Der Wert von Recycling für das Gelingen der deutschen Energiewende

09.09.21 | F. KULLMANN, P. MARKEWITZ, L. KOTZUR, D. STOLTEN

12. INTERNATIONALE ENERGIEWIRTSCHAFTSTAGUNG AN DER TU WIEN

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Agenda

- Motivation and Objective
- Energy System Model FINE.NESTOR
- Results
- Summary

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Motivation and Objective

Deutsches Ressourceneffizienzprogramm III

- Emphasizing role of **resource efficiency** to reach **climate goals** [1]

Die Bundesregierung

Deutsches Ressourceneffizienzprogramm (ProgRess)

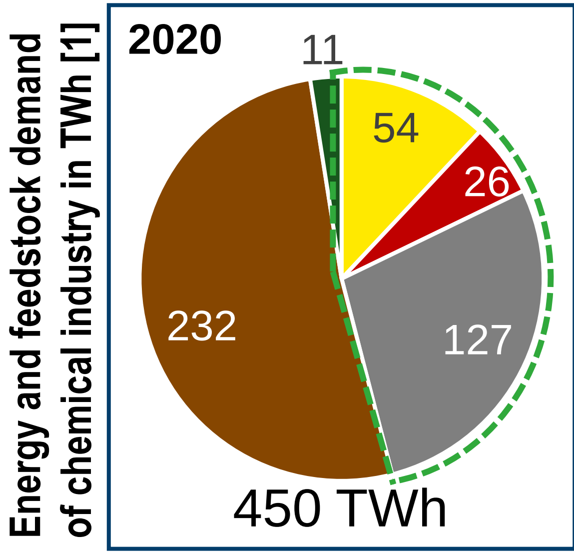
Programm zur nachhaltigen Nutzung und zum Schutz der natürlichen Ressourcen

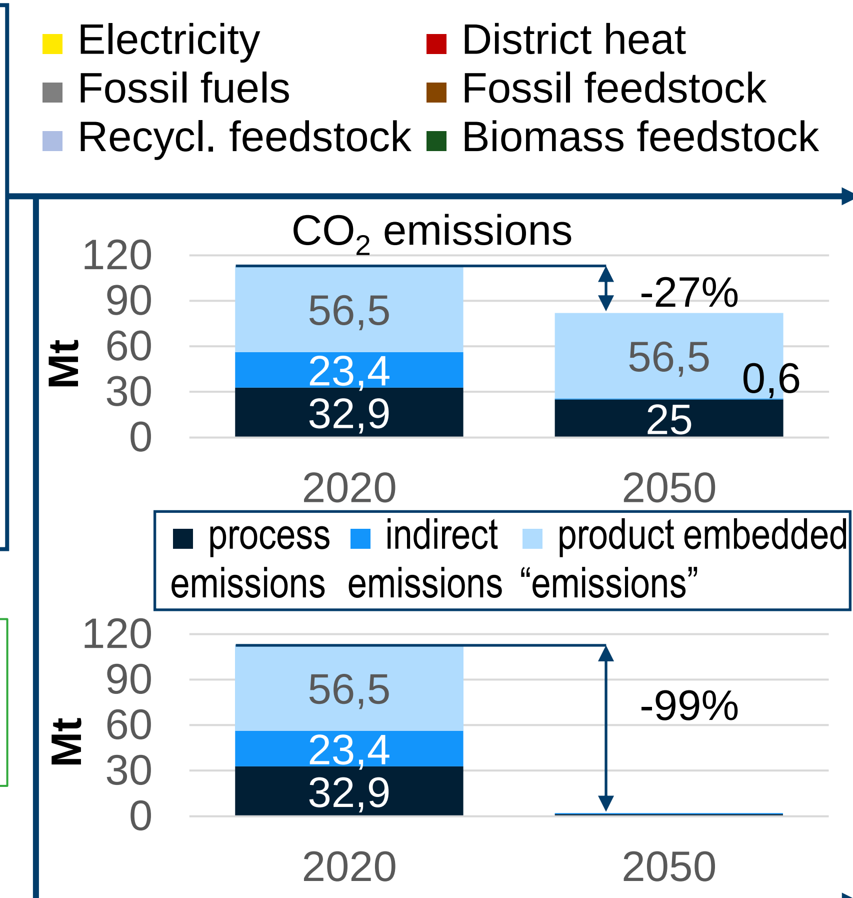
- „The chemical industry faces the challenge of **electrifying** their production processes, **close carbon cycles,** and **substitute fossil with renewable raw materials.** This requires **inter-sectoral solutions**, […] supply of **renewable electricity** and **raw materials,** expansion of **electricity and gas grids,** and addressing questions of **societal acceptance** […]“ [2]

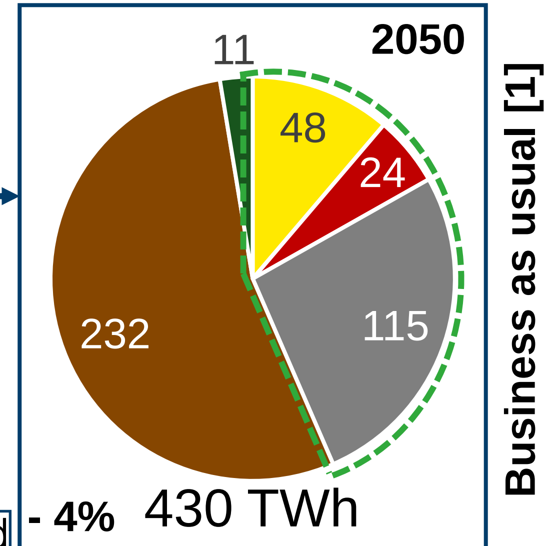
What is the impact of recycling on the German energy system?
How does the defossilization of the chemical industry affect the industrial transformation?
►Analyses of these two strategies are necessary to evaluate future…
- … primary energy demand
- … import dependency
- ... Energy system design costs
- etc.

[1] BMU 2020. Deutsches Ressourceneffizienzprogramm ProgRess III. [2] BMU-PM Nr. 086/21. 03.05.2021. Bundesumweltministerium unterstützt Chemische Industrie auf dem Weg zur Treibhausgasneutralität

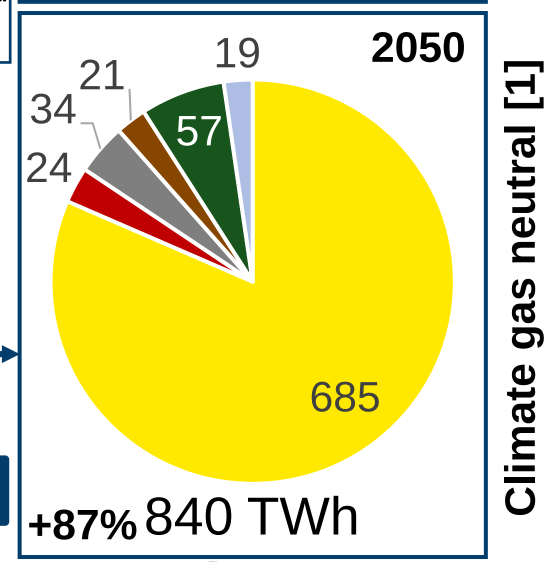
Non-energetic Demand of the Chemical Industry







▶ Energetic share considered in most energy scenarios



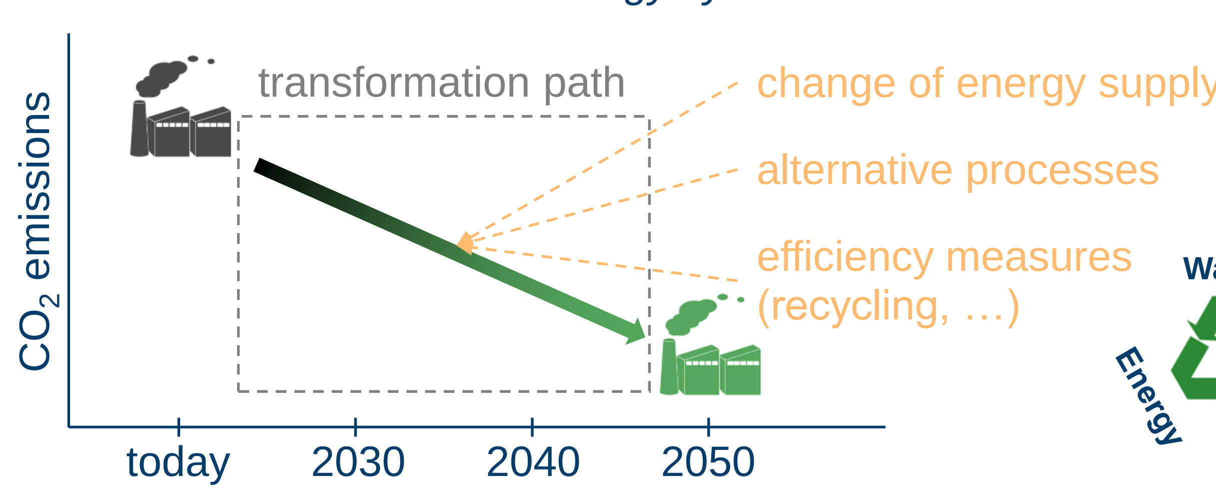
Non-energetic feedstock has a dramatic effect on the **energy system**

[1] FutureCamp Climate GmbH, DECHEMA. Roadmap Chemie 2050, München 2019.

Objective

Research Question

How does the German industry develop under the transformation towards a national low-carbon energy system in 2050?



What are cost-efficient CO_2-reduction strategies in the industry sector?

Shortcomings of current energy system models

- *Consideration of material flows*
- *Consideration of non-energetic demand*
- *Integrated recycling measures*

Journal article:
Combining the worlds of energy systems and material flow analysis: a review

[1] Kullmann et al., Combining the worlds of energy systems and material flow analysis: a review. Energy, Sustainability and Society, 2021.

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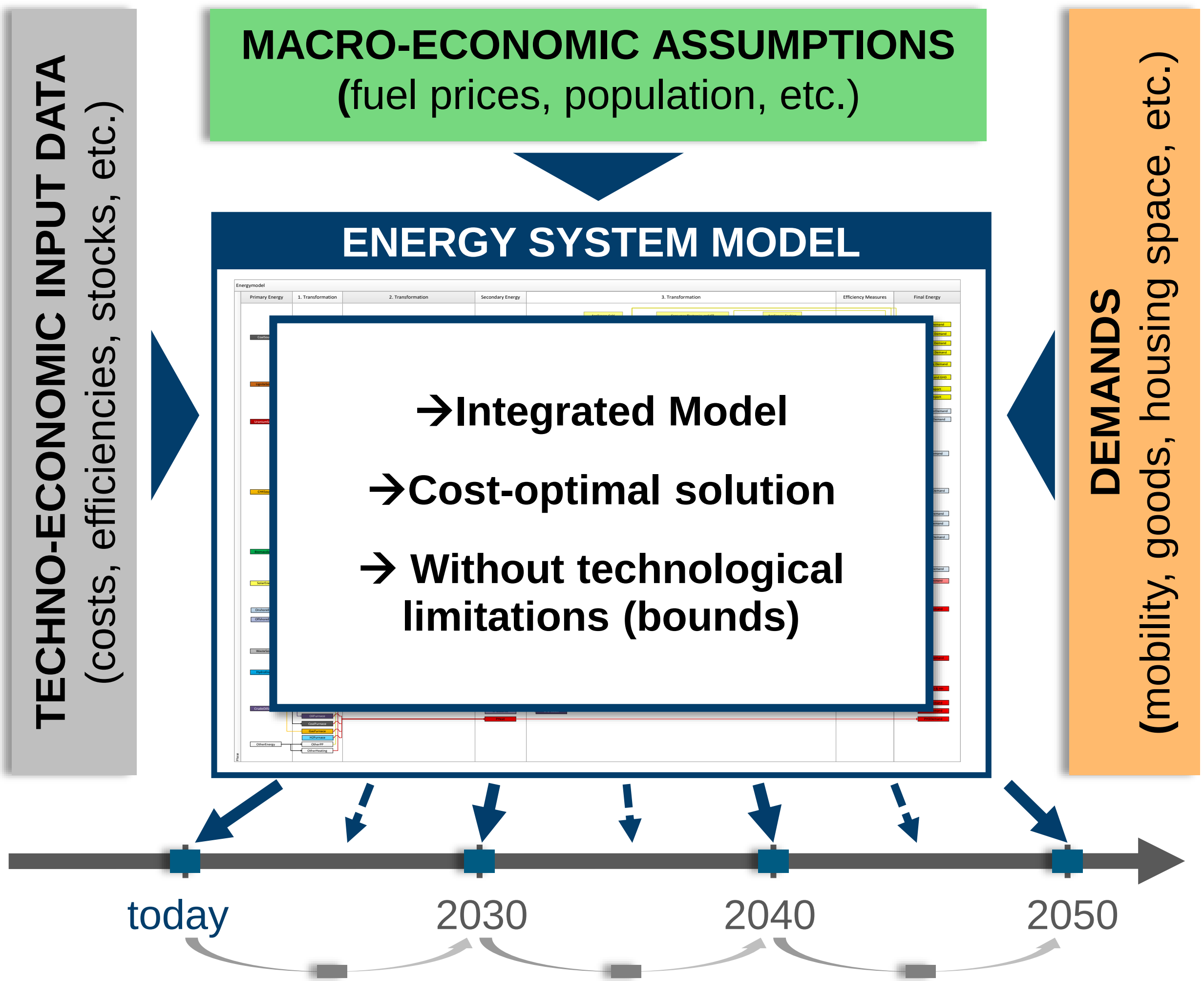
Energy System Model FINE.NESTOR [1]

'How does the least-cost future energy system of Germany look like under consideration of climate goals?'



Basic Approach

Integrated energy system model

- Hybrid bottom-up approach
- Quadratic Programming – Cost Optimization
- Myopic transition analysis
- Time series aggregation
- Temporal resolution of 1 hour
- Spatial pseudo-resolution of 9 regions

Highlights

- Detailed implementation of:
  - PtX technologies
  - Infrastructural aspects
  - Biomass allocation
  - Energy efficiency measures
  - Energy storage technologies
- Consideration of cost uncertainties
- Interaction with other models

[1] Lopion, P. et al., Cost Uncertainties in Energy System Optimization Models: A Quadratic Programming Approach of Avoiding Penny Switching Effects. Energies 2019, 12, 4006 pp.

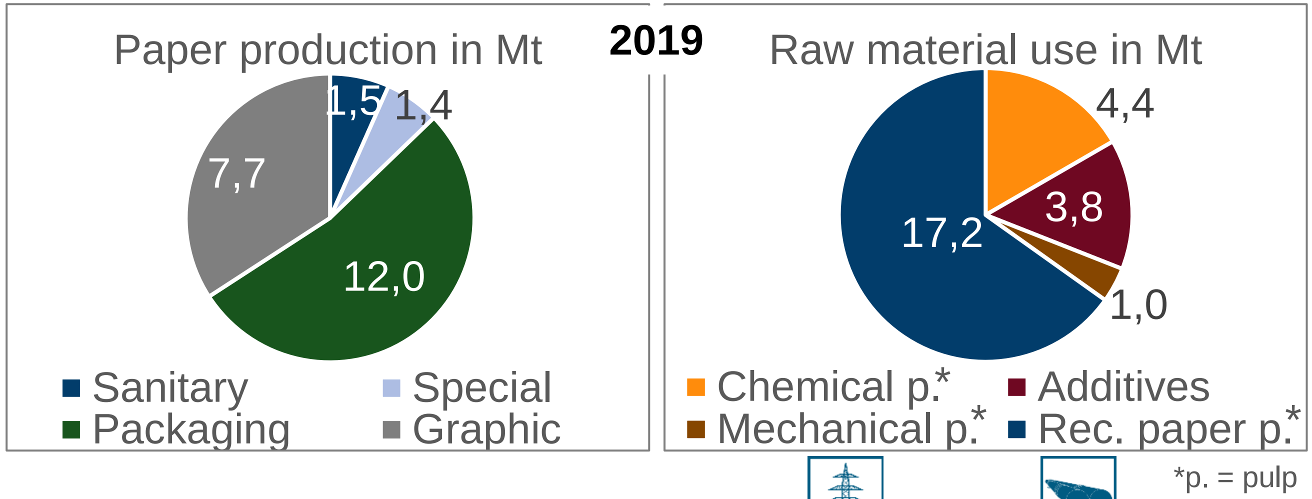
Implementation

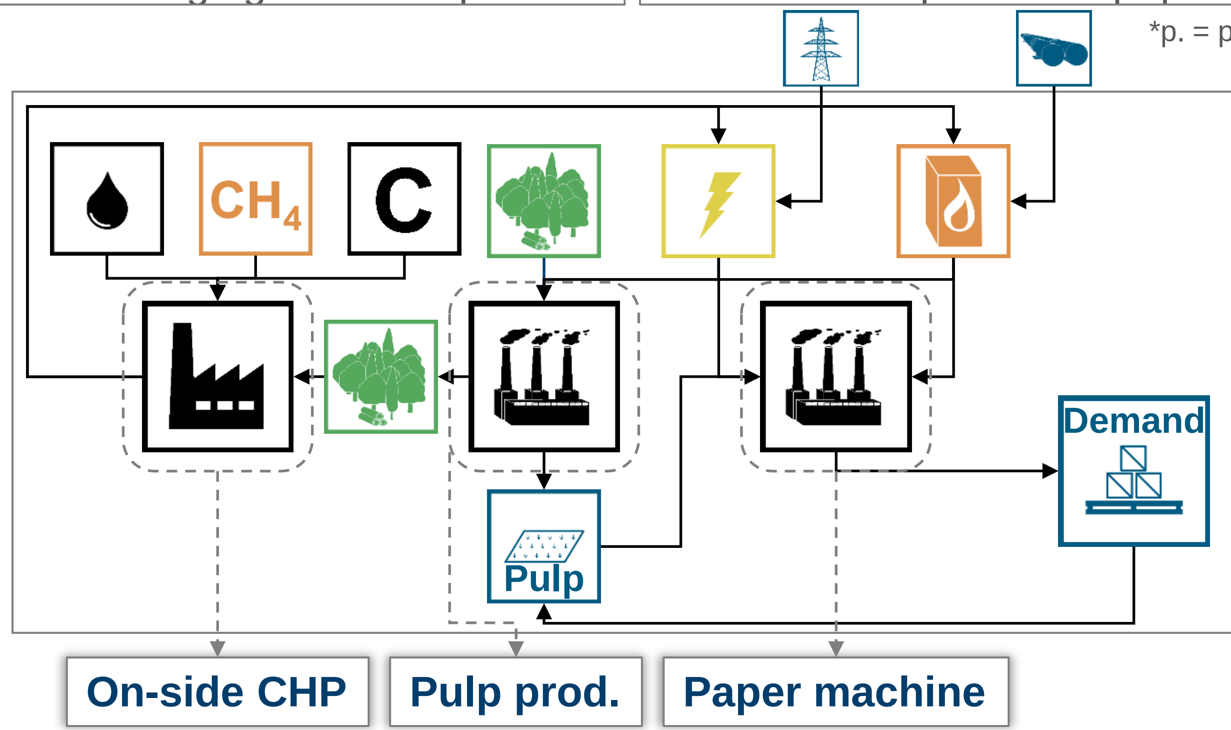
- Example: production of paper

→ Industry sector with high process heat demand **(~60 TWh final energy demand, 15.5 TWh electricity demand[1])**

→ High share of biomass-based energy use from process residues and on-side electricity production **(11 TWh residues, 7.2 TWh electricity production[1])**

→ High share of waste paper recycling **(Recycling rate is at 100% for some paper qualities[1])**





[1] Verband deutscher Papierfabriken, Papier 2019 – ein Leistungsbericht, 2019

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Scenario Definition

Reference

- -95% CO_2-emissions
- today's recycling rates
- consideration of non-energetic feedstock

Systemic effects of recycling

w/oRec

▶ No recycling allowed

Defossilization of the chemical industry

Defossilization

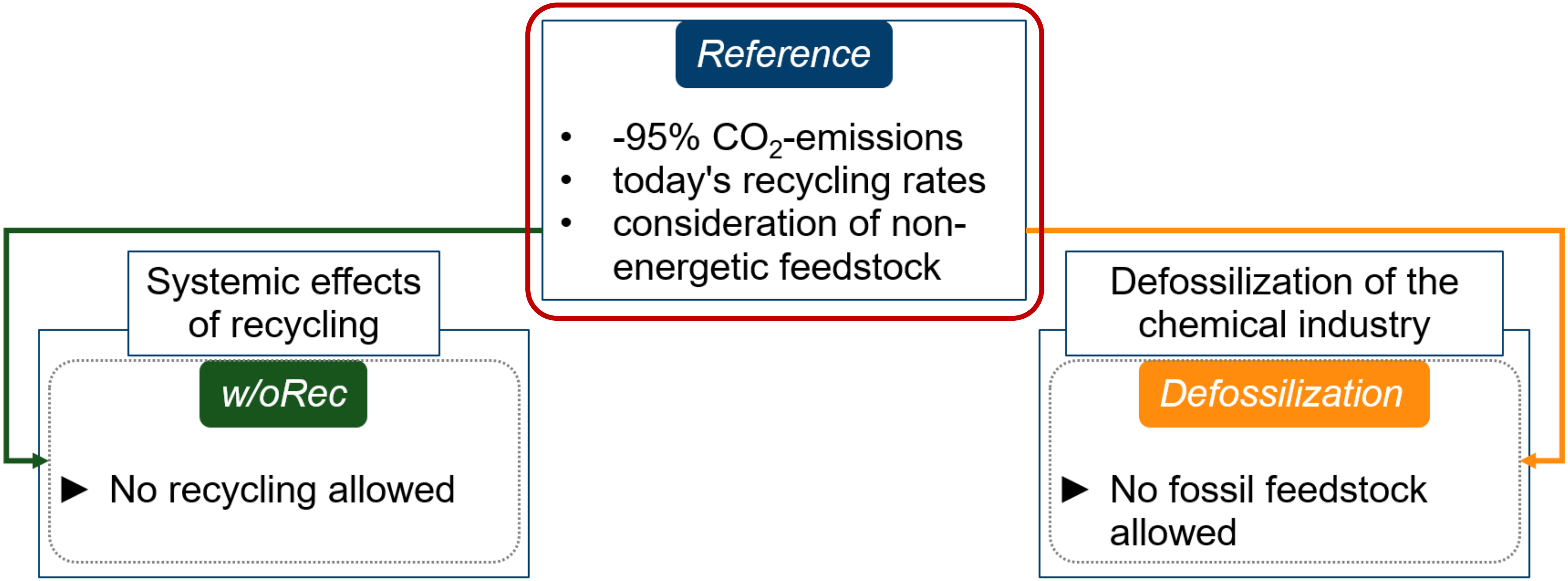
▶ No fossil feedstock allowed

Reference scenario as base line for comparison

Recycling scenario to evaluate the worth of recycling for the German energy system

Defossilization scenario to analyse the effects of feedstock substitution in the chemical industry

Scenario Definition



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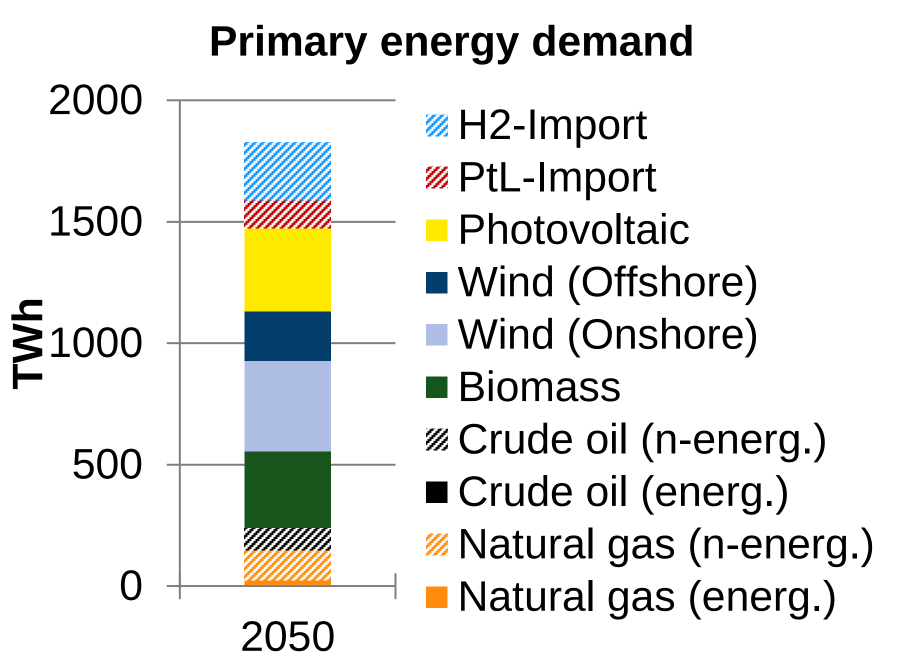
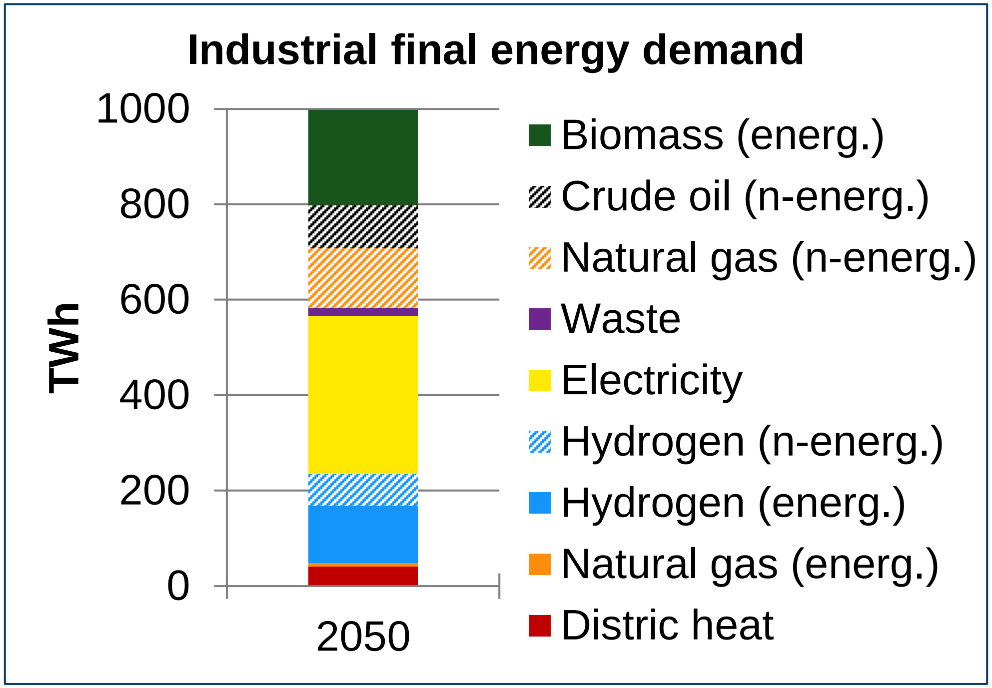
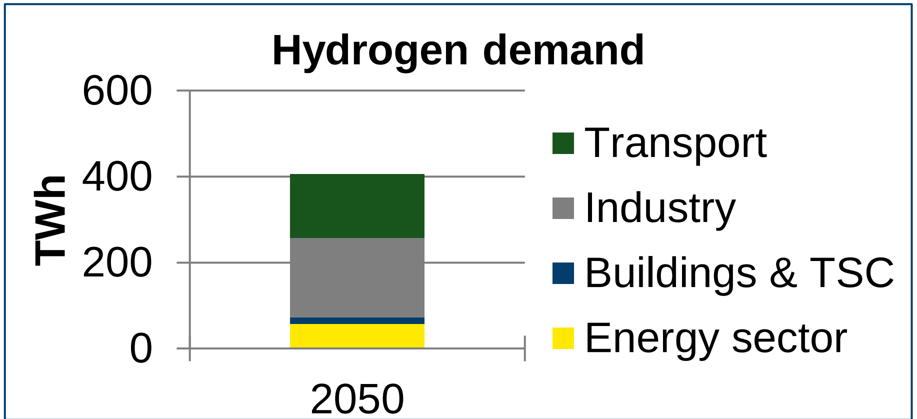
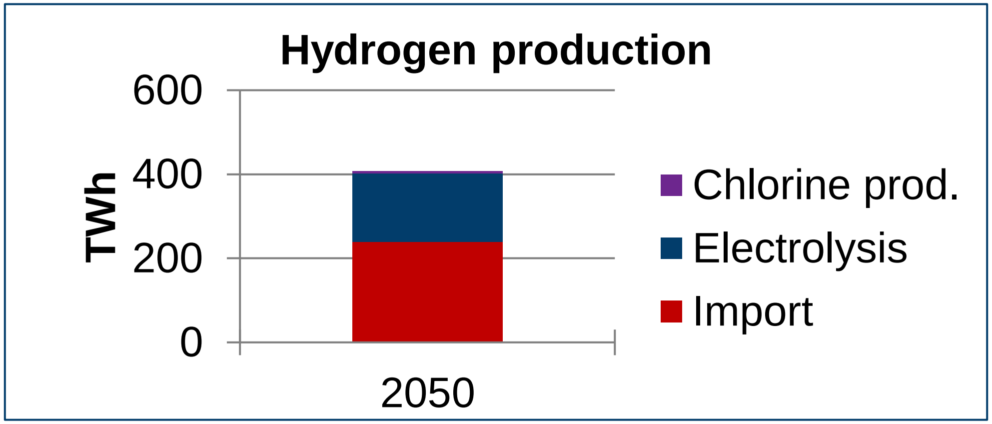
Reference Scenario – selected results









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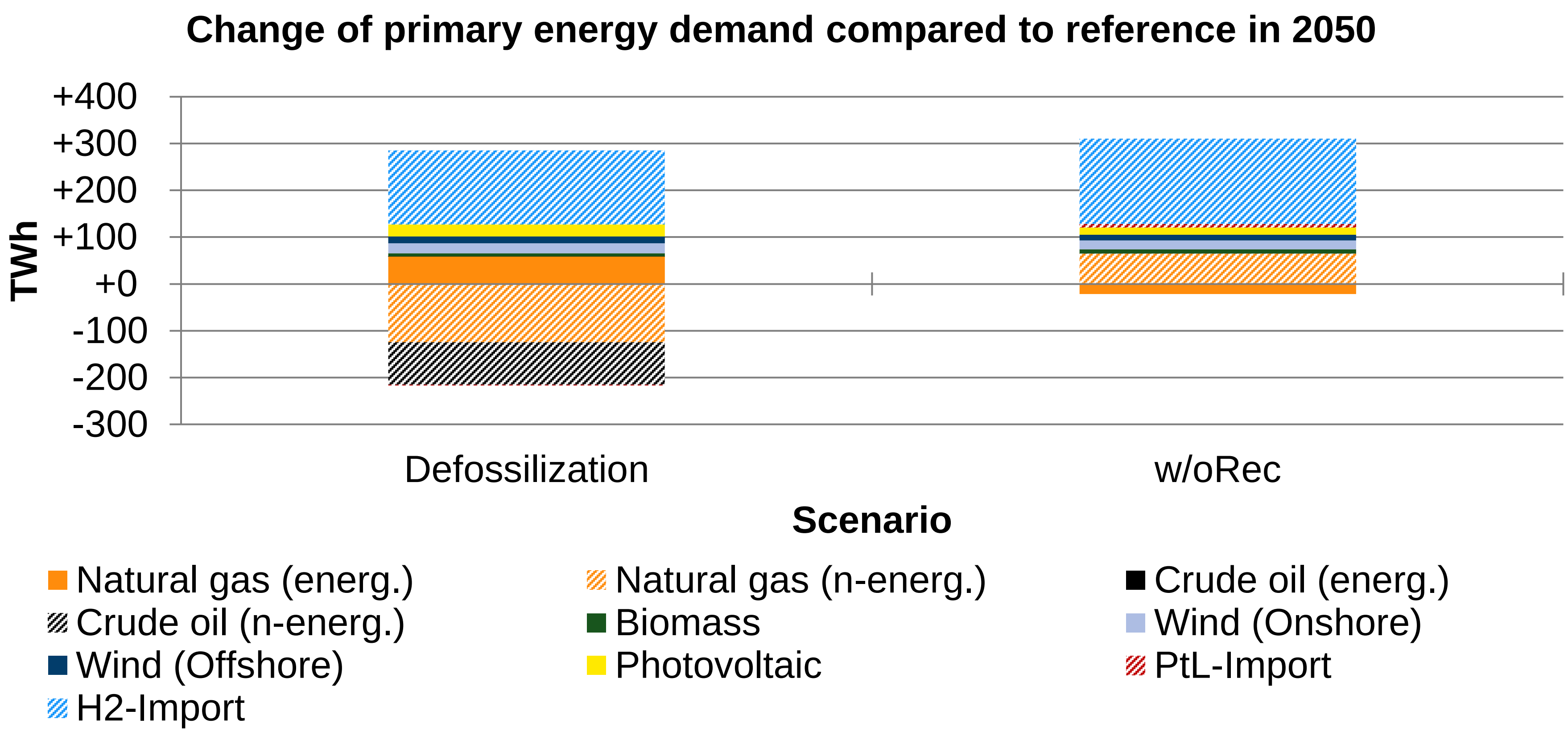
Results

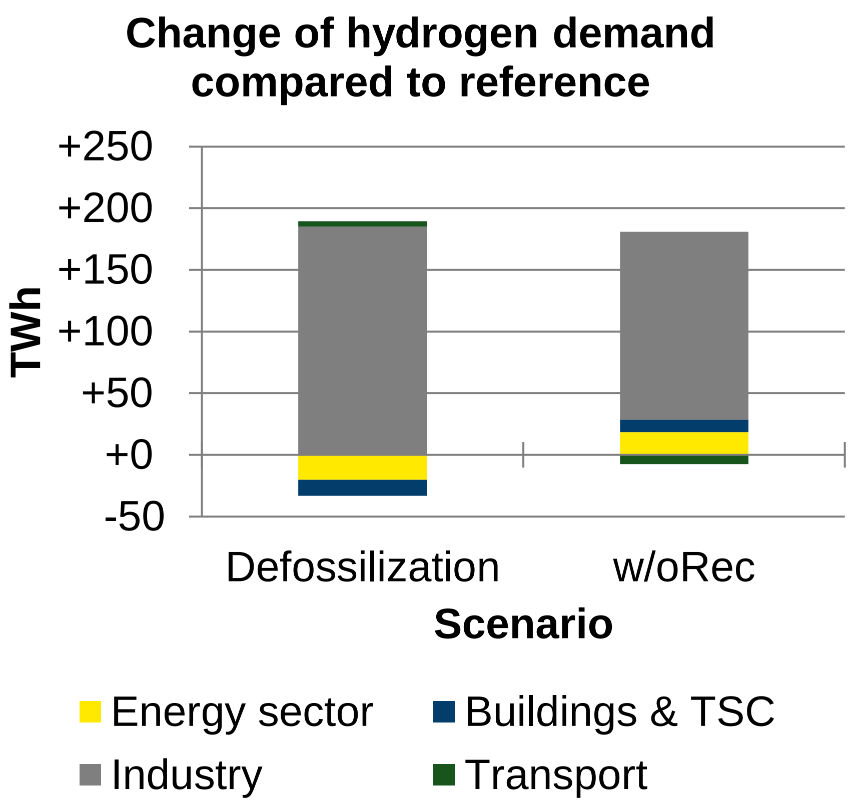
Comparison of Primary Energy Demand in 2050

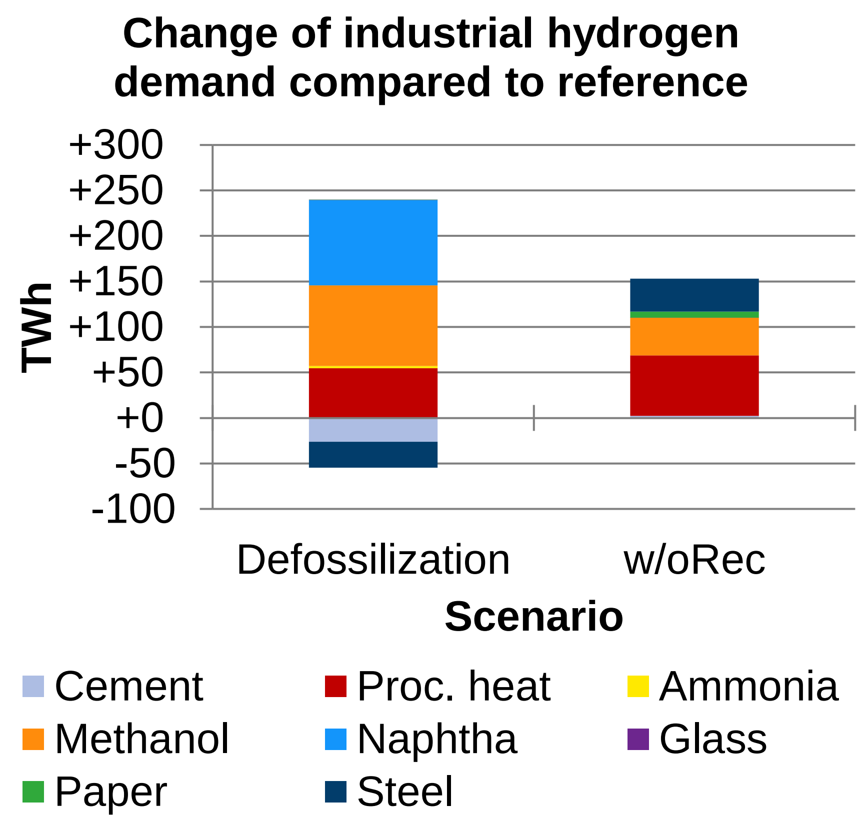


Defossilization: change of energy mix, substitute of fossil raw materials with ca. 160 TWh H_2
Without recycling: +300 TWh primary energy demand

Results

Comparison of Hydrogen Demand in 2050

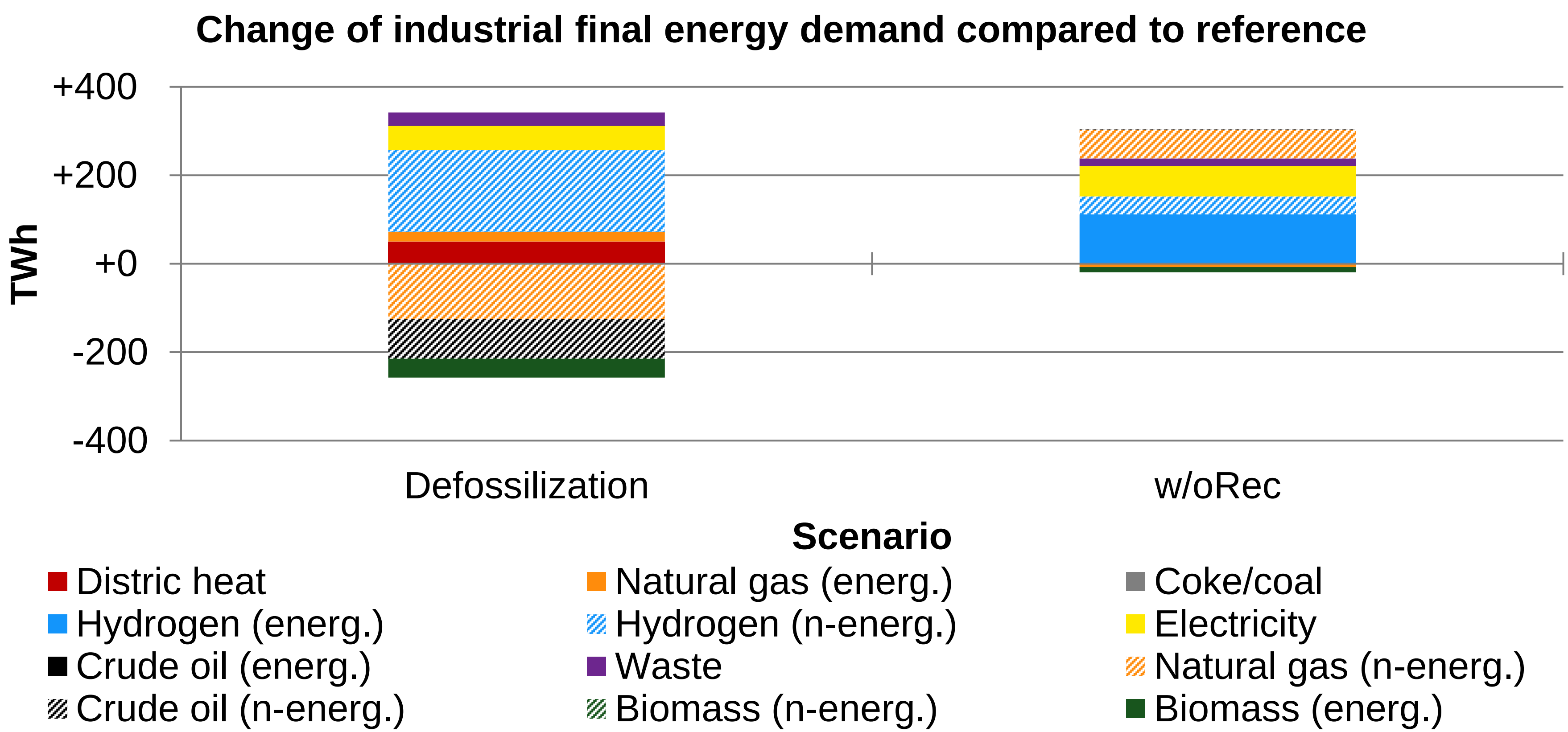




Significant increase of hydrogen demand in industry sector (+185 TWh and +152 TWh)
Defossilization leads to competition for hydrogen amongst sectors and industry branches

Results

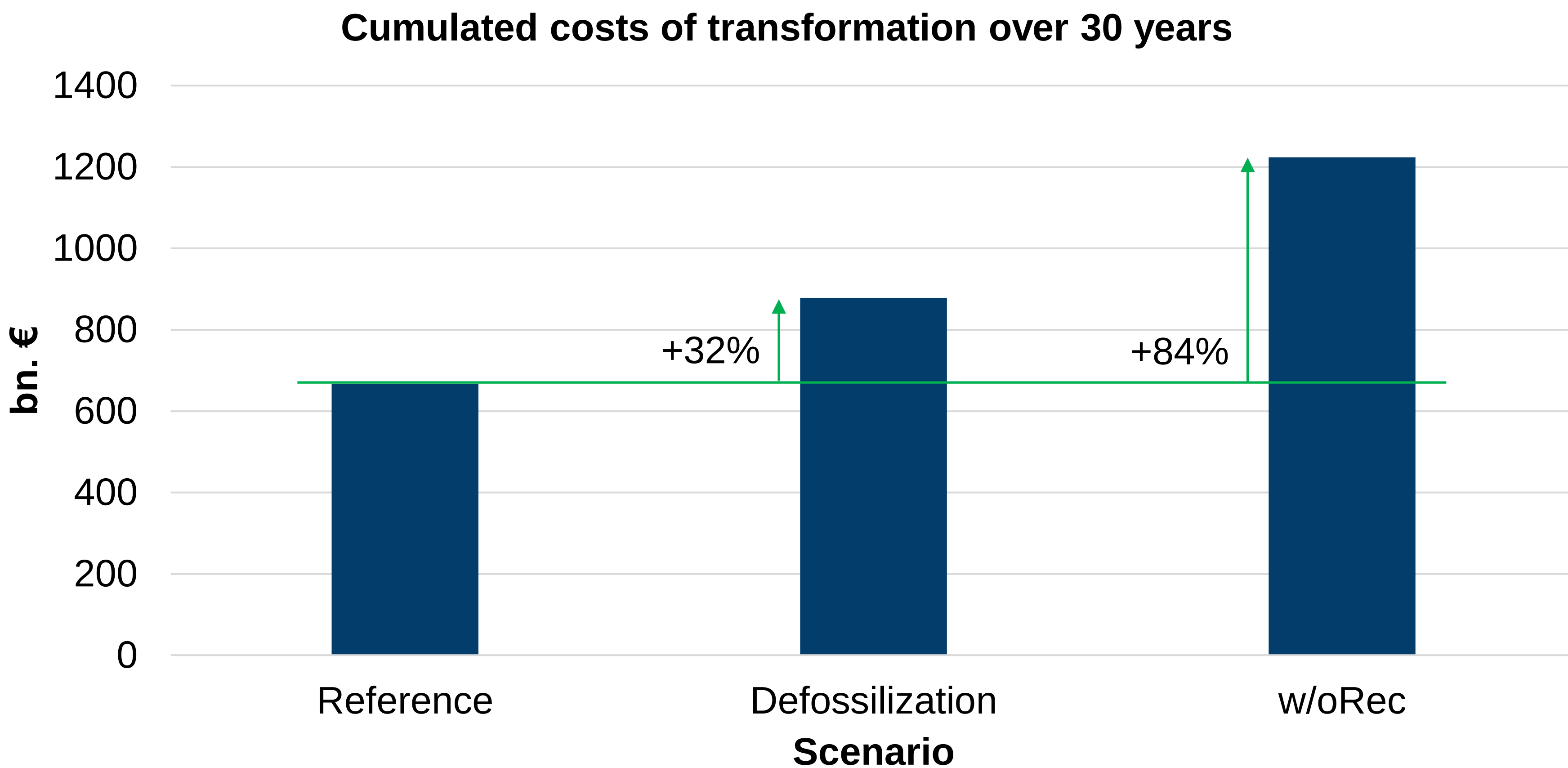
Comparison of Industrial Final Energy Demand in 2050



Defossilization: change of energy mix, no change in absolute final energy demand
Without recycling: +290 TWh (mostly hydrogen), recycling as energy efficiency measure

Results

Comparison of cumulated costs of transformation



Defossilization: cost of transformation increases by one third
Without recycling: significant increase of cost of transformation without recycling measures

Summary

Recycling

- Without recycling, there is an additional demand of 300 TWh of primary energy demand in 2050
- The industrial hydrogen demand increases to 350 TWh (+150 TWh compared to reference
  - Steel production requires 36 TWh more hydrogen compared to the reference scenario
  - Additional 41 TWh of hydrogen is needed for methanol production compared to reference
- In contrast to the reference case, the cumulative costs of transformation increase by an additional 84%, or €557 billion.

Defossilization

- The entire non-energy demand for natural gas and crude oil is replaced by hydrogen
- Hydrogen demand in steel production decreases by 29 TWh compared to the reference in favor of higher hydrogen demand in the chemical industry (+89 TWh H_2 for methanol production)
- The hydrogen demand of the total energy system increases by 160 TWh (provided via import)
- In contrast to the reference case, the cumulative costs of transformation increase by an additional 32%, or €212 billion