaluation of students
- Evaluation and feedback on course

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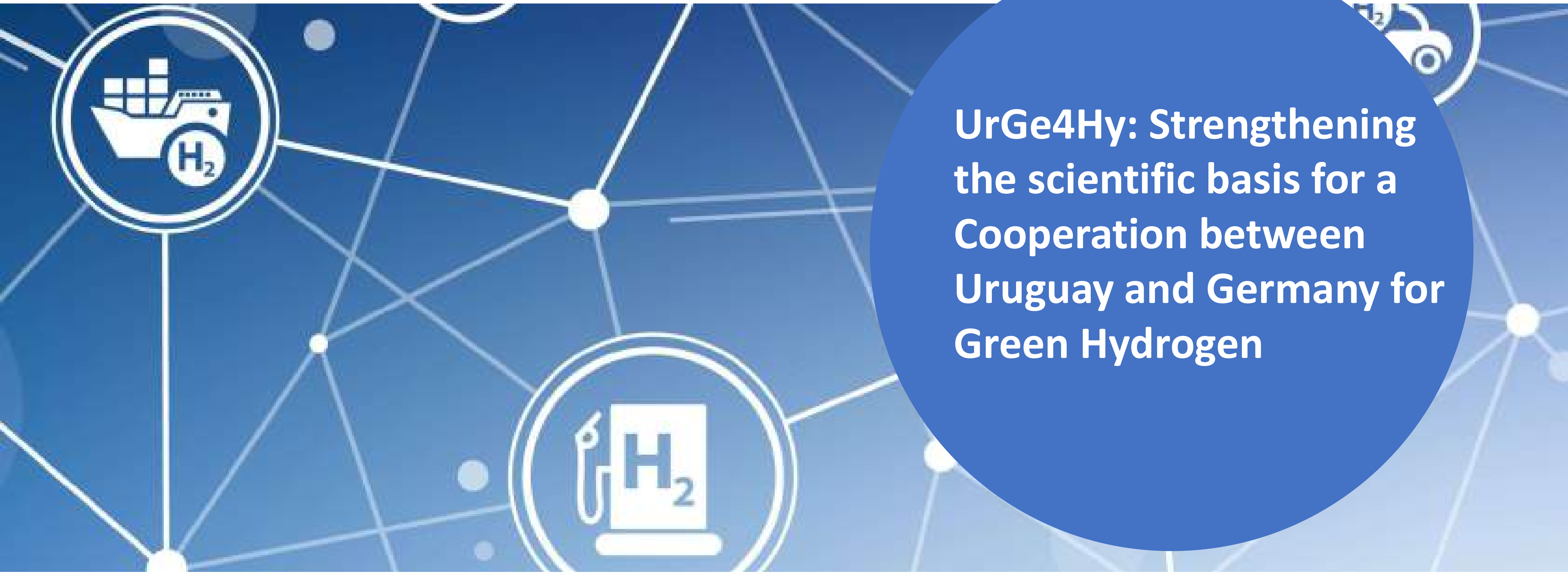

UrGe4Hy: Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen

image: ewi

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„Mission“ and working areas of Institute of Energy Economics and Rational Energy use (IER), University of Stuttgart, Germany

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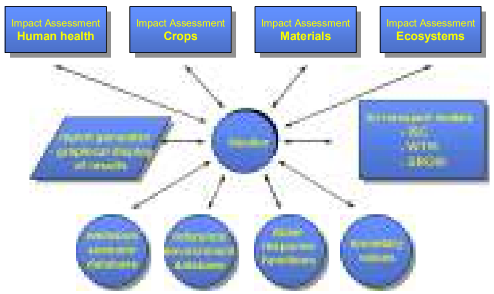
IER contributes towards solution for local, regional and global energy issues through the integrative and systemic analysis and evaluation of energy technologies and energy systems.

- Interdisciplinary collaboration of experts from engineering, economics, natural, political and social sciences
- Development and application of decision-support tools for the analysis of complex systems
- Support of political and entrepreneurial decisions under uncertainties and high complexity

Optimisation models
Energy & Economy: NEWAGE
Energy systems: TIMES
Energy markets: E2M2

Externalities
EcoSense



Life Cycle Assessment (LCA)
GABI/SimaPro

Spatial Planning
ArcGIS

URGE4HY Project

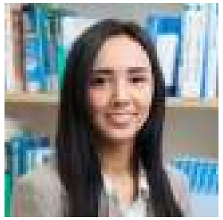
Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen

Call. Funding of scientific and technological cooperation (STC) between Uruguay and Germany – ANII-MIEM-BMBF

Main Theme. Processes and strategies for hydrogen transportation and supply chains, including life cycle analyses, storage, and conversion pathways

Partner. **Uruguay:** Instituto de Ingenieria Quimica (IIQ), Universidad de la Republica (UdelaR), Facultad de Ingeniera → Dr. Mariana Corengia, Dr. Jimena Ferreira & Team

Germany: Institute of Energy Economics and Rational Energy Use (IER), University of Stuttgart, Faculty 4 Energy, Process and Bio Engineering
→ Dr. Ulrich Fahl, Dr. Ludger Eltrop, Dr. Audrey Dobbins, Jithin Jose, Isela Bailey



URGE4HY Project

Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen

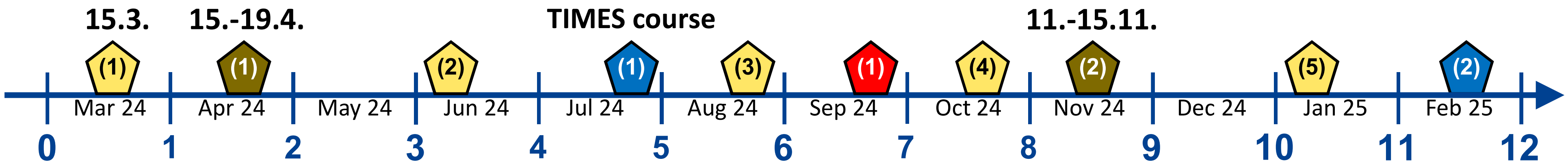
Project goals.

- to strengthen the scientific basis for the integration of green hydrogen into transformation pathways towards carbon neutrality in Uruguay and Germany.
- To analyse the role of green hydrogen as a basis for restructuring industrial value chains
- To explores how the German and Uruguayan energy systems can be connected through green hydrogen
- To collaboratively explore opportunities for the entire green hydrogen-based value chain

UrGe4Hy Project

Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen

Project duration. 01.03.2024 – 28.02.2025 (12 months)



Activities.

- Online Meetings (yellow)
- Project Meetings in Stuttgart (brown)
- Project Meetings in Montevideo (blue)
- International Conference (red)

1: Conference with expert lectures

2: Excursion to innovation locations/spaces for green hydrogen

3: Project development in discussion rounds with local partners

4: Involvement and activation of interest groups (stakeholders)

URGE4HY Project

Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen

Results.

- Challenges and opportunities for companies and national economies are identified
- a pre-feasibility study for potential future collaboration projects between Uruguay and Germany with a focus on green hydrogen development is carried out.
- A list of key topics relevant for further exchange and cooperation between Uruguay and Germany in the context of green hydrogen will be developed.

URGE4HY Project

Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen

Project goals.

The first goal is to strengthen the scientific basis for the integration of green hydrogen into transformation pathways towards carbon neutrality in Uruguay and Germany.

The second goal consists of analysing the role of green hydrogen as a basis for restructuring industrial value chains.

Work goals.

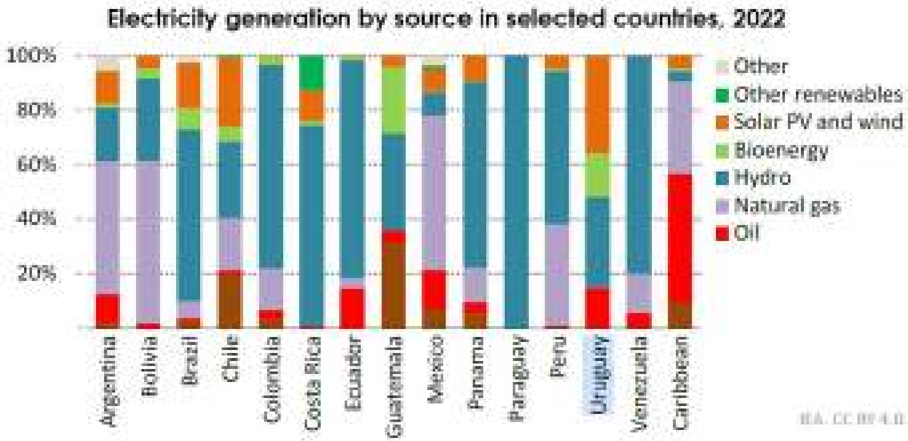
The project explores how the German and Uruguayan energy systems can be connected using green hydrogen. The project focuses on creating a collaborative opportunity among Uruguay and Germany over the complete green hydrogen-based value chain. Moreover, the widely-used energy system modelling framework TIMES will be introduced to the partners in Uruguay.

Structure of the overall project.

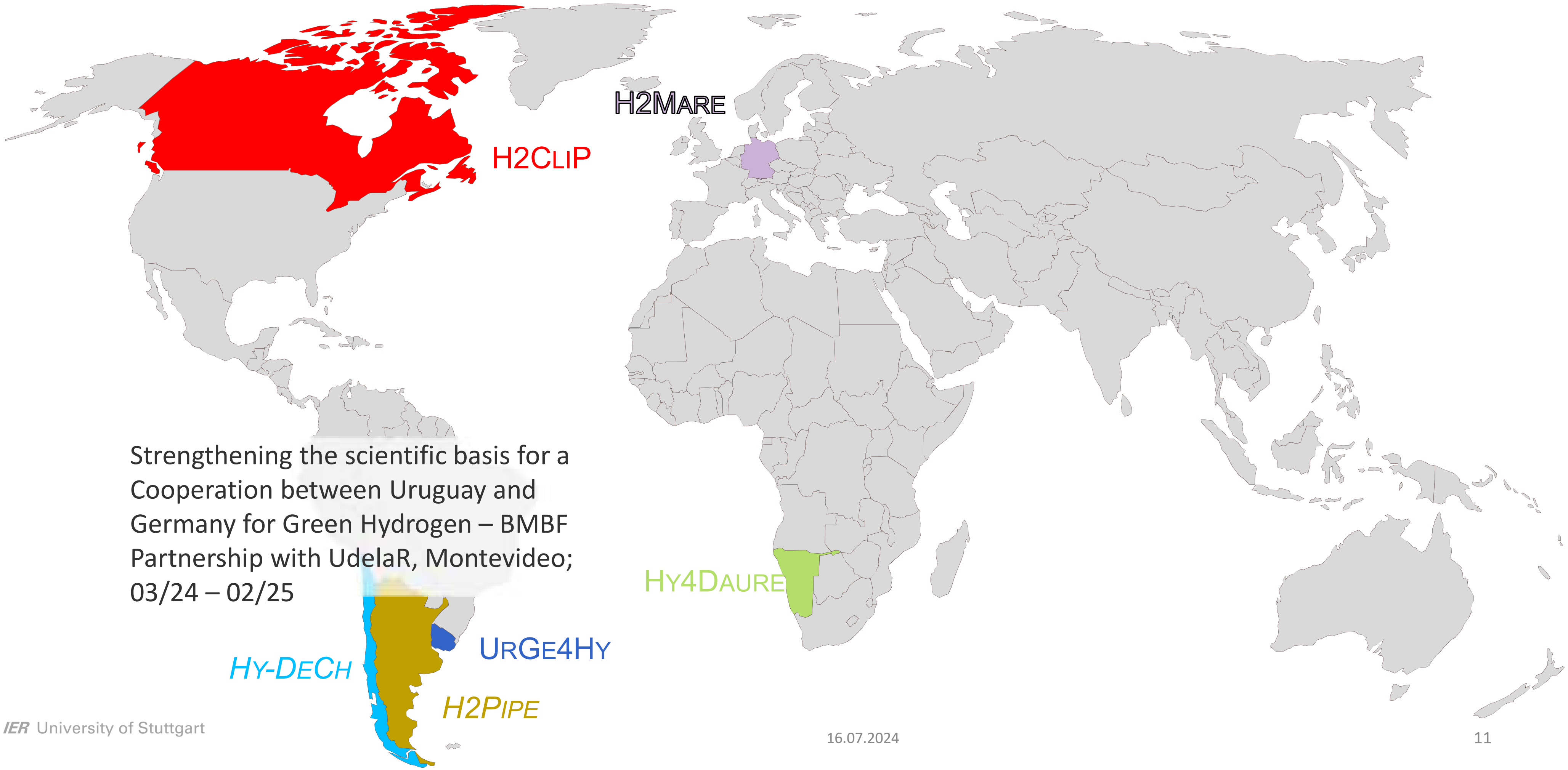
The collaboration in the project is enhanced through various kinds of exchanges between the partners. The exchanges lead to an inter- and trans-disciplinary connection between science, practice, politics and society.

Results.

- Challenges and opportunities for companies and national economies are identified and a pre-feasibility study for potential future collaboration projects between Uruguay and Germany with a focus on green hydrogen development is carried out.
- A list of key topics relevant for further exchange and cooperation between Uruguay and Germany in the context of green hydrogen will be developed.



Hydrogen projects at IER



Strengthening the scientific basis for a Cooperation between Uruguay and Germany for Green Hydrogen – BMBF Partnership with UdelaR, Montevideo; 03/24 – 02/25

Hydrogen projects at IER

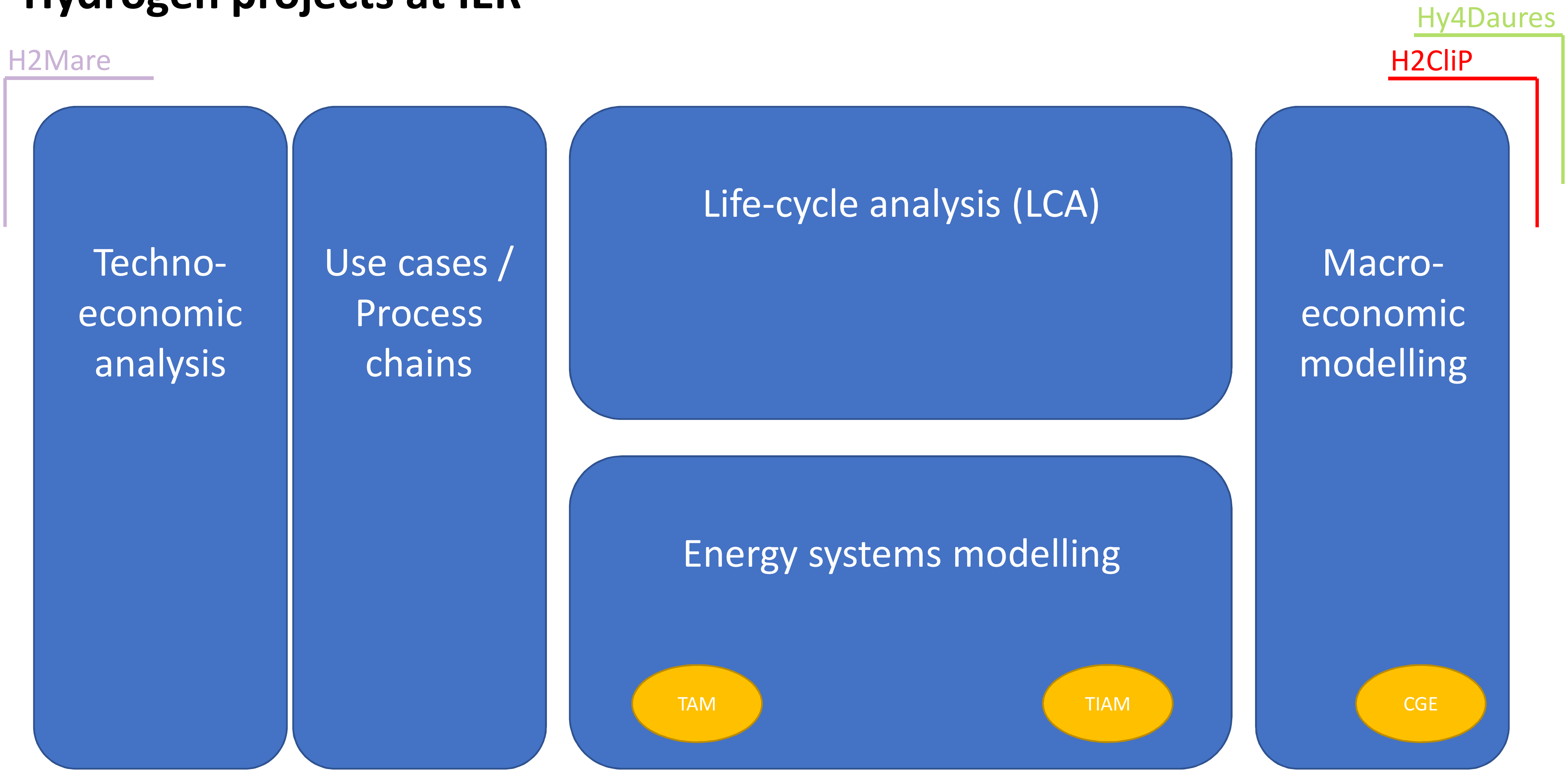
H2Mare-PtX-Wind & -TransferWind: Offshore production of Hydrogen and further power-to-X products in Germany; BMBF, 2021-2025, https:// www.wasserstoff-leitprojekte.de/leitprojekte/h2mare

H2CliP: Hydrogen and Climate Partnership - A new hydrogen network between Canada and Germany as a key component of a climate-neutral energy system; BMBF, 2022-2025

Hy4Daure Namibia Module 2 Research Component: The Daures Green Hydrogen and PTX Project as a key component of the German-Namibian Partnership on Green Hydrogen – Module 2 "Research for a sustainable approach"; BMBF, 1. phase 2023 - 2025

Grafik: Projektträger Jülich im Auftrag des BMBF

Hydrogen projects at IER



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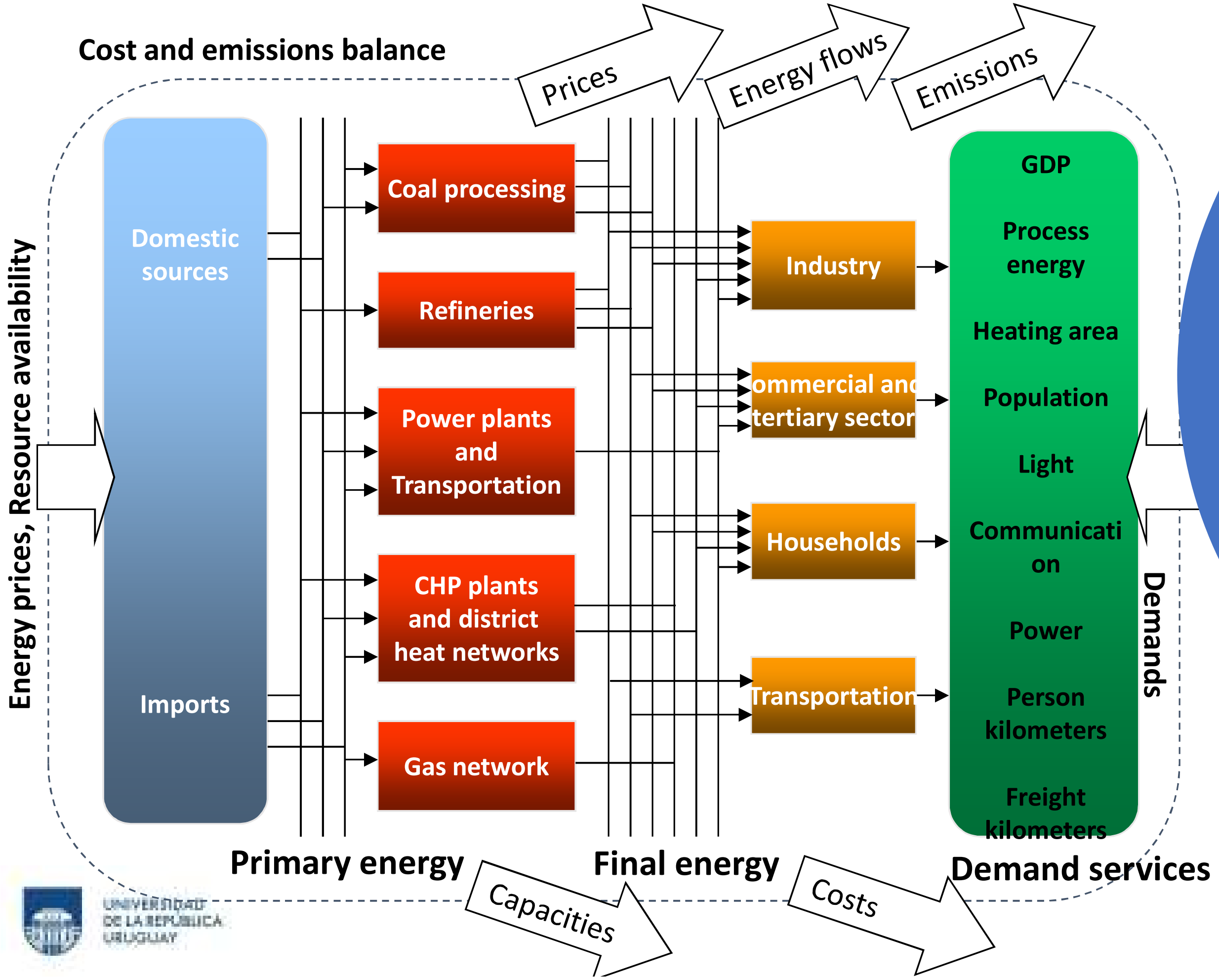

Basics of Energy Planning and role of Energy System Models

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What do we mean with „energy system“?

IPCC defines an energy system as "all components related to the production, conversion, delivery, and use of energy“

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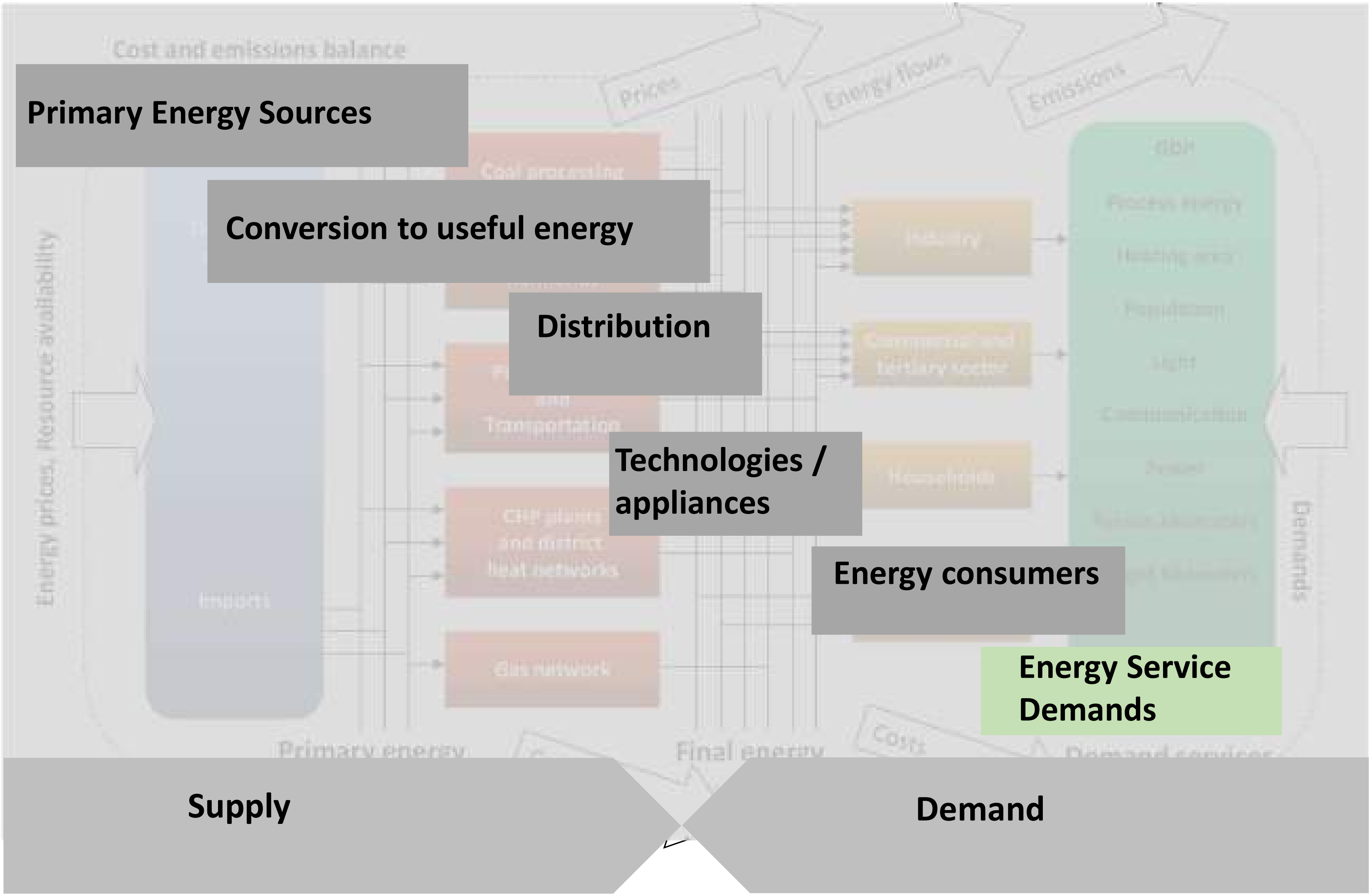
Structure of the energy system



Supply options:

- Wind
- Solar
- Biomass
- Coal
- Natural Gas
- Crude Oil
- Nuclear
- etc.

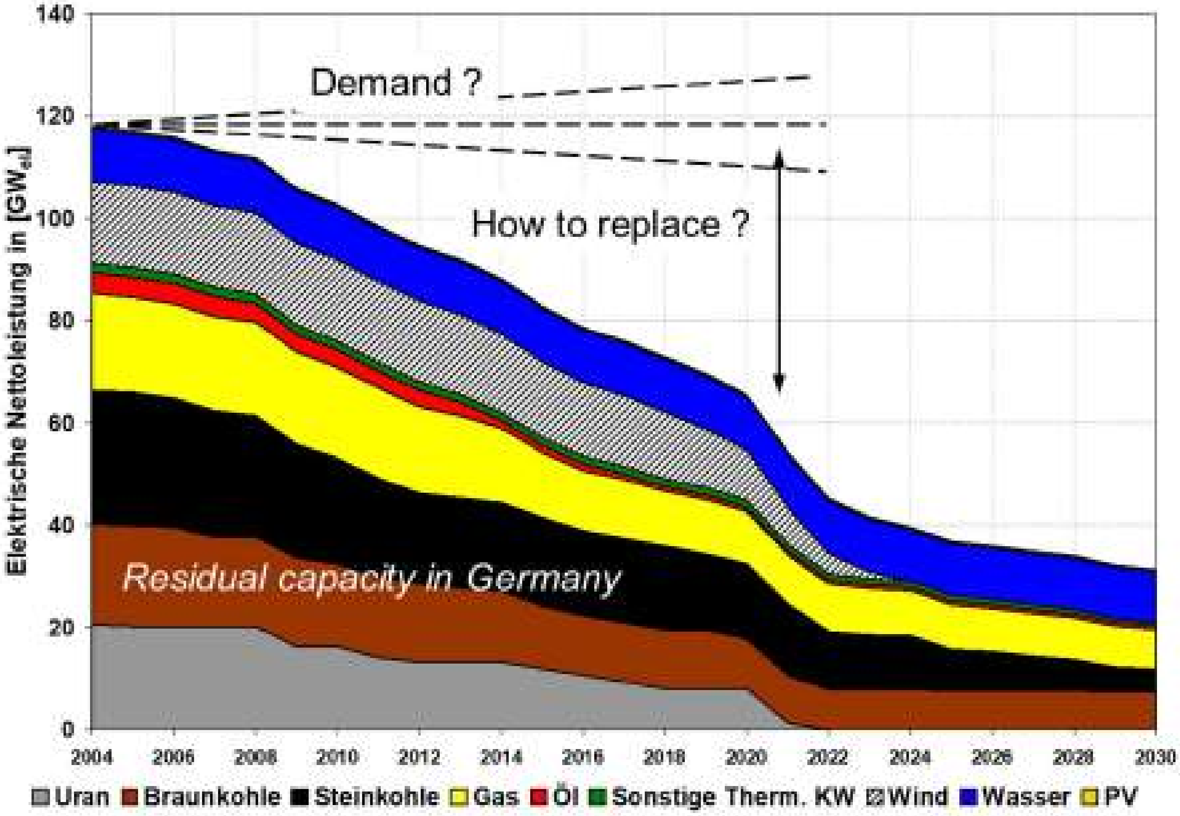
Energy service demands:

- Transportation
- Heating, cooking, lighting
- Commercial services
- Industrial processes
- Etc.

Challenges of Energy Systems

- Complexities
- Uncertainties
- Multi-dimensionalities
- Conflicting objectives
- Long-running nature

Challenges of Energy Systems

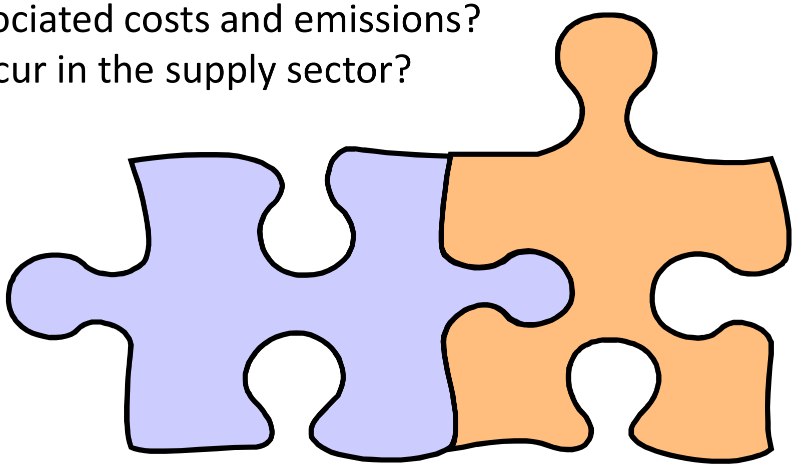


- Complexities
- Uncertainties
- Multi-dimensionalities
- Conflicting objectives
- Investment decisions
  - Aging power capacity has to be replaced
  - High upfront capital requirements
- Decisions have to take into account long time horizon with uncertain conditions:
  - Long and varying lead and life times?
  - Long-term energy prices of various carriers?
  - Market conditions?
  - Economic development and objectives?
  - Demands?
  - Climate and energy strategies?

Challenges of Energy Systems

SUPPLY:

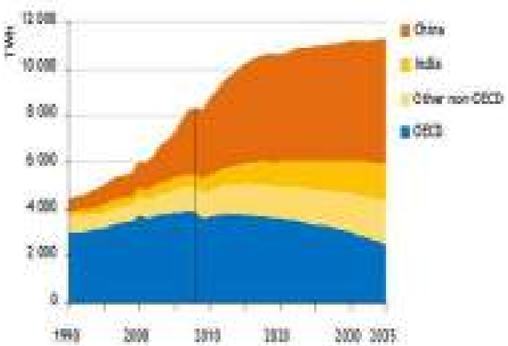
- How can supply meet demand?
- What are the associated costs and emissions?
- What changes occur in the supply sector?



DEMAND:

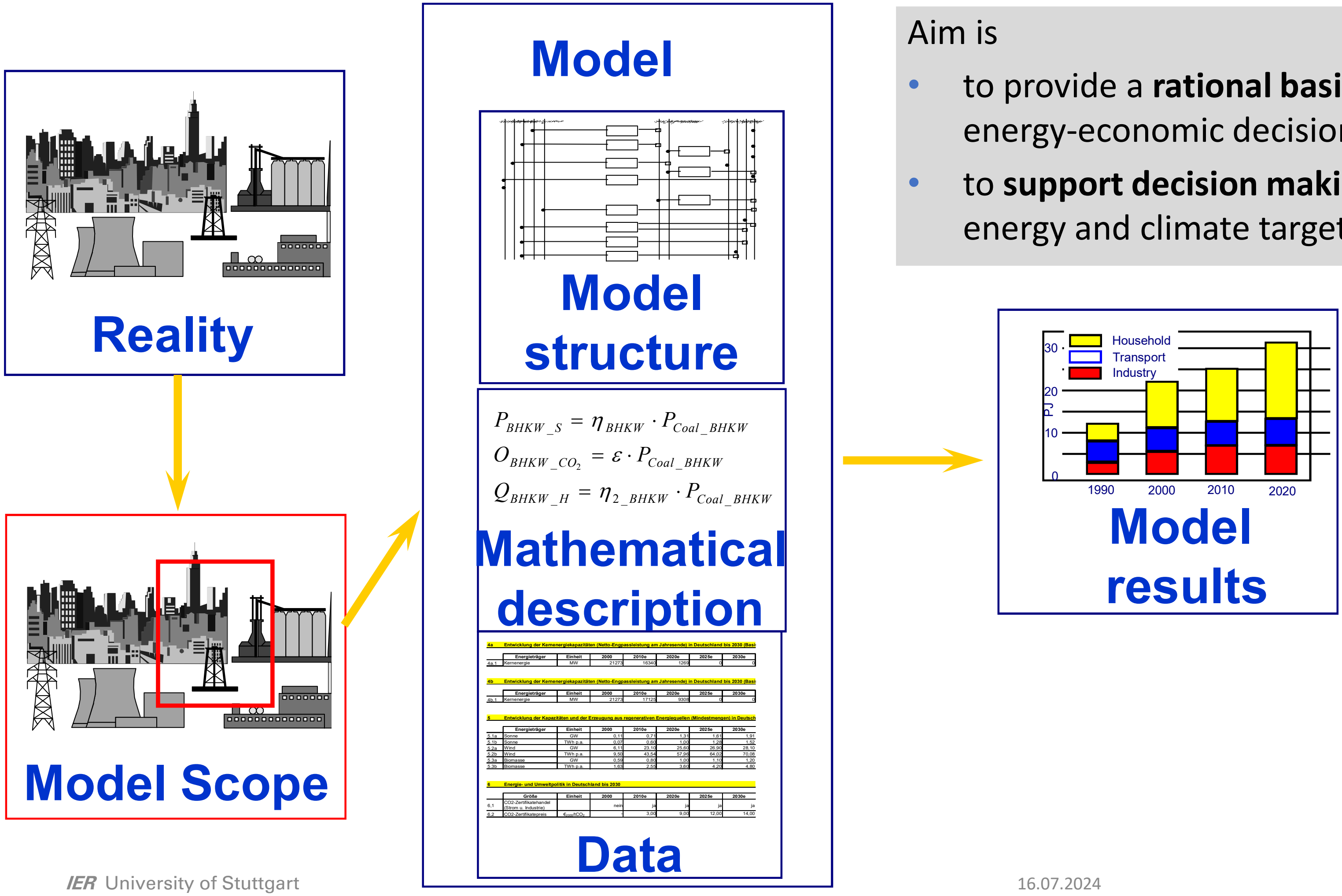
- Which factors influence energy demand and how do these change over time?
- What influence does energy demand have on the supply side?

Energy planning vs Forecast



- Although energy planning is focussed on the future, it is not the aim to predict the future.
- The aim of energy planning is to demonstrate the consequences of
  - different decisions (e.g. fully electrified system, decarbonisation, etc).
  - under specific assumptions (e.g. inflation rate, energy prices etc).
- Scenario analysis is often utilised as a method for energy planning.
  - Different scenarios demonstrate consequences of different decisions
  - Models are required since experiments are not feasible or possible.

Model-based energy systems analysis: Why use an energy system model?



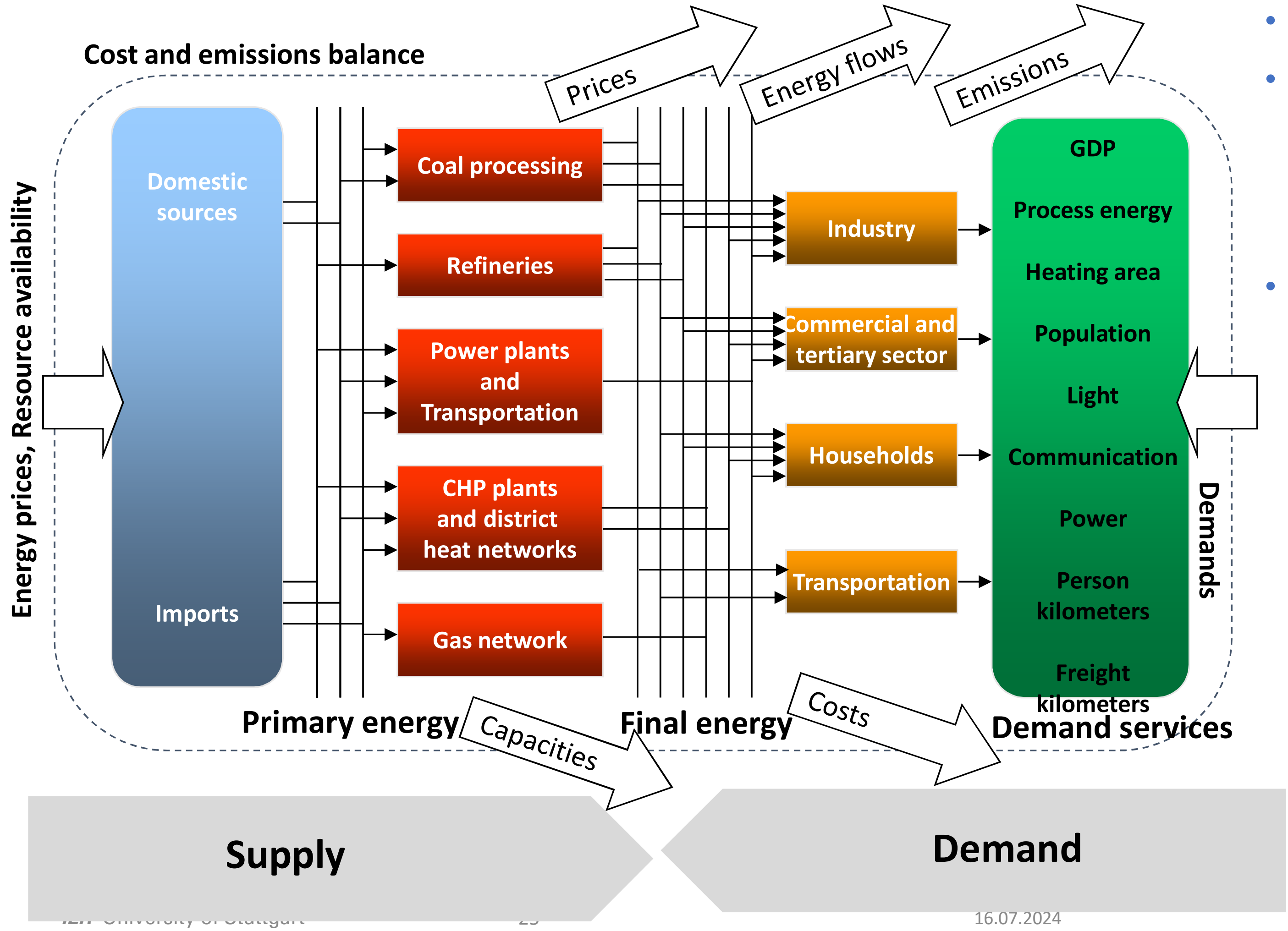
Aim is

- to provide a **rational basis** for decisions on energy policy and energy-economic decisions and
- to **support decision making** for investments and achieving energy and climate targets

An energy system model can:

- Reflect complex systems in an understandable form
- Organise and process large amounts of data
- Provide ability to assess long-term decisions and optimize trade-offs between sectors, fuel types, technologies, etc.

Fundamental features of TIMES Energy System Optimisation Model



- Optimisation, bottom-up model
- Model structure
  - Flexible time horizon
  - User-defined time slice resolution within a year
  - Multi-regional
- Model formulation
  - Process description:
    - Single process type with access to all model features
    - Vintaged process properties
    - Transformation eqn with overall and commodity-specific efficiencies
  - Objective function:
    - Different treatment of process investments based on investment lead time
    - Other optimization functions than total system costs can be defined by modeller

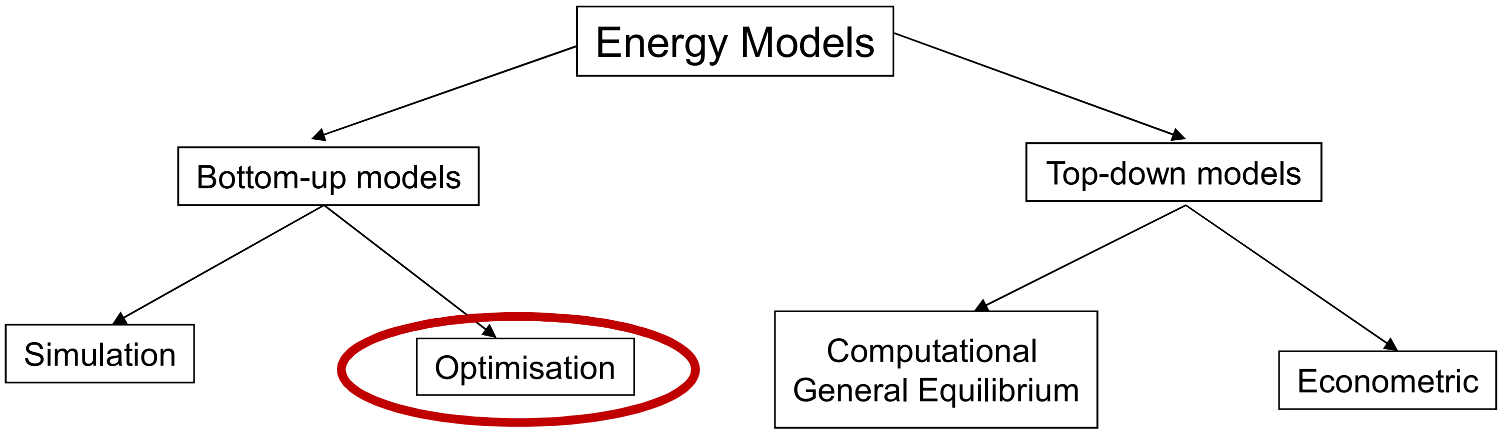
User constraints

- Framework to formulate virtually any linear relationship between decision variables

Analysis and Scenarios

- Explorative scenarios (*what-if*): Impacts of policy measures, e.g.:
    i. Consequences of coal phase-out or impacts of integration of hydrogen and derivatives in terms of structure of the energy sector, costs and emissions
- Normative scenarios (*how-to*): Achievement of policy goals, e.g.:
    i. How to reach CO_2 reduction targets, renewable quotas, etc.
    ii. Which sectors/technologies become important (renewables, CCS, efficiency)
    iii. Associated costs
- Assessing the future role of energy technologies/energy carriers, e.g.:
    i. Renewables
    ii. Alternative fuel technologies
    iii. Carbon capture and storage

Energy System Model classification and selection



Selection criteria:	Top-down	Bottom-up
Application	• General • Macroeconomic • Global or national energy system	• Specific • Energy sector only or entire energy system
Characteristics	• Single or multi region • Recursive dynamic or perfect foresight • Predictive	• Single or multi region • Short or long term • Recursive dynamic or perfect foresight • Explorative
Methodology	• Aggregate data variables (energy, capital, labour)	• Disaggregated data • Detailed end-use technology descriptions and energy consumption
Parameters	• Prices • Elasticities	• Demand curves • Supply curves • Economic, political and social objectives

Development
- **By ETSAP**
- **Implementation in GAMS**

IER:

- **Germany**
  - **TIMES-D**
  - **TIMES Actors Model (TAM)**
- **Europe (TIMES-PanEU)**
- **European electricity and gas sector model (TIMES-EG)**
- **Global model (TIAM-IER)**
- **Electricity sector model for South America (TIMES-ESA)**
- **Gauteng (TIMES-GEECO)**

Other places:

- **Finland (VTT, Helsinki)**
- **Belgium (KUL, Leuven)**
- **Italy (Turin)**
- **South Africa model, Village model (ERC, Cape Town)**
- **EU-NEEDS project**
- **Global models (EFDA, ETSAP-TIAM)**

Methodology
- **Bottom-up Model**
- **Perfect competition**
- **Perfect foresight (or myopic)**
- **Optimisation (LP/MIP/NLP)**

Min/Max Objective function subject to:
- **Equations, Constraints**
- **Decision Variables <=> Solution**
- **Input parameters**

TIMES

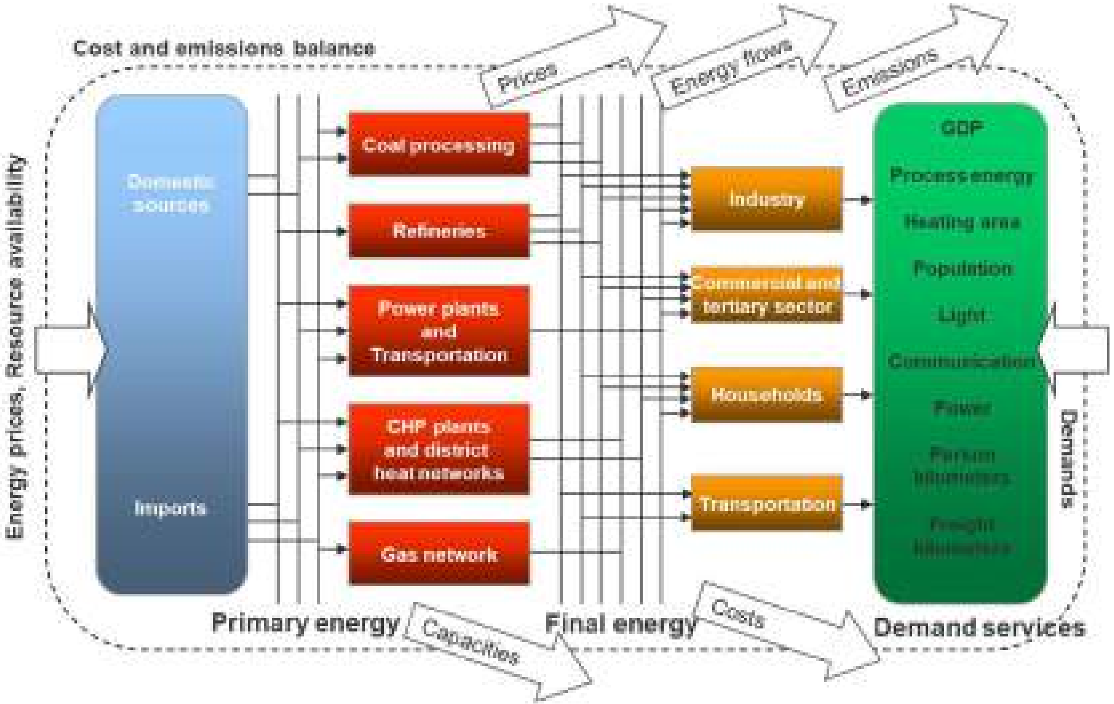
(The Integrated MARKAL EFOM System)

Advanced Features/Variants
- **Multi-regional**
- **Inter-temporal**
- **Elastic demands**
- **Endogeneous learning**
- **Discrete capacity expansion**
- **Macroeconomic linkage**
- **Climate extension**
- **Stochastic programming**
- **Alternative objective functions**
- **Multi-criteria optimisation**

- **Particular strengths:**
  1. Detailed representations of energy technologies and their linkages across sectors
  2. Consideration of inter-dependencies in the energy system
  3. Analysis of competition and substitution effects between technologies
  4. Detailed representation of results: energy flows, new capacities, emissions, costs
- **Limits:**
  1. Partial equilibrium model,
  2. only energy sector considered,
  3. effects of energy policies on the remaining economy not always included

TIMES for analysis of role of hydrogen in the energy system

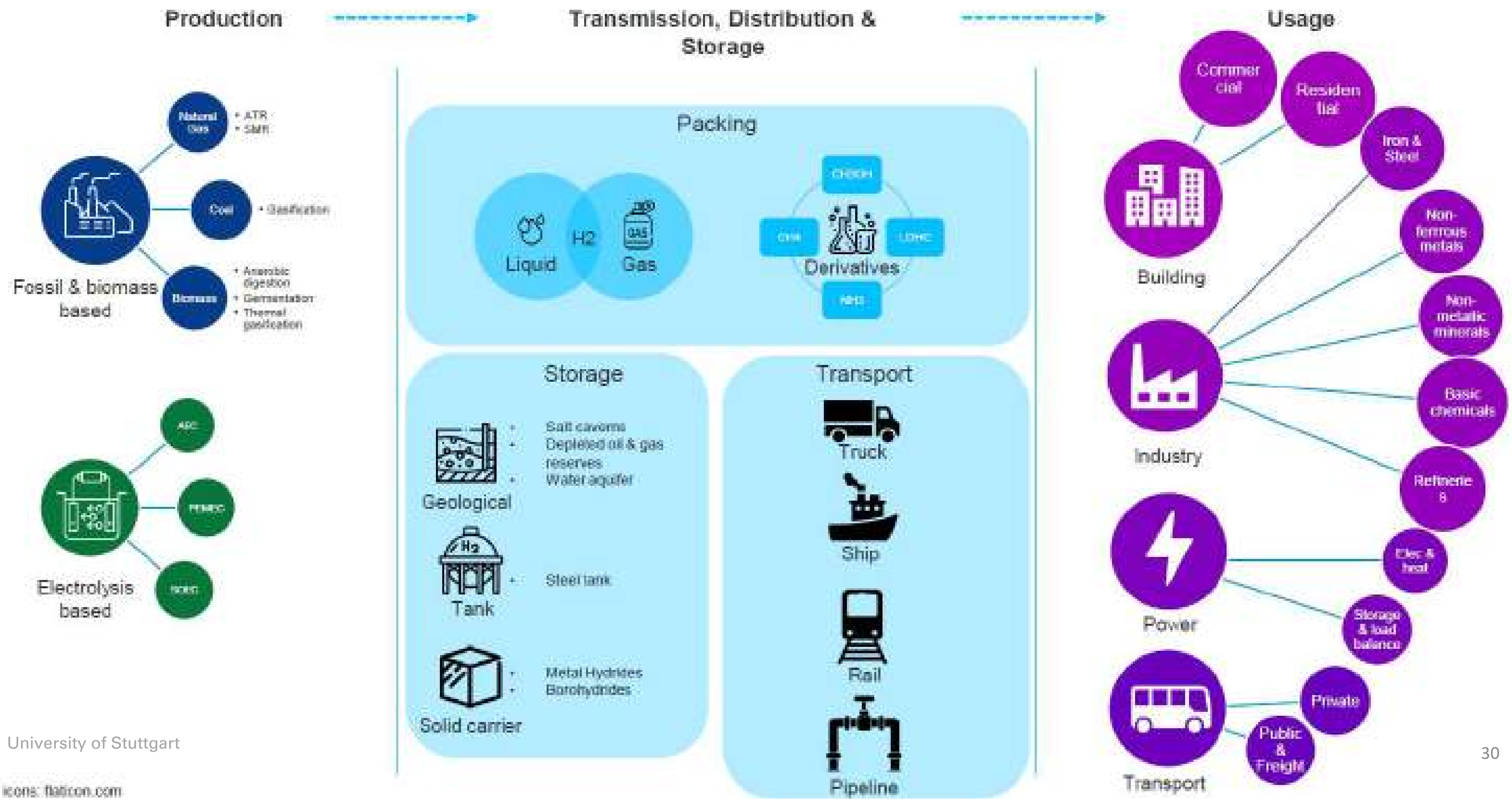
→ Towards a carbon-neutral energy system in 2045 in Germany



<u>Example research questions from UrGE4Hy:</u>

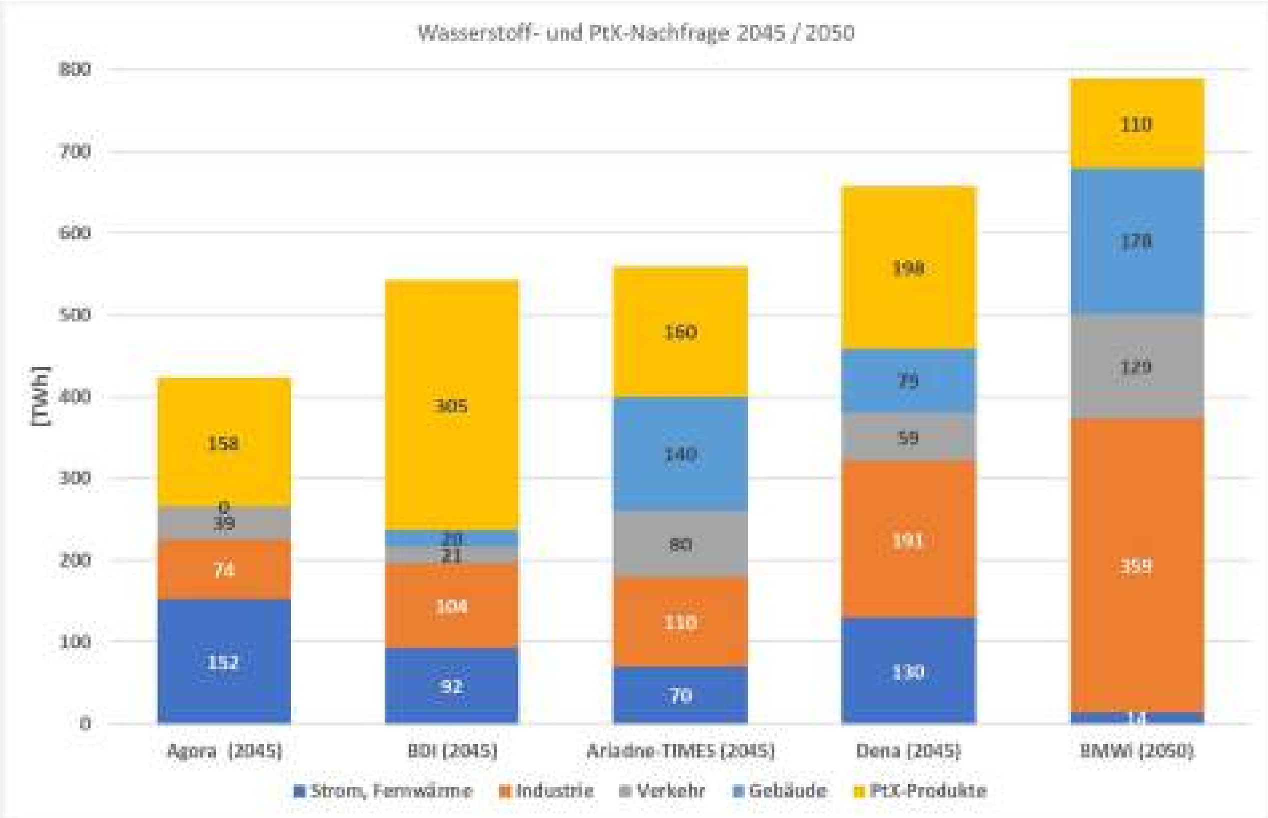
- **How, where and when can hydrogen play a role in the Uruguayan and German energy system?**
- What role can green hydrogen play for restructuring industrial value chains?
- What are the challenges and suitable frame conditions (e.g. on price developments volatility, networks/grids, transport routes, regulatory frameworks) in the **Uruguayan, German and international energy system**?
- What are the possible impacts toward a **carbon-neutral energy system** (in Uruguay and Germany)?

Hydrogen system integration



icons: flaticon.com

Possible modelling outputs



- Demands for hydrogen by sector
- Curtailment, storage, investment in more expensive renewables within a region or grid development for power exchange.

✓ **Techno-economic aspects of both grids in the regions, i.e. transmission and distribution, is incorporated in the model.**

✓ **Overview of consumption by sector**

✓ **Associated cost and emissions**

TIMES as a tool for Hydrogen Analysis

- An energy system model is a useful tool to
  - analyse options for hydrogen export or direct use
  - support decision-making
  - explore long-term options
  - assess competition between energy carriers and end-uses
  - determine how best to achieve specific energy and climate-related targets
  - associated costs and emissions of different investment decisions

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Showcase: Results & Analyses possible with ESOMs
– Overview of Insights

Jithin Jose

image: ewi

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Modelling Frameworks

- MESSAGE – Model for Energy Supply Strategy Alternatives and their General Environmental Impact
- OSeMOSYS – Open Source Energy Modelling System
- NEMS – National Energy Modelling System
- ESME – Energy Systems Modelling Environment
- PyPSA – Python for Power System Analysis
- TIMES – The Integrated MARKAL-EFOM System

- And many others..

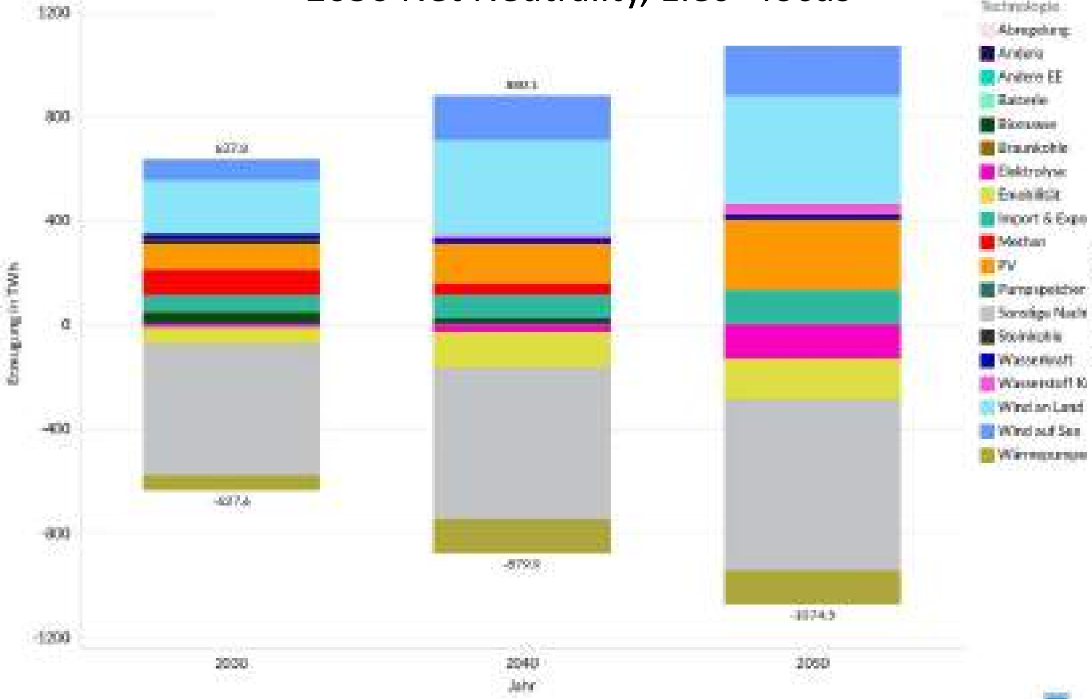
- Different based on:
  - Regional Scope
  - Temporal Scope
  - Language written
  - Accessibility – Open Source/Not
  - Focus of model – power/energy/material
  - Contributing and usage stakeholders

Model results

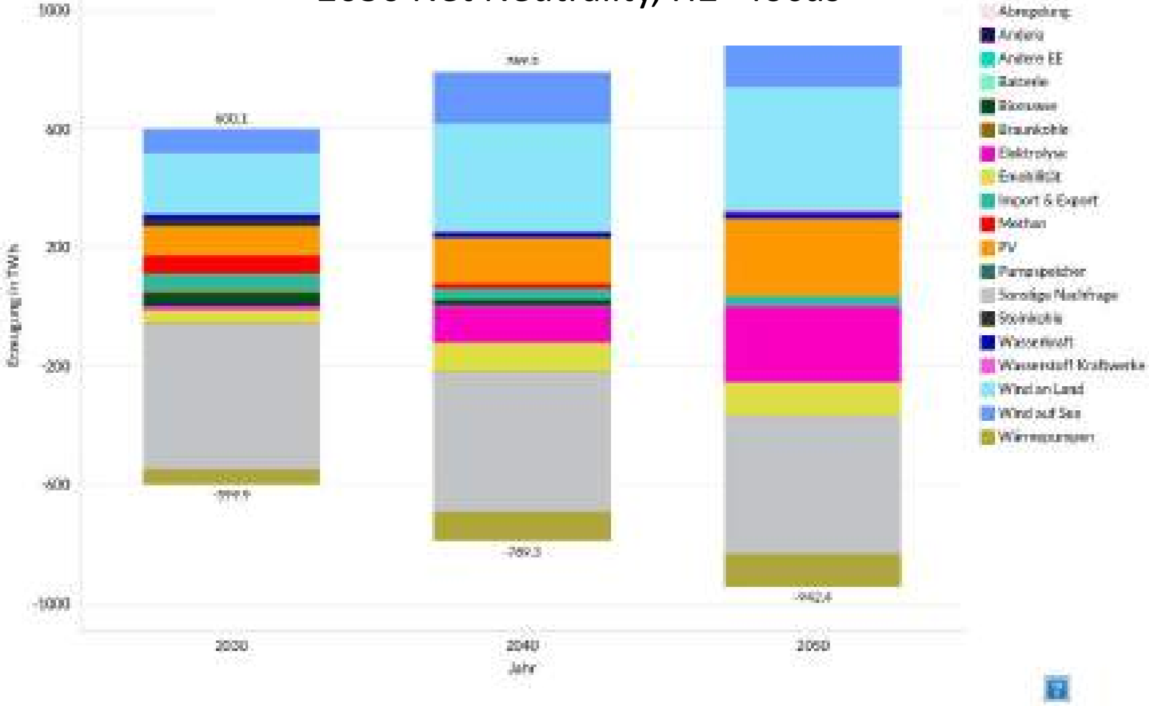
Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

Electricity Balance: Supply & Demand

2050 Net Neutrality, Elec - focus



2050 Net Neutrality, H2 - focus



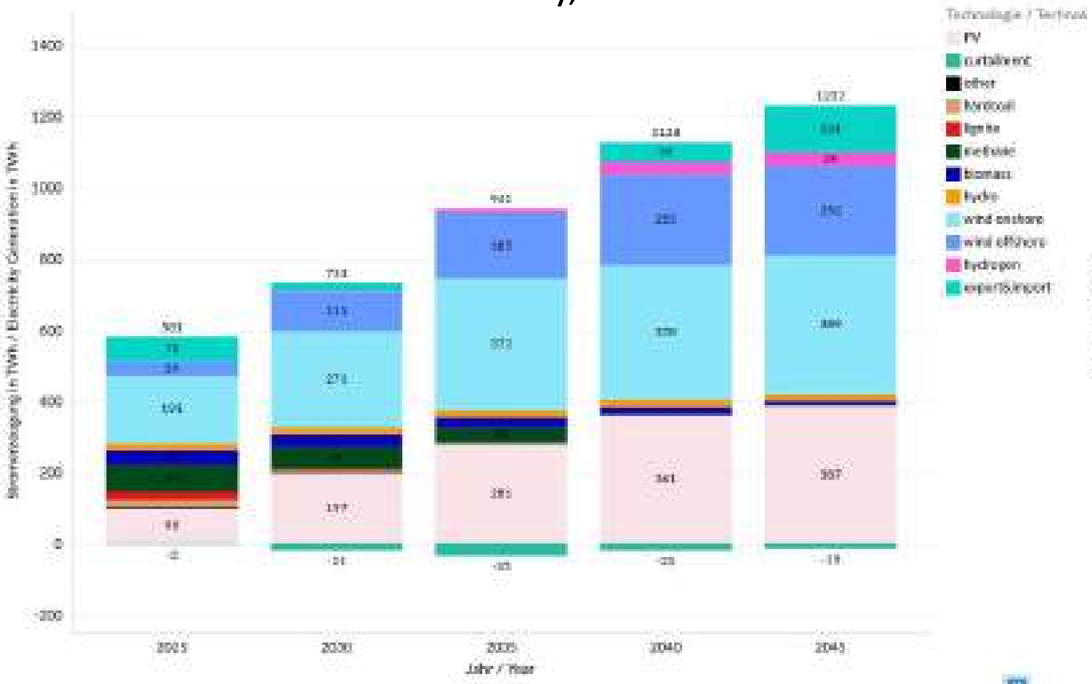
Dashboard: Energy supply | Langfristszenarien

Model results

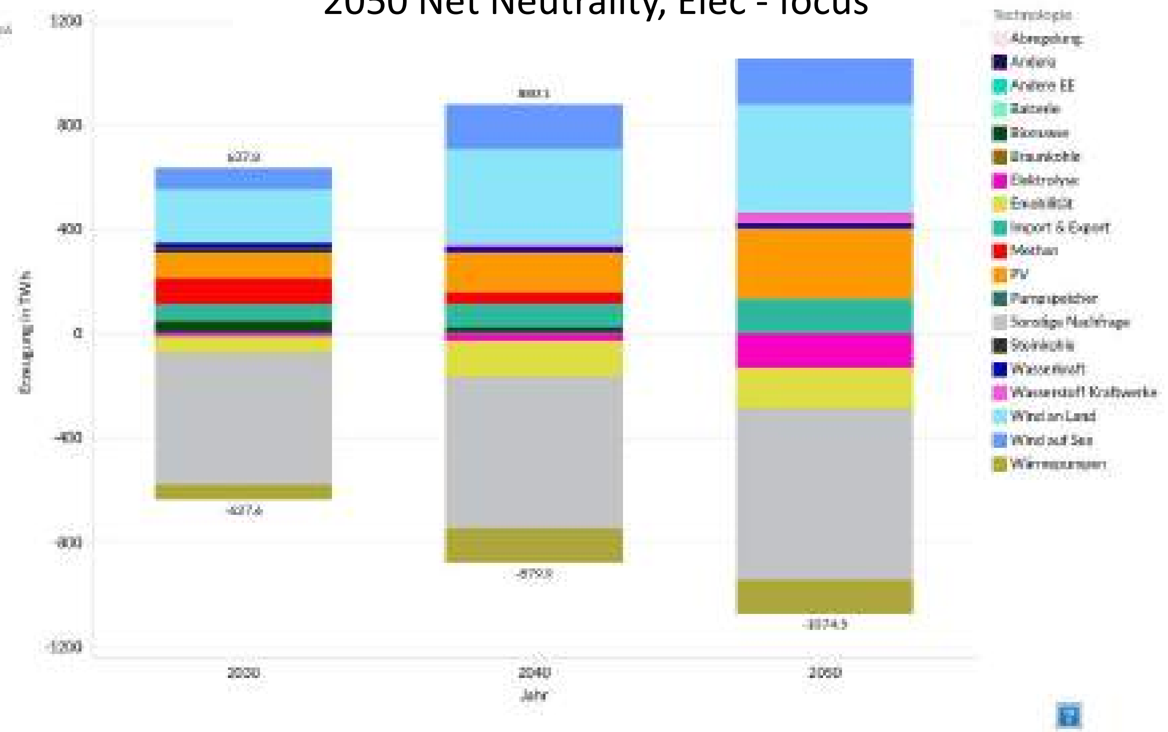
Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

Electricity Generation

2045 Net Neutrality, Elec - focus



2050 Net Neutrality, Elec - focus



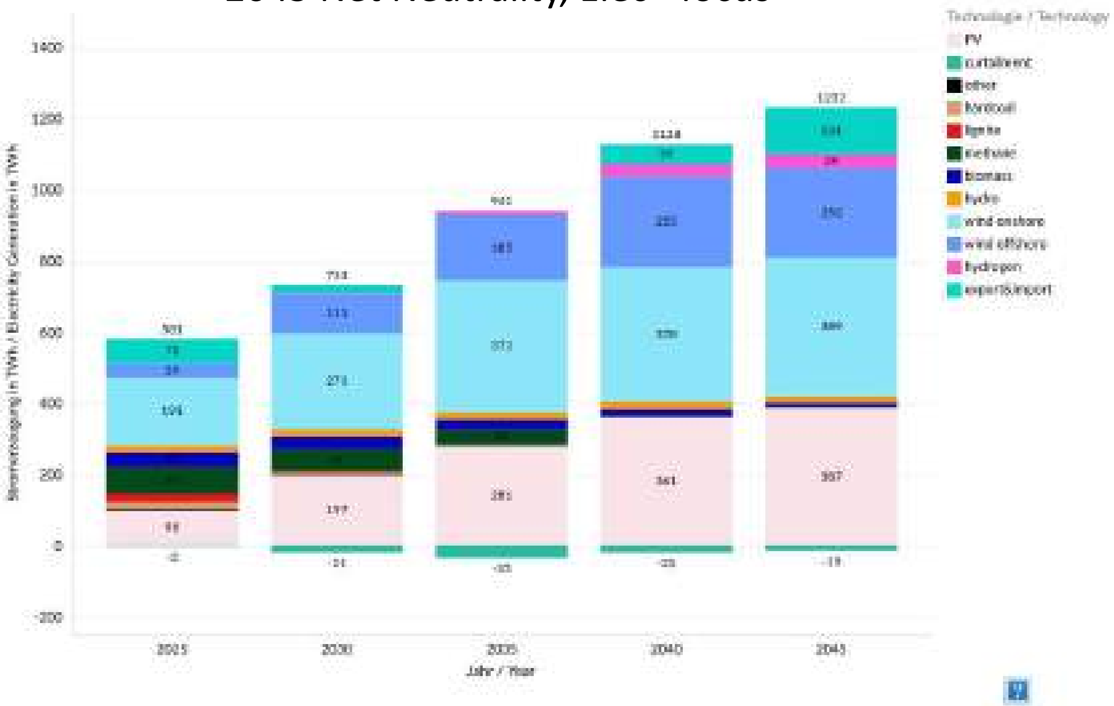
Dashboard: Energy supply | Langfristszenarien

Model results

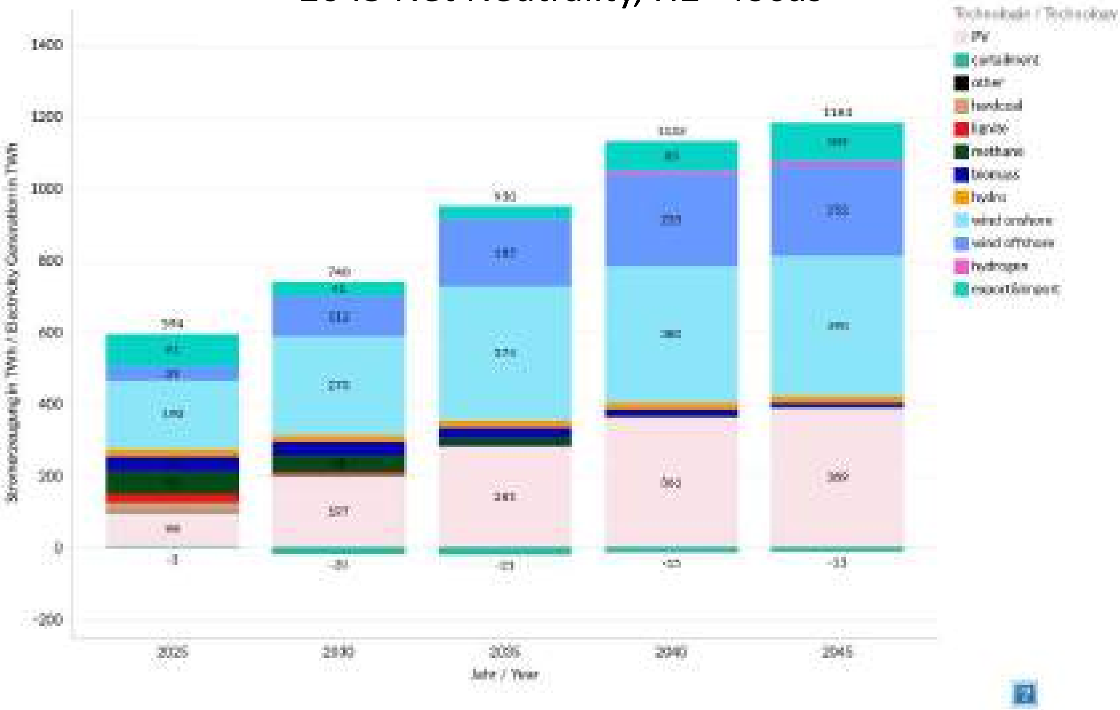
Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

Electricity Generation

2045 Net Neutrality, Elec - focus



2045 Net Neutrality, H2 - focus



Dashboard: Energy supply | Langfristszenarien

Model results

Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

RE share in Gross Elec. consumption

2045 Net Neutrality, Elec - focus

2045 Net Neutrality, H2 - focus

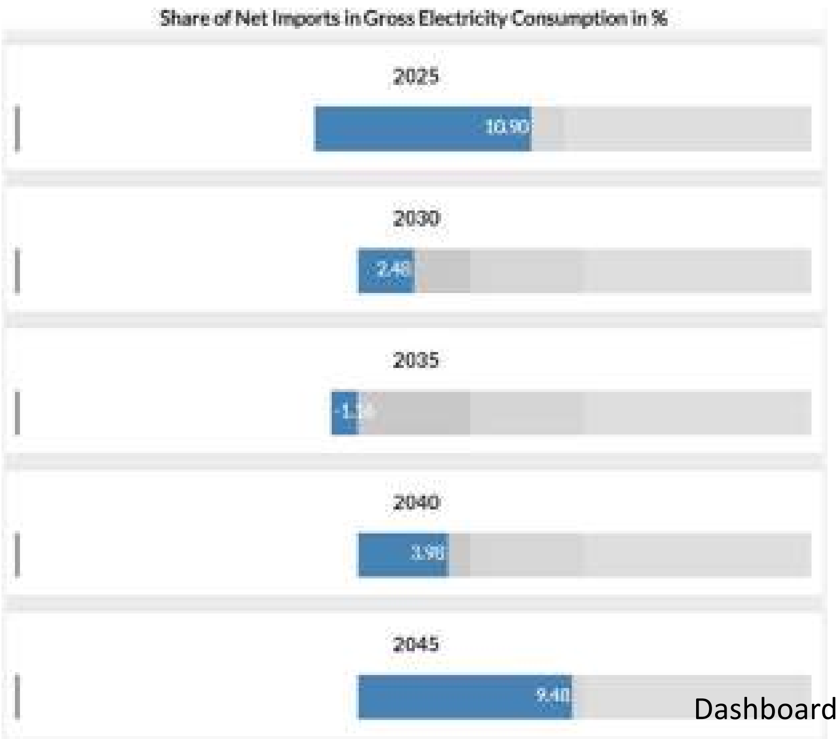
Dashboard: Energy supply | Langfristszenarien

Model results

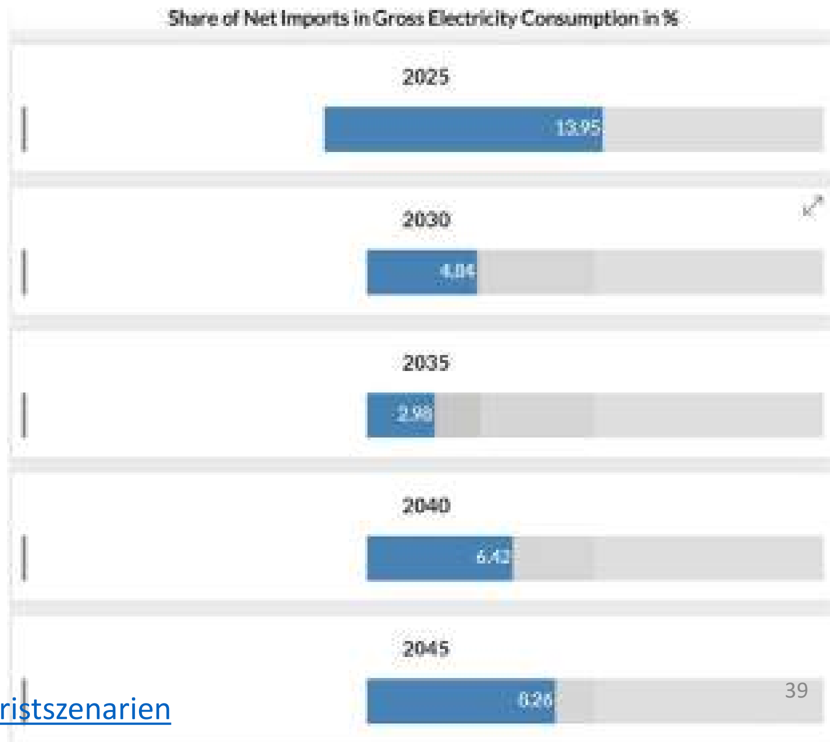
Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

Import share in Gross Elec. consumption

2045 Net Neutrality, Elec - focus



2045 Net Neutrality, H2 - focus



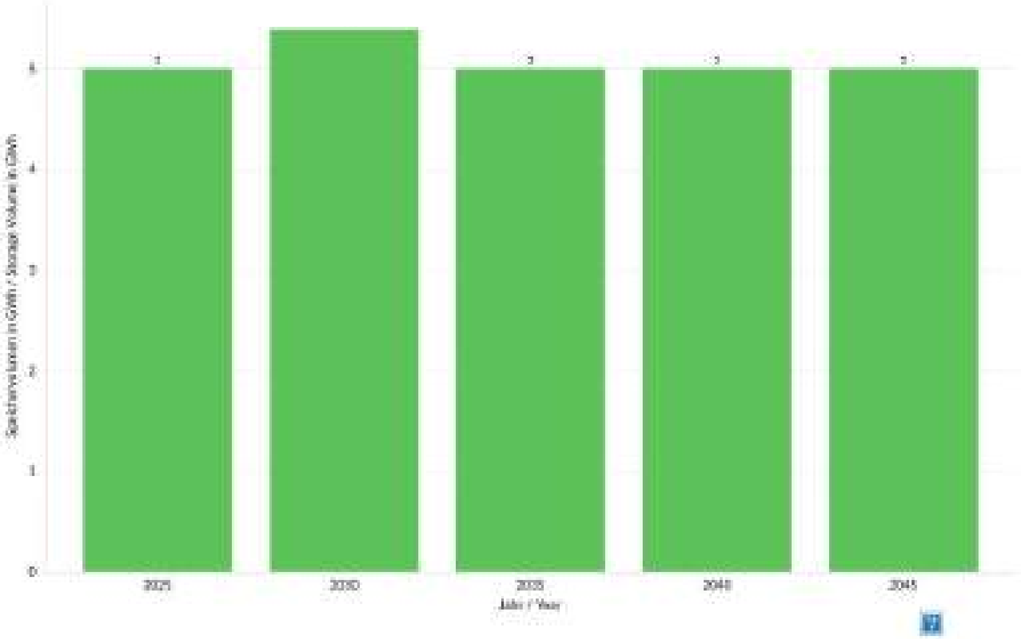
Dashboard: Energy supply | Langfristszenarien

Model results

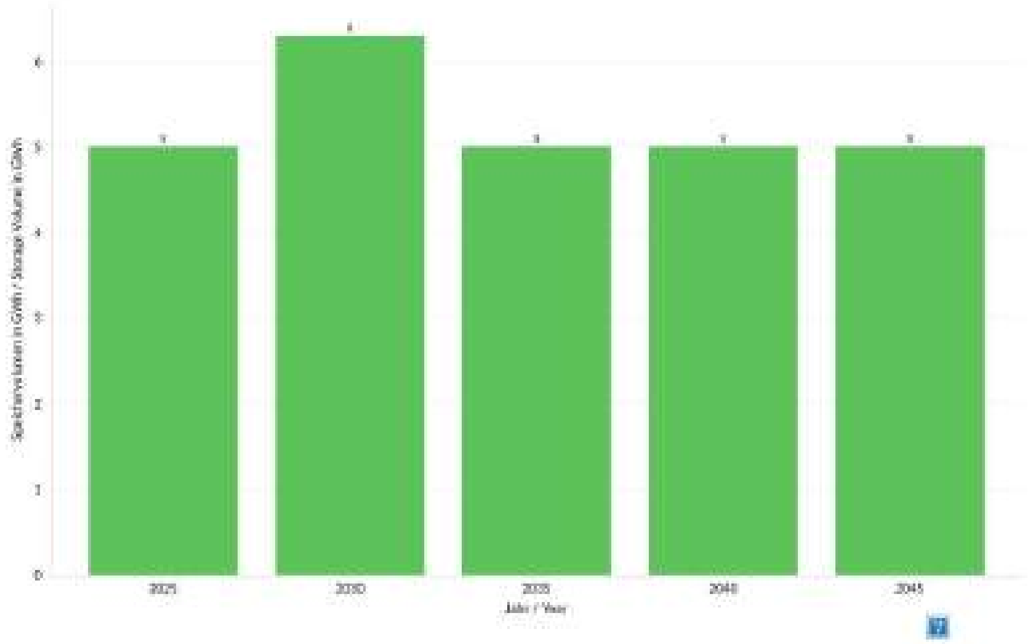
Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

Battery Storage

2045 Net Neutrality, Elec - focus



2045 Net Neutrality, H2 - focus

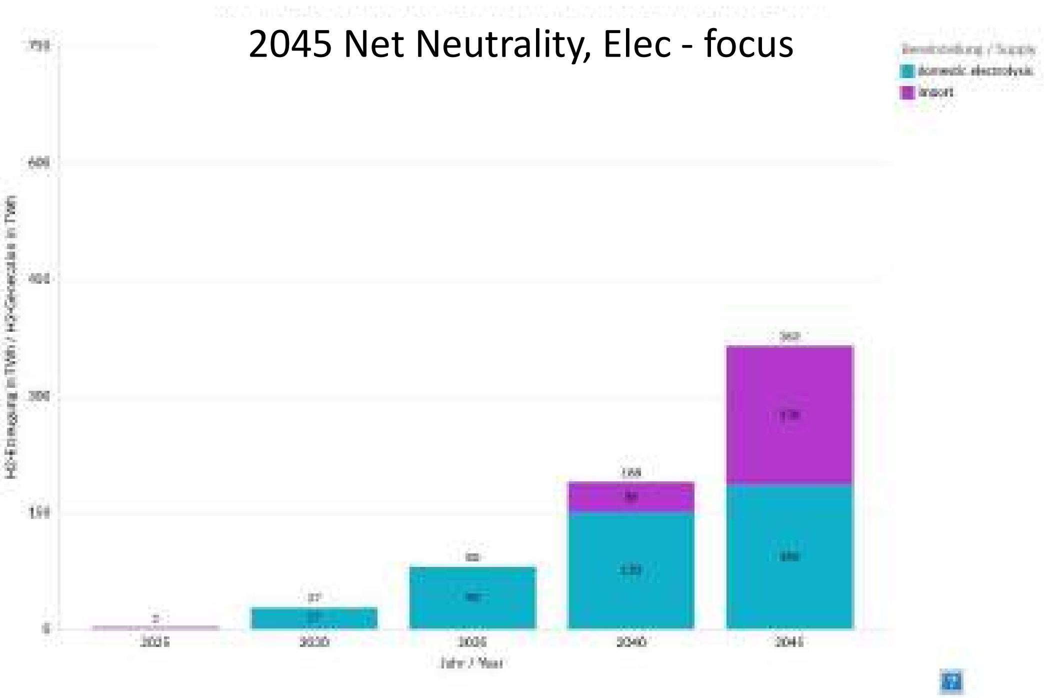


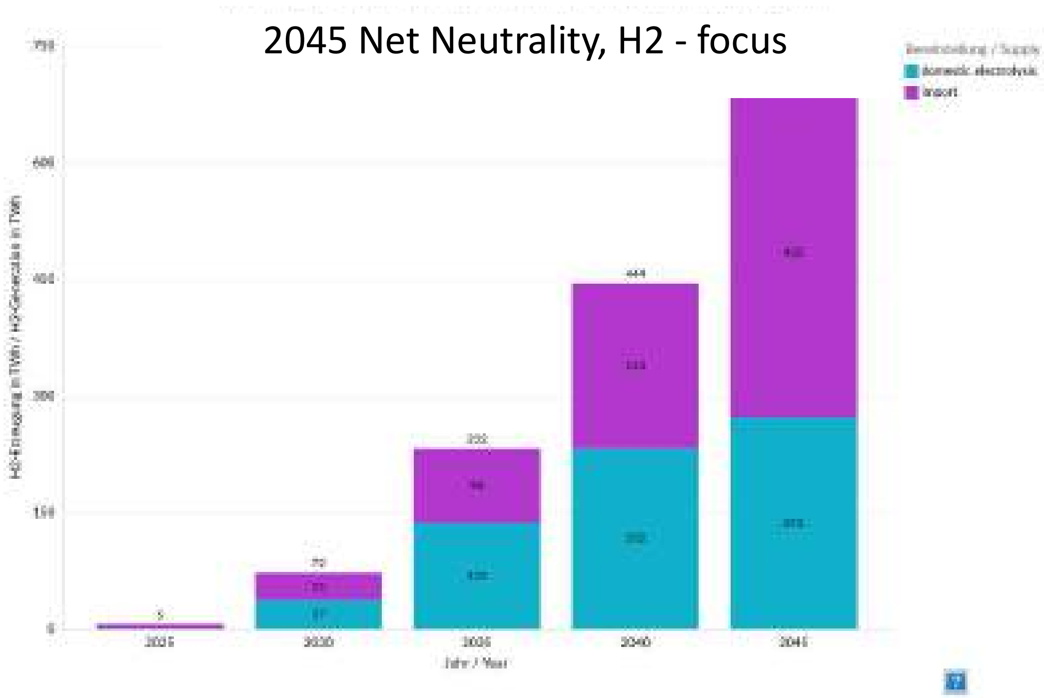
Dashboard: Energy supply | Langfristszenarien

Model results

Long-term scenarios – Fraunhofer ISI (enertile) **Germany**

Hydrogen Supply





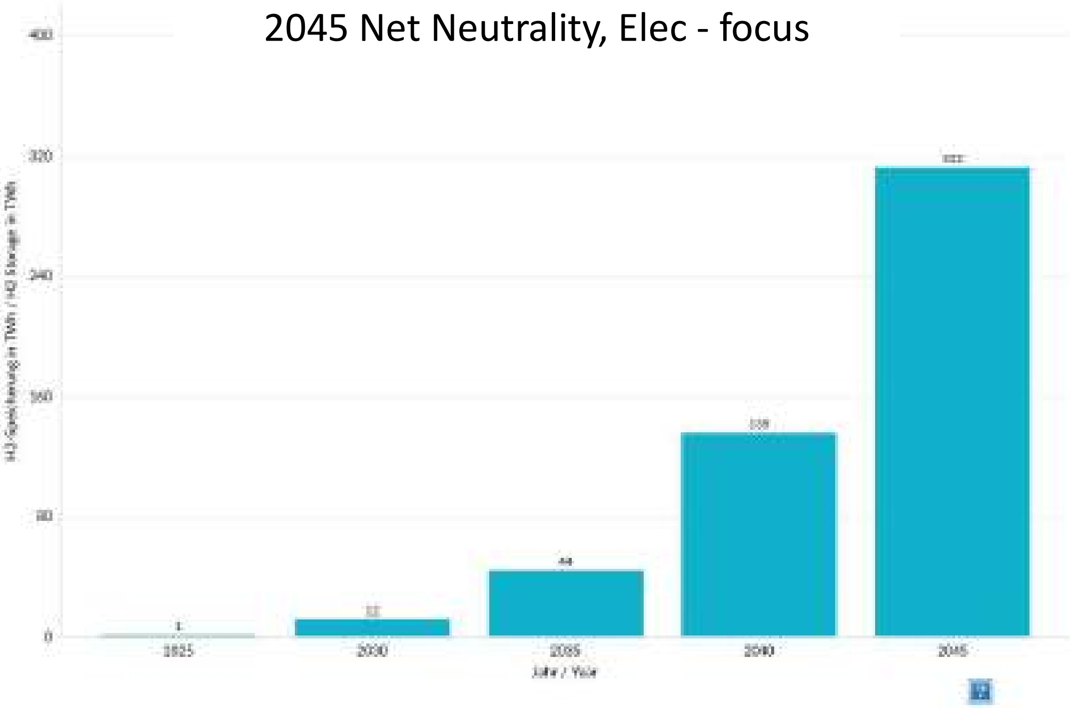
Dashboard: Energy supply | Langfristszenarien

Model results

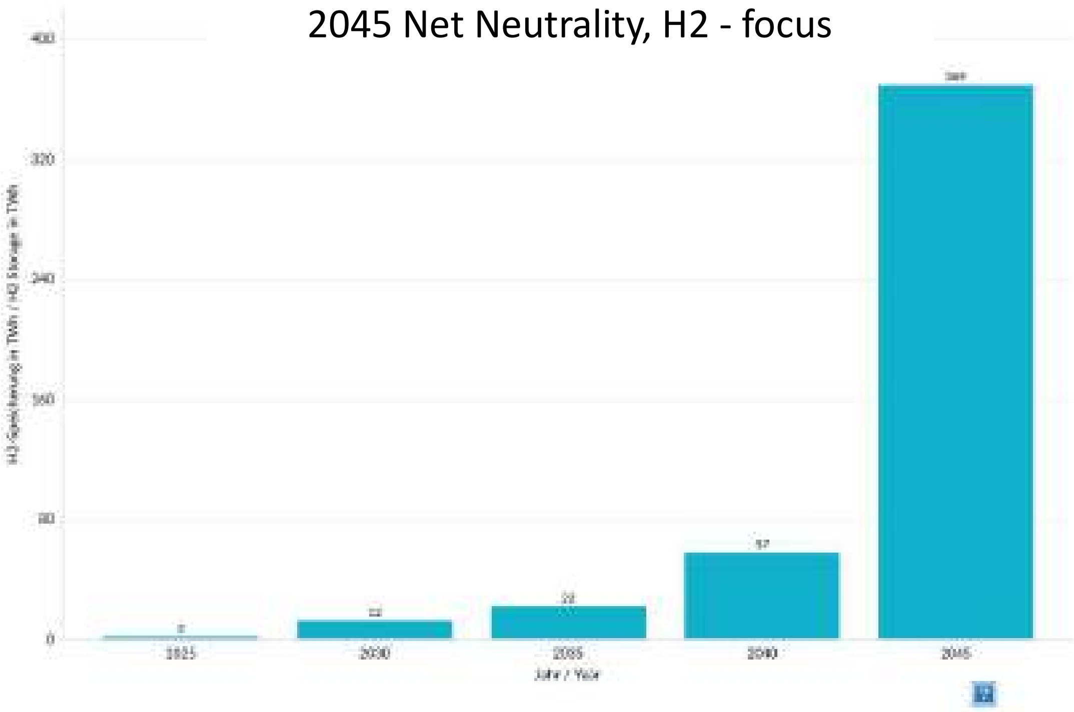
Long-term scenarios – Fraunhofer ISI (enertile) **Europe**

Hydrogen Storage

2045 Net Neutrality, Elec - focus



2045 Net Neutrality, H2 - focus



Dashboard: Energy supply | Langfristszenarien

Model results

Long-term scenarios – Fraunhofer ISI (enertile) **Europe**

Hydrogen Storage

2045 Net Neutrality, Elec - focus

2045 Net Neutrality, H2 - focus

H2 Storage in Europe

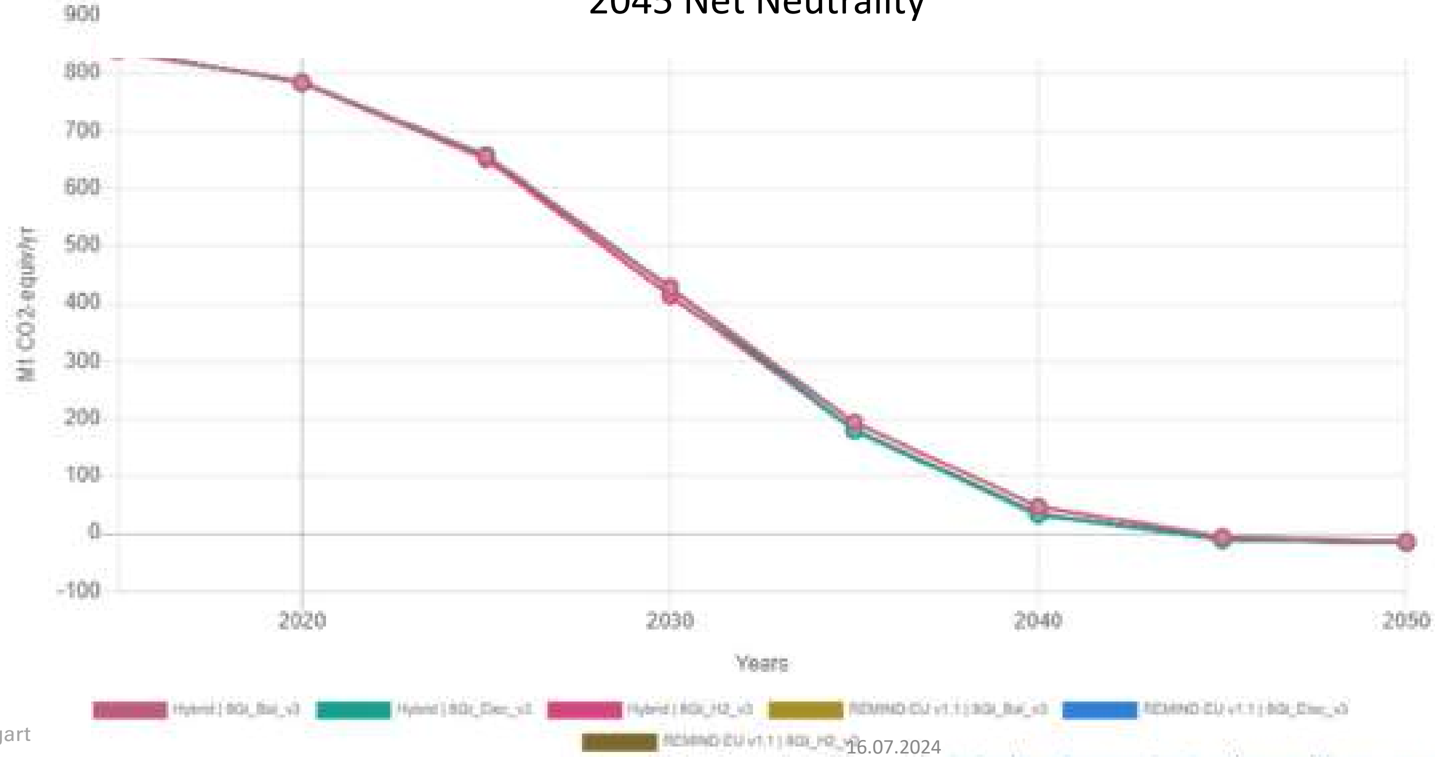
Dashboard: Energy supply | Langfristszenarien

Model results

Ariadne (Ariadne Pathfinder | Ariadne (ariadneprojekt.de)) **Germany**

Model Comparisons – CO_2 emissions

2045 Net Neutrality



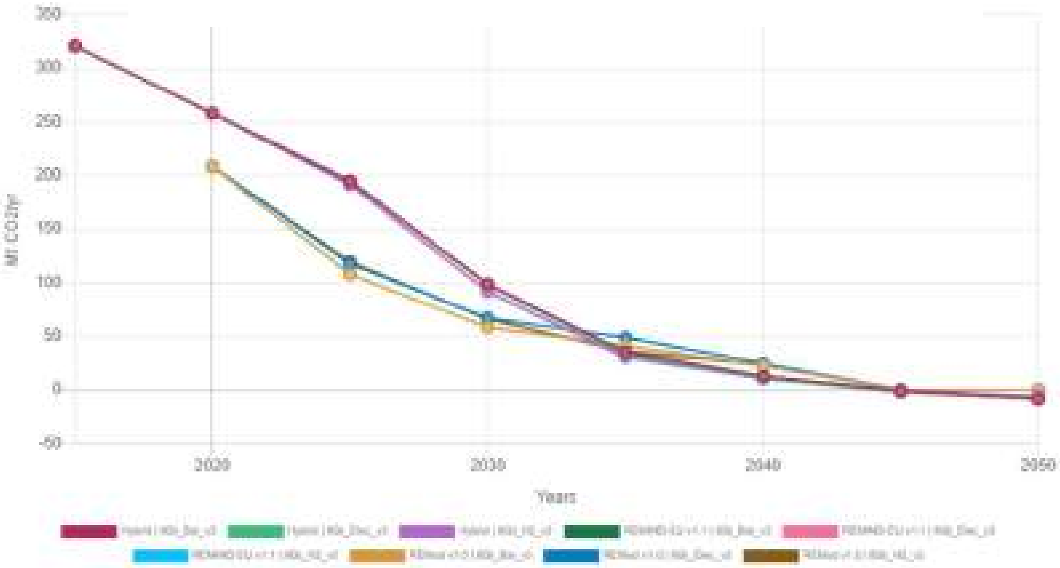
Dashboard: Ariadne Scenario Explorer (iiasa.ac.at)

Model results

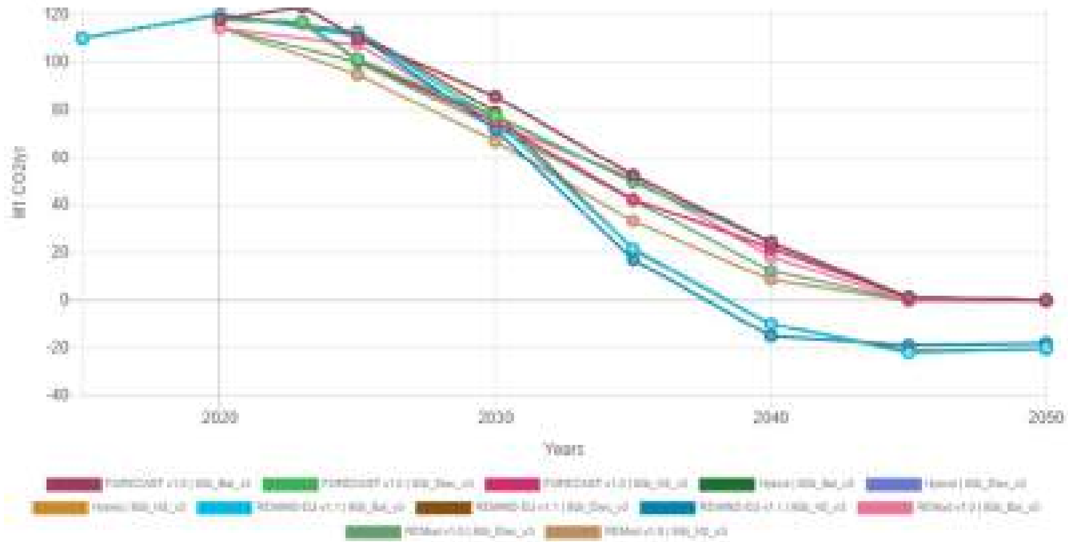
Ariadne (Ariadne Pathfinder | Ariadne (ariadneprojekt.de)) **Germany**

Model Comparisons – Sectoral CO_2 emissions

2045 Net Neutrality, **Energy Production**



2045 Net Neutrality, **Industry**



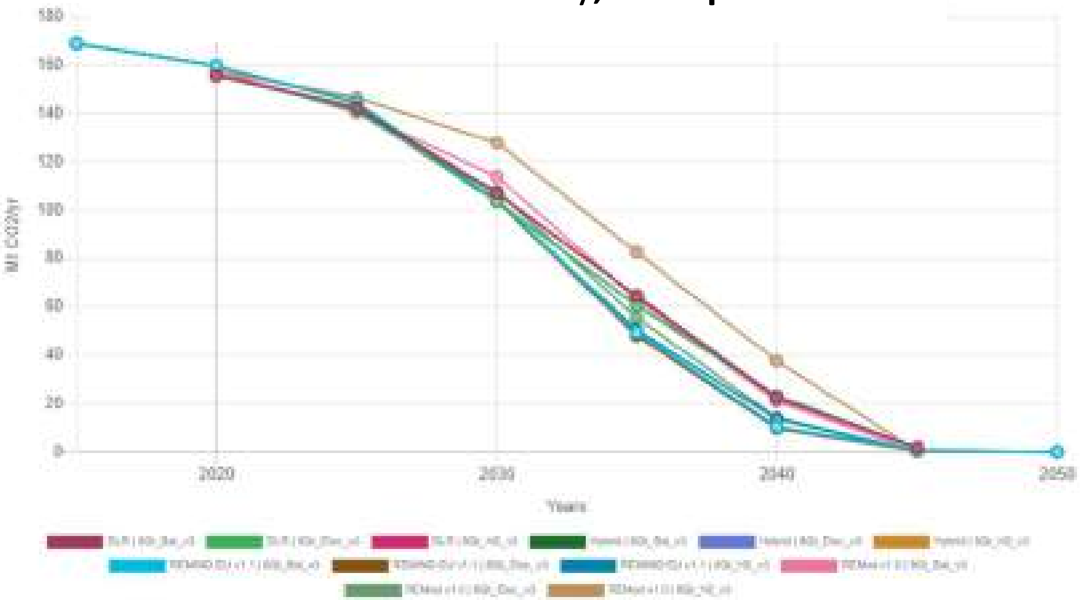
Dashboard: Ariadne Scenario Explorer (iiasa.ac.at)

Model results

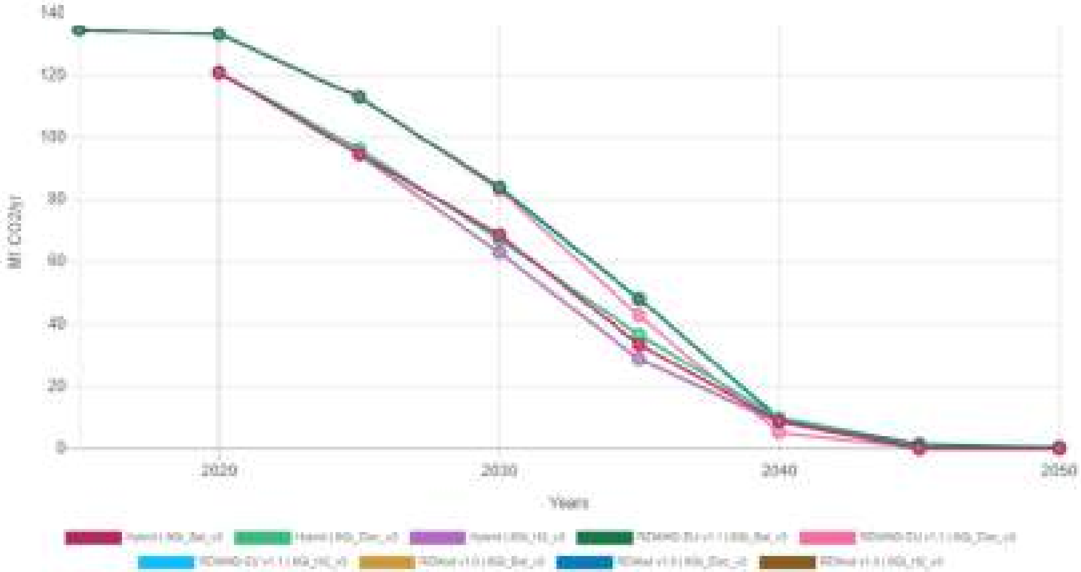
Ariadne (Ariadne Pathfinder | Ariadne (ariadneprojekt.de)) **Germany**

Model Comparisons – Sectoral CO_2 emissions

2045 Net Neutrality, **Transport**



2045 Net Neutrality**, Buildings**



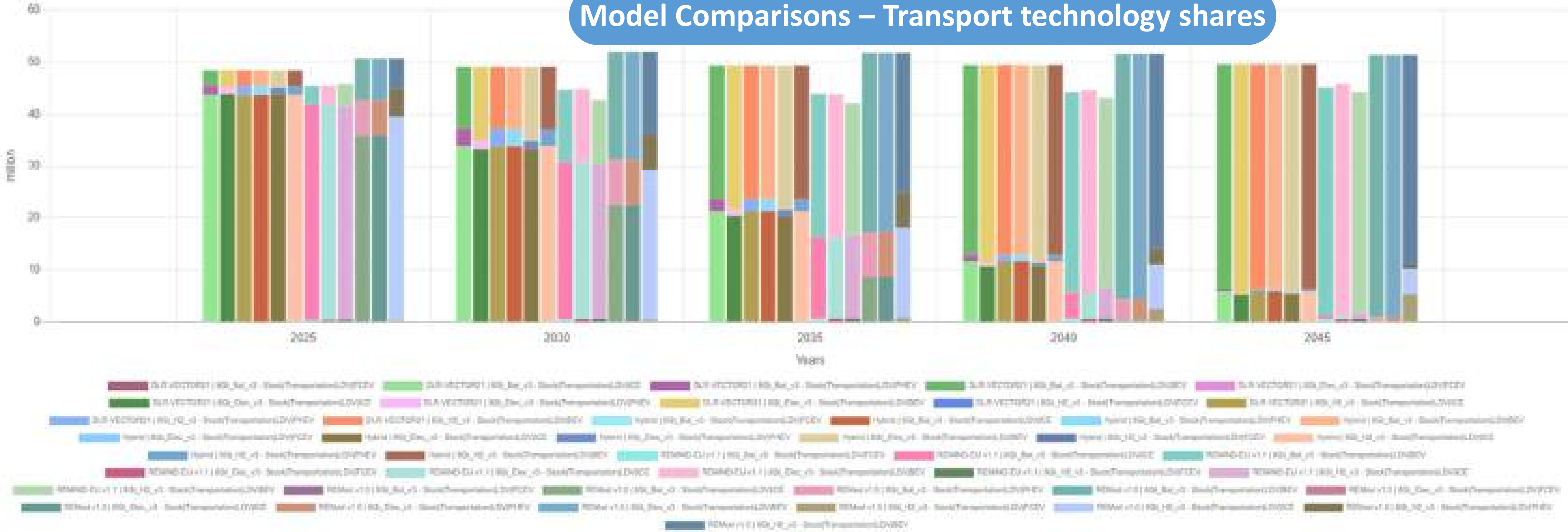
Dashboard: Ariadne Scenario Explorer (iiasa.ac.at)

Model results

Ariadne (Ariadne Pathfinder | Ariadne (ariadneprojekt.de))

Germany

Model Comparisons – Transport technology shares



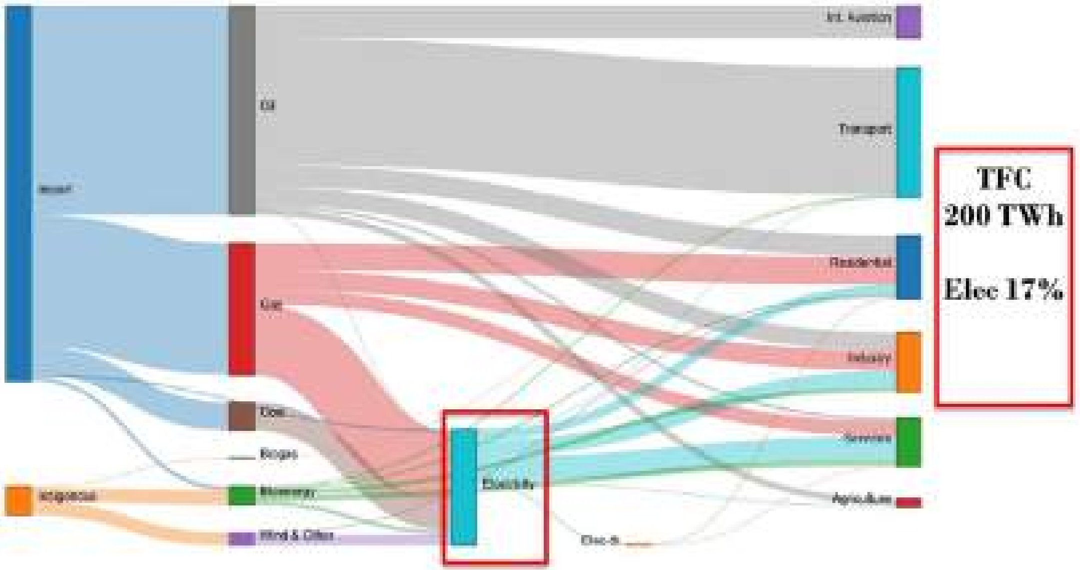
Dashboard: Ariadne Scenario Explorer (iiasa.ac.at)

Model results

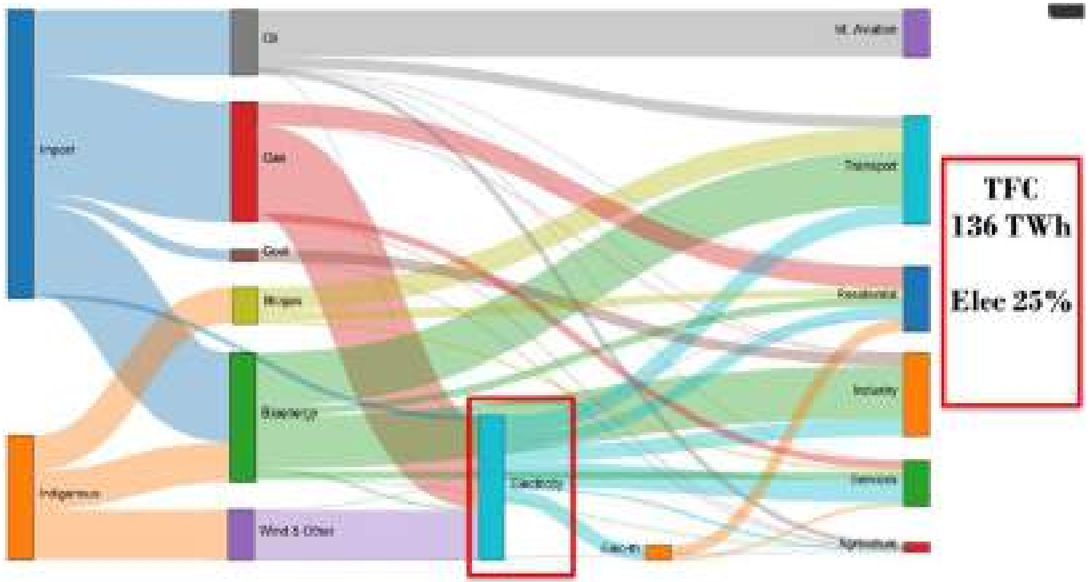
TIMES applications **Ireland**

Energy Balance: Supply & Demand

TIMES – IRELAND
Net Neutrality 2050, BAU



TIMES – IRELAND
Net Neutrality 2050, -80% CO2

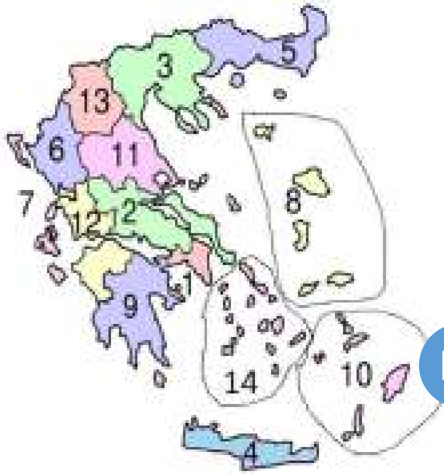


Source: [TIMES course]

Model results

TIMES applications

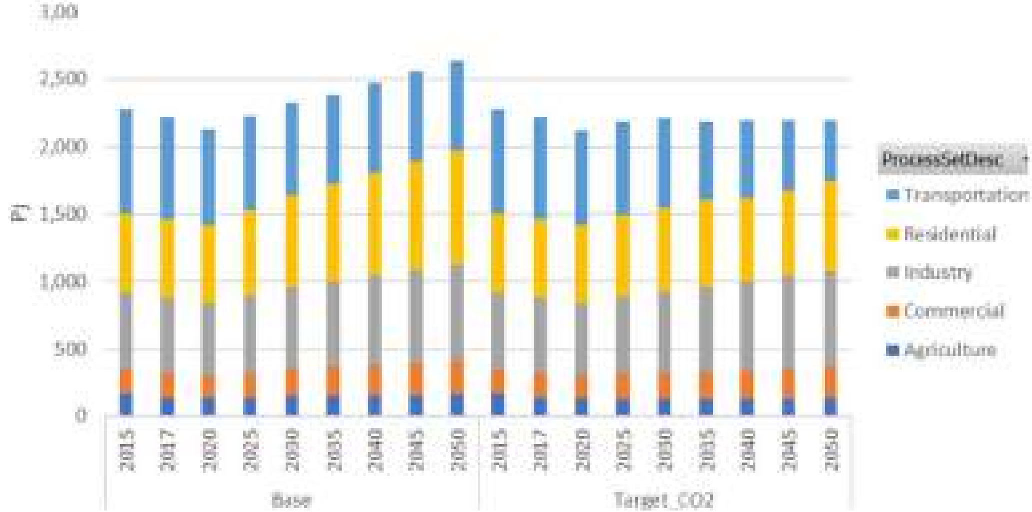
Greece



Primary (left) & Final (right) Energy Consumption

TIMES – Greece
Roadmap to 2035, BAU vs CO2 Target

TIMES – Greece
Roadmap to 2035, BAU vs CO2 Target



Source: [TIMES course]

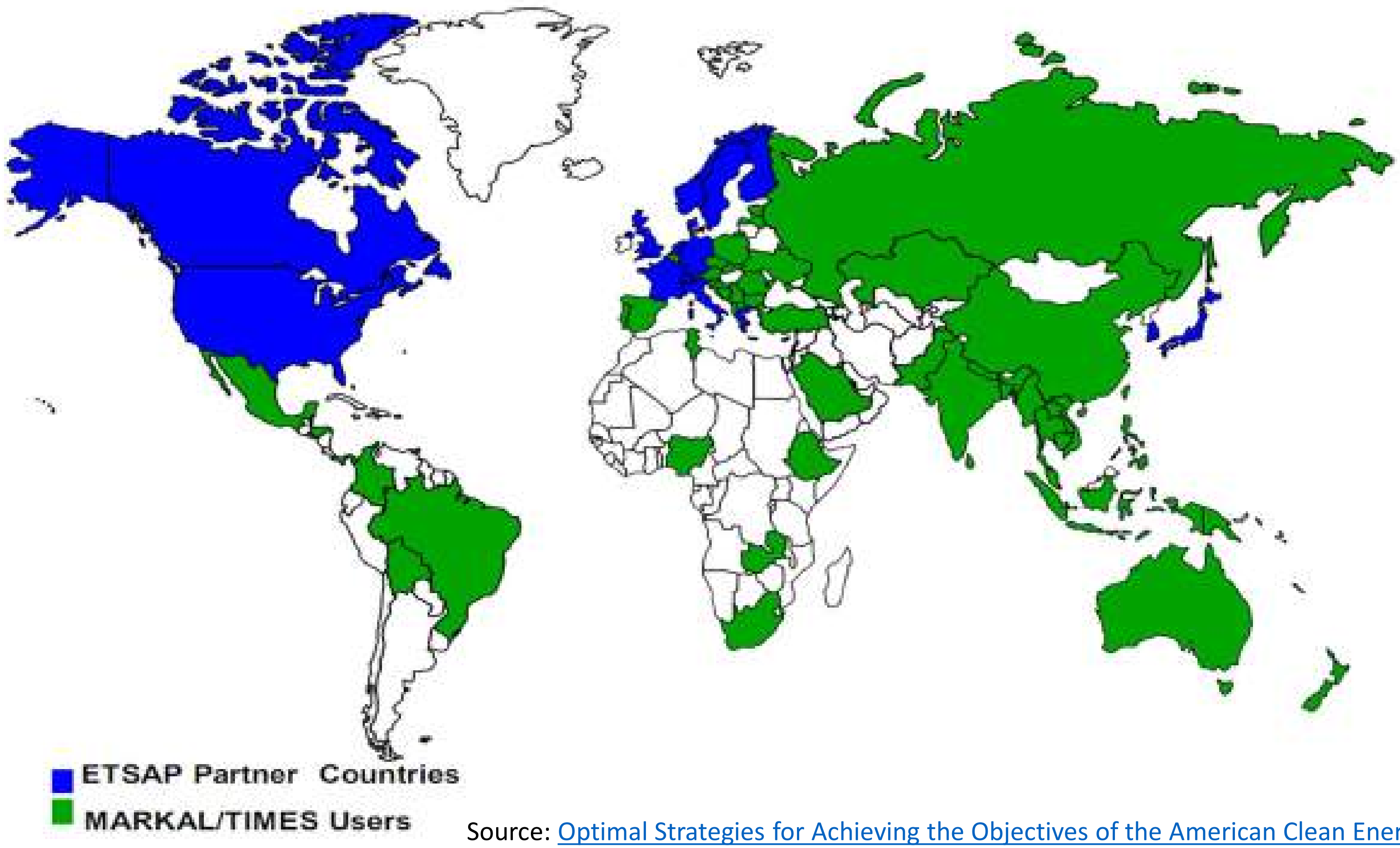
Model results

TIMES applications

Modal shifts in transport sector based on income groups (socio-economic aspects)

Source: TIMES course

TIMES Models



Source: [Optimal Strategies for Achieving the Objectives of the American Clean Energy and Security Act (decisionwaregroup.com)]

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Introduction to Uruguayan Energy System

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University of Stuttgart, Institute of Energy Economics and Rational Energy Use,
Hessbruehl Str. 49a, 70565 Stuttgart, Germany
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Troubleshooting – VEDA installation

image: ewi

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