LIFE CYCLE ASSESSMENT OF THE INTEGRATED PRODUCTION OF STEEL AND CHEMICALS

Berlin, October 28, 2020

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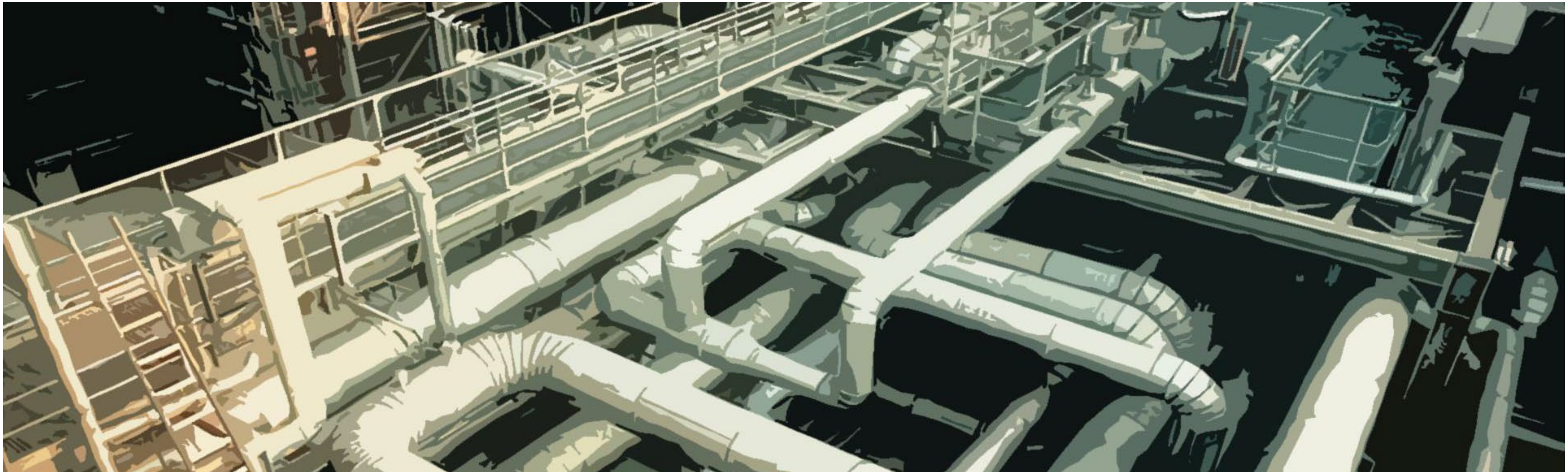


Goal and scope

Goal

- Comparative life cycle assessment of the integrated production of steel and chemicals in comparison to stand-alone production

Investigated scenarios

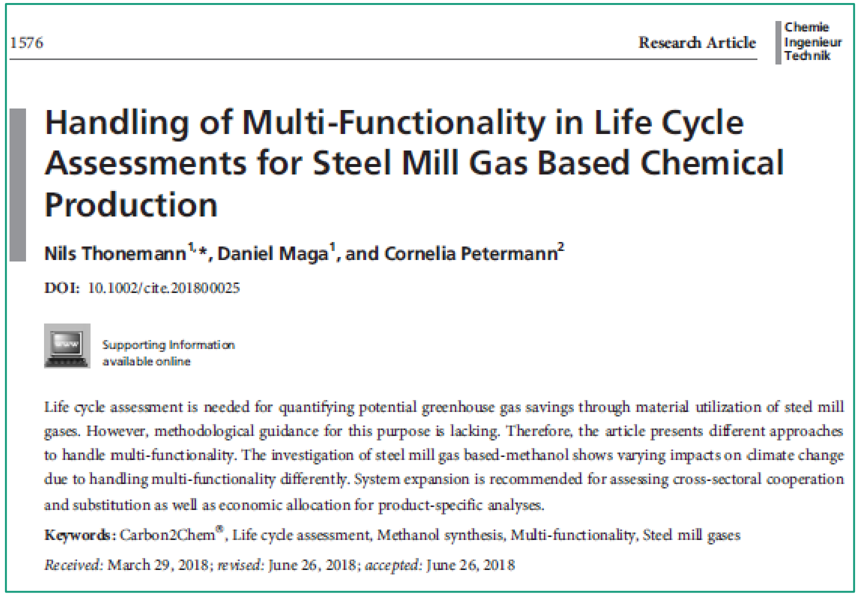
- Integrated production of steel and
  - Methanol
  - Urea
  - Higher alcohols
  - Methanol and polycarbonates

Quelle: Thyssen Krupp
https://www.thyssenkrupp-steel.com/de/
https://steelguru.com/steel/thyssenkrupp-presents-innovative-concept-for-green-transformation-of-duisburg-steel-mill/562765#

Quelle: [MEV-Verlag]

System boundary

Handling of multi-functionality


1576 Research Article Chemie Ingenieur Technik

Handling of Multi-Functionality in Life Cycle Assessments for Steel Mill Gas Based Chemical Production

Nils Thonemann[1,*], Daniel Maga[1], and Cornelia Petermann[2]

DOI: 10.1002/cite.201800025

Supporting Information available online

Life cycle assessment is needed for quantifying potential greenhouse gas savings through material utilization of steel mill gases. However, methodological guidance for this purpose is lacking. Therefore, the article presents different approaches to handle multi-functionality. The investigation of steel mill gas based-methanol shows varying impacts on climate change due to handling multi-functionality differently. System expansion is recommended for assessing cross-sectoral cooperation and substitution as well as economic allocation for product-specific analyses.

Keywords: Carbon2Chem®, Life cycle assessment, Methanol synthesis, Multi-functionality, Steel mill gases

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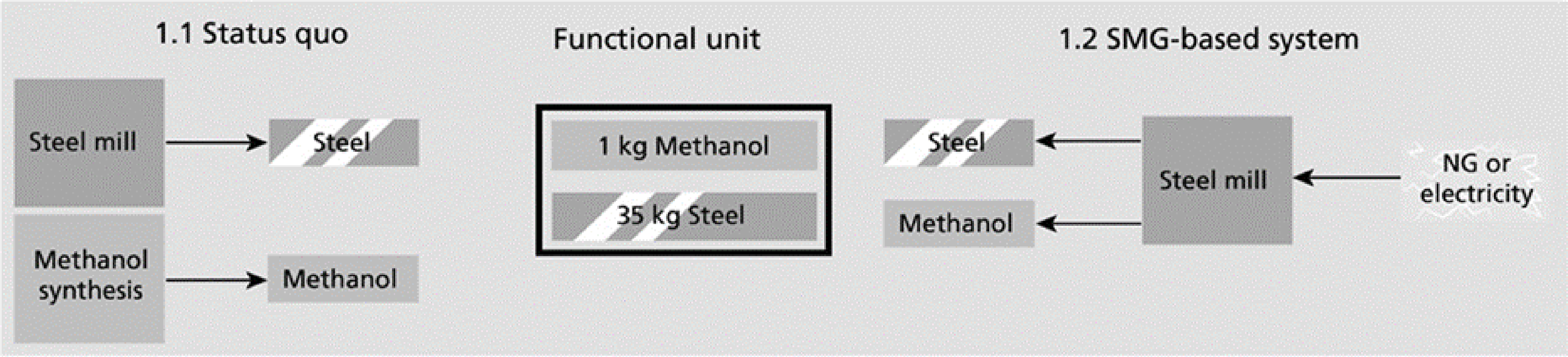
Approach to compare stand-alone production of steel and chemicals with integrated production

- System expansion
  - Functional unit covers steel and chemical production

Example of steel and methanol production



Thonemann, Nils; Maga, Daniel; Petermann, Cornelia (2018): Handling of Multi-Functionality in Life Cycle Assessments for Steel Mill Gas Based Chemical Production. In Chemie Ingenieur Technik 103 (2), p. 469. DOI: 10.1002/cite.201800025.

SMG = Steel Mill Gas
NG = Natural Gas

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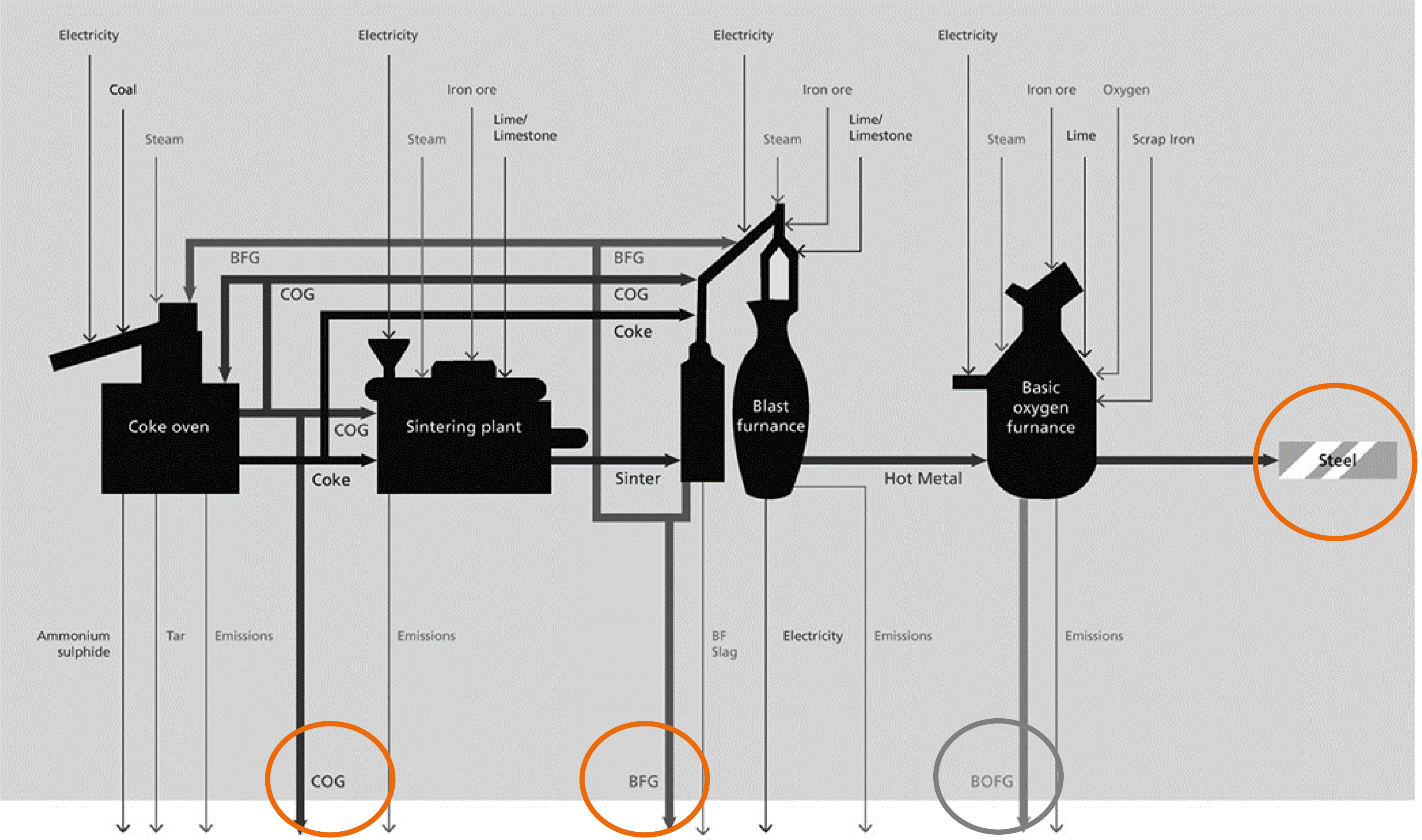
System boundaries of integrated steel mill

- Main inputs
  - Iron ore
  - Coal
  - Steam
  - Lime
  - Oxygen
- Produced steel mill gases (SMG)
  - Blast furnace gas (BFG)
  - Basic oxygen furnace gas (BOFG)
  - Coke oven gas (COG)



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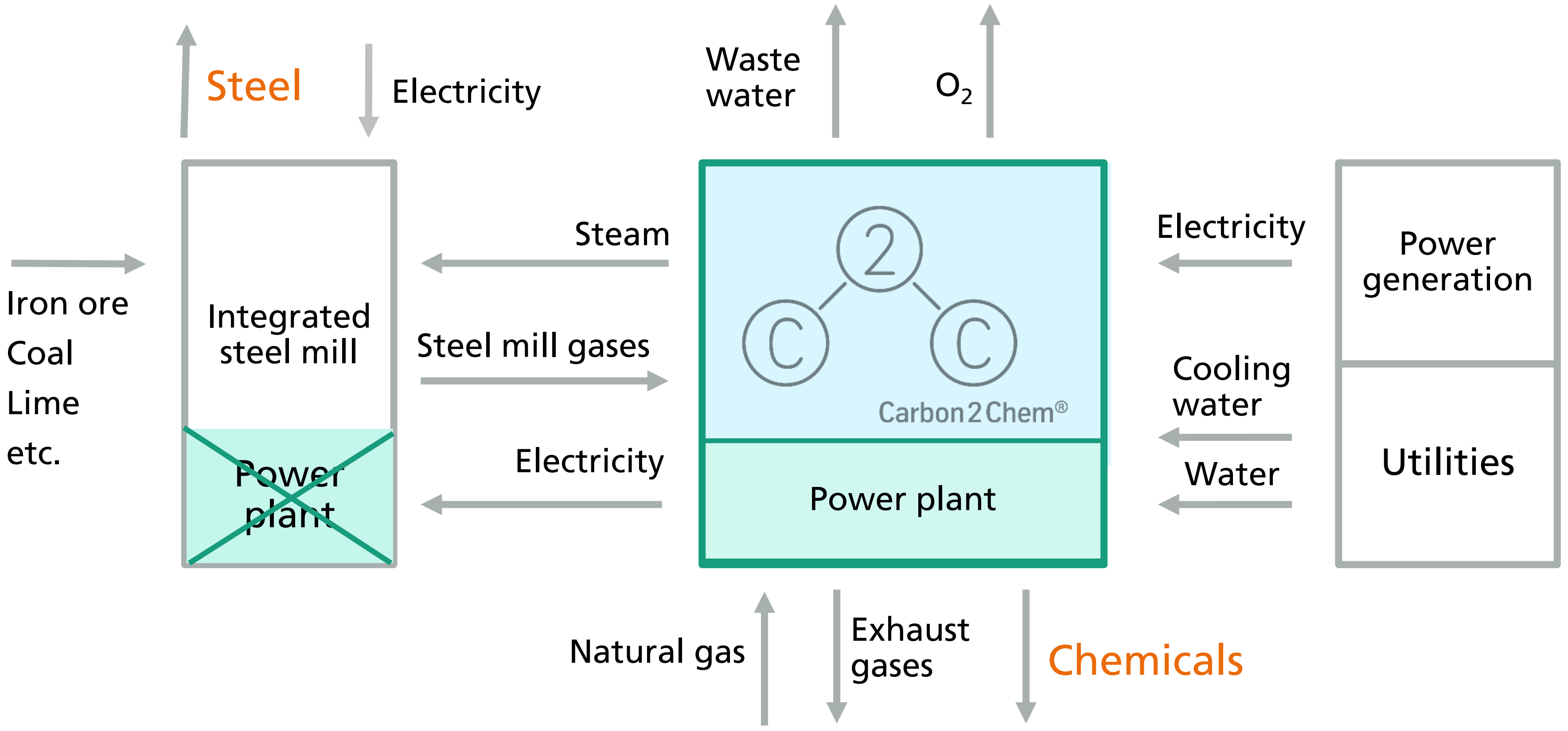
System boundaries of integrated steel and chemical production

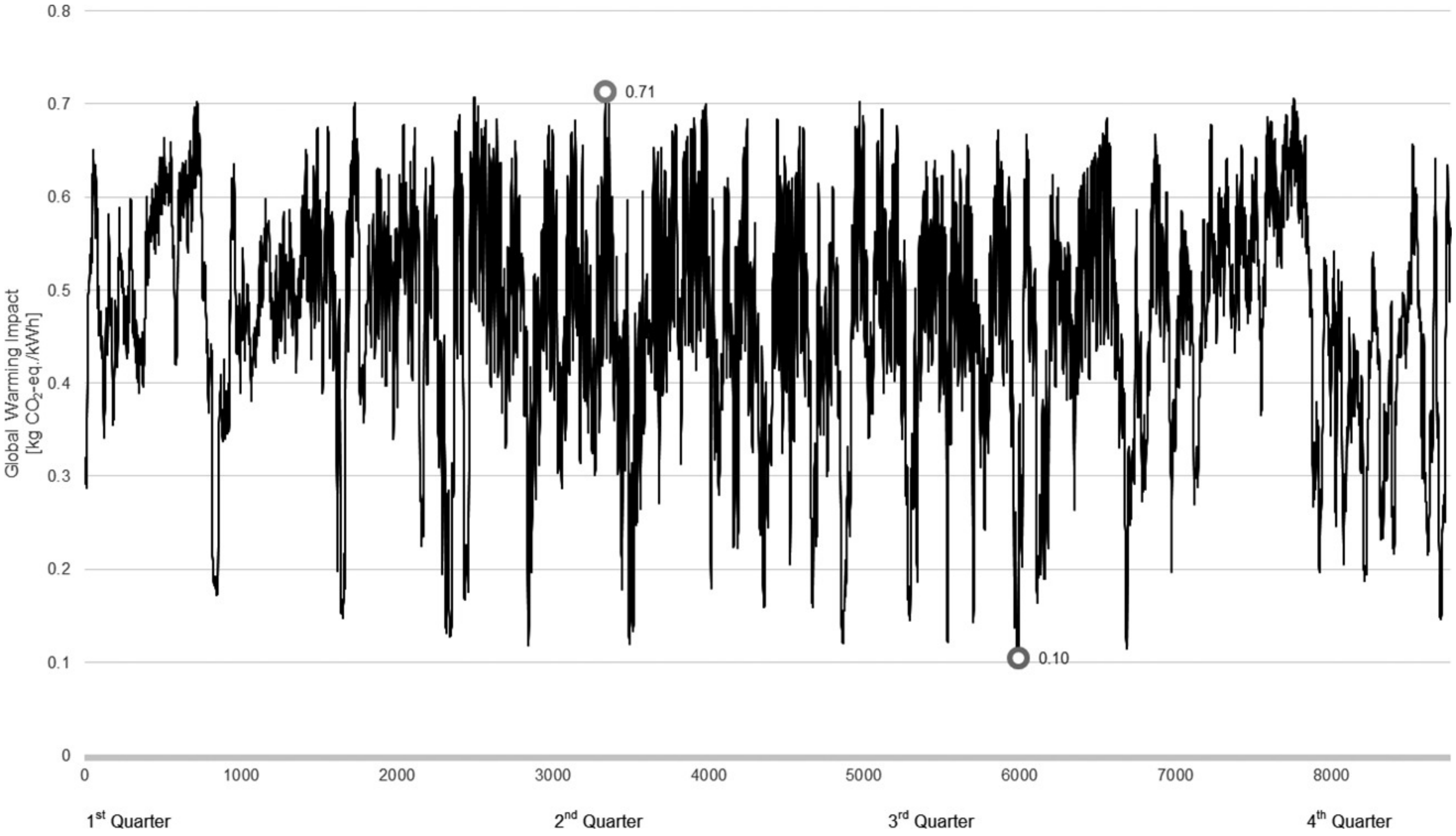
- Electricity from the power plant is used in integrated steel mill
- Additional electricity demand is supplied
  - by the grid mix in 2030 (ESDP*)
  - by wind power (wind)



* ESDP = Energy System Development Plan

Power supply

- Data from Energy System Development Plan (ESDP)
  - tool to calculate energy generation, consumption, and conversion flows for a concrete national or regional energy system
  - Time horizon 2030
- Average Carbon Footprint ~ 0.5 kg CO_2-eq./kWh
- Alternatively wind power



Thonemann, Nils; Maga, Daniel; Petermann, Cornelia (2018): Integration of Results from the Energy System Development Plan into Life Cycle Assessment. In Chemie Ingenieur Technik 23 (11), p. 11386. DOI: 10.1002/cite.201800117.

Data basis for the life cycle assessment
Process simulations

1. Process-technology model (PT)
   - precise modeling of the reactors links this model to a dynamic process simulation of the network
2. Co-Simulation (CS)
   - links sub models of several academic and industrial partners within the Carbon2Chem® project via the internet to a cross-industrial network simulation
3. Process-logistics model (PLM)
   - mixed-integer linear programming model that focuses on the precise simulation of the management and supply of energy and materials between units

Investigated scenarios
Main assumptions

- Basic assumptions for all simulation models
  - About 8.5 Mio. tons of steel mill gases (SMG) are directed to the Carbon2Chem® facilities and are avoided in the power plant of the integrated steel mill (BFG and COG)
  - No changes in the operation of the integrated steel mill
- Scenarios
  - Jumbo: 8.5 Mio. tons of SMG are directed to chemical production
  - Industrial: Only a small part of SMG is directed to chemical production, rest goes to power plant
  - COG max: The entire COG is used for chemical production
  - Watergas shift reaction (WGS): Additional reactor to shift CO to CO_2 and H_2 (higher yields vs. additional process unit)

SMG = Steel Mill Gas
COK = Coke Oven Gas

Functional unit in the case of methanol production

- The functional unit refers to the steel production in Duisburg in 2016 and the investigated scenario
  - 8.4 Mio. t steel per year
  - 0.3 – 5.8 Mio. t methanol per year
- Reference: Average methanol production mix of Germany
  - Synthesis gas for methanol production is produced by steam reforming and partial combustion

https://www.thyssenkrupp-steel.com/de/

8.4 Mio. t steel

https://steelguru.com/steel/thyssenkrupp-presents-innovative-concept-for-green-transformation-of-duisburg-steel-mill/562765#

0.3 – 5.8 Mio. t methanol

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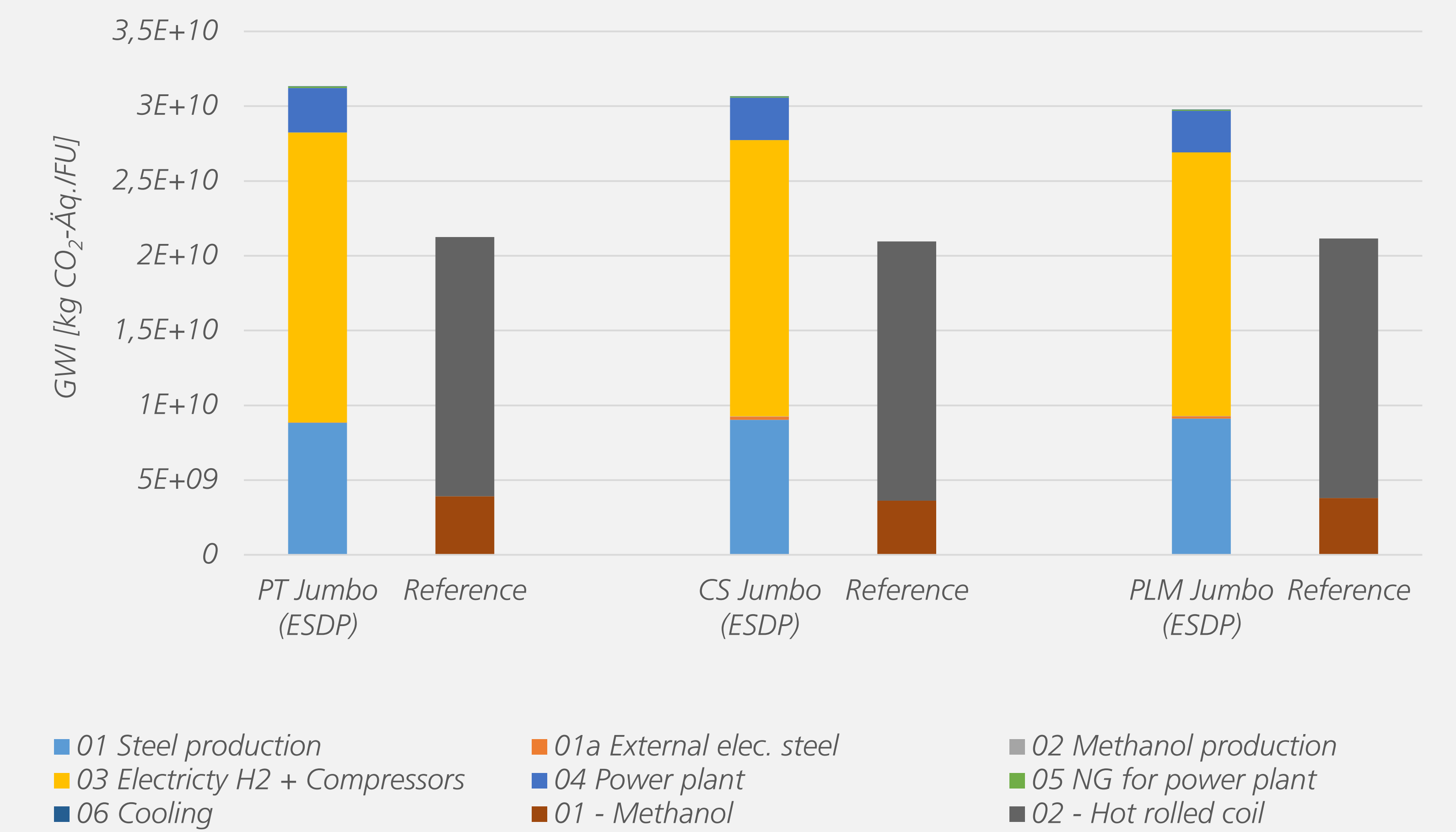
Further assumptions

- Emissions of the integrated steel mill are reduced by the use of steel mill gases
- Total CO_2 emissions of the integrated steel mill incl. prechains: approx. 17 Mio. t per year
- Avoided greenhouse gas emissions by utilization of SMG in Carbon2Chem® are calculated through 100 % conversion of SMG to CO_2
- Steam produced in new power plant covers the entire steam demand of the integrated steel mill
- Not considered processes
  - Waste water treatment
  - Gas purification for watergas shift reaction
  - Catalysts
  - Transport of hydrogen

SMG = Steel Mill Gases

Results for methanol jumbo scenarios (ESDP mix 2030)
Global warming impact

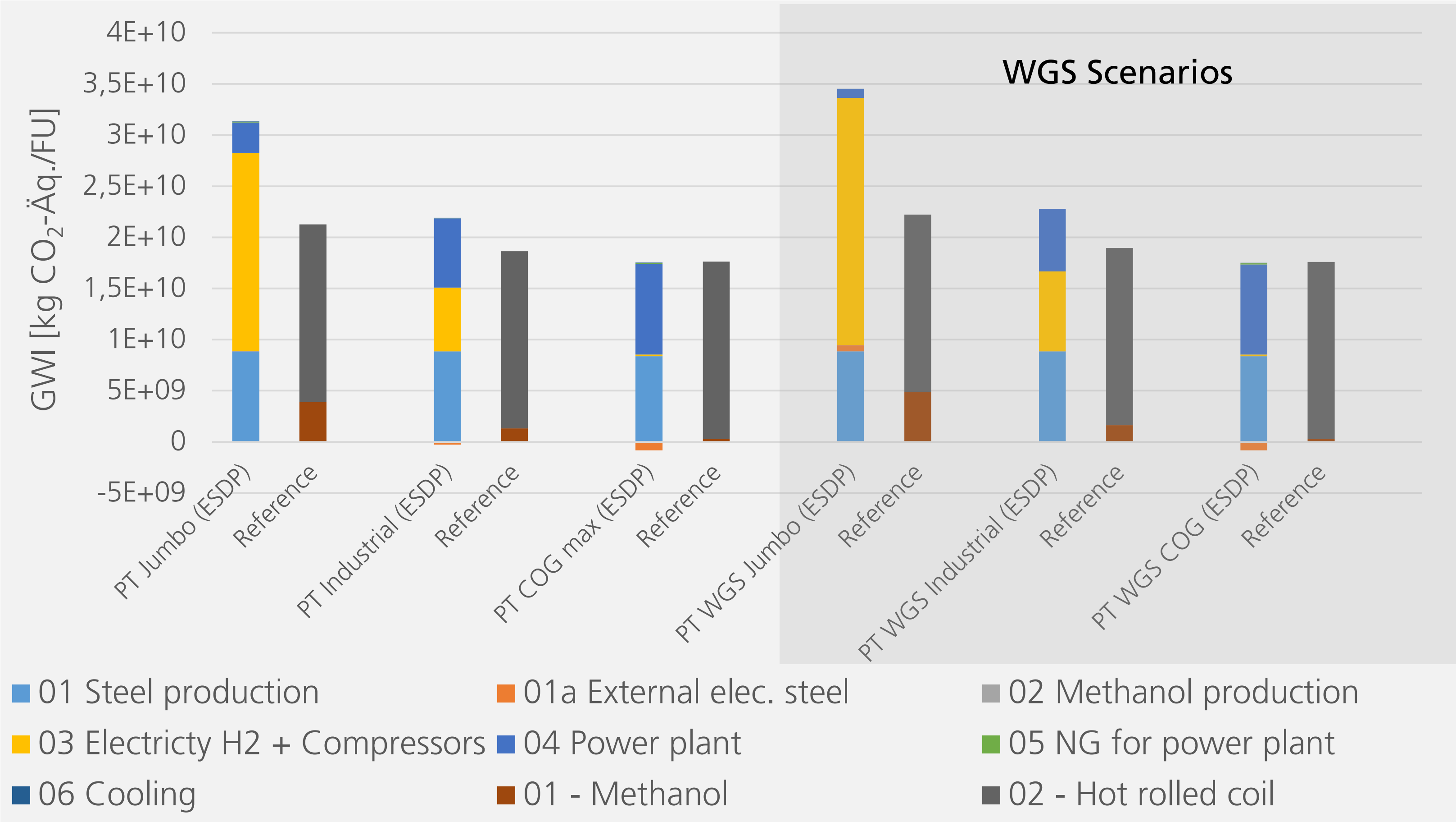
- Products
  - ~ 4.1 – 4.4 Mio. t methanol and 8.4 Mio. t steel
  - Jumbo scenario
- Different simulation tools lead to similar results
- Integrated production of steel and methanol shows higher GWI compared to stand-alone production



GWI = Global Warming Impact;
ESDP = Energy System Development Plan

Results for methanol | Various scenarios (ESDP mix 2030)
Global warming impact

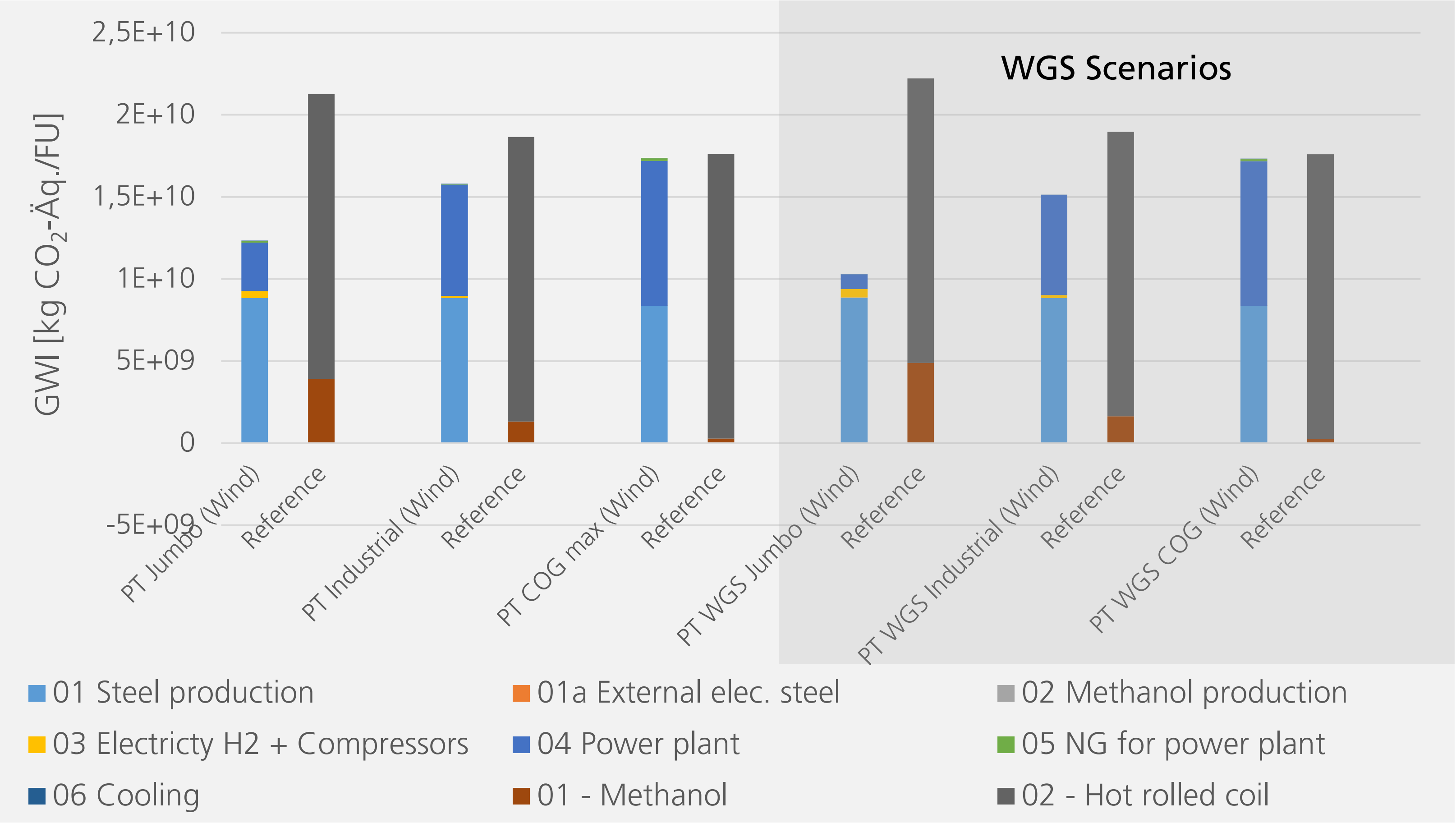
- Products
  - ~ 0.3 - 5.8 Mio. t methanol and 8.4 Mio. t steel
- Industrial scenario
  - Less methanol and less H_2 demand
- COG max scenarios
  - No external H_2 demand (similar to reference)
- WGS scenarios slightly better



GWI = Global Warming Impact
ESDP = Energy System Development Plan

Results for methanol (Wind power)
Global warming impact

- Products
  - ~ 0.3 - 5.8 Mio. t methanol and 8.4 Mio. t steel
- Power provided by wind
- Integrated production of steel and methanol shows smaller global warming impact compared to stand-alone production



GWI = Global Warming Impact
NG = Natural Gas

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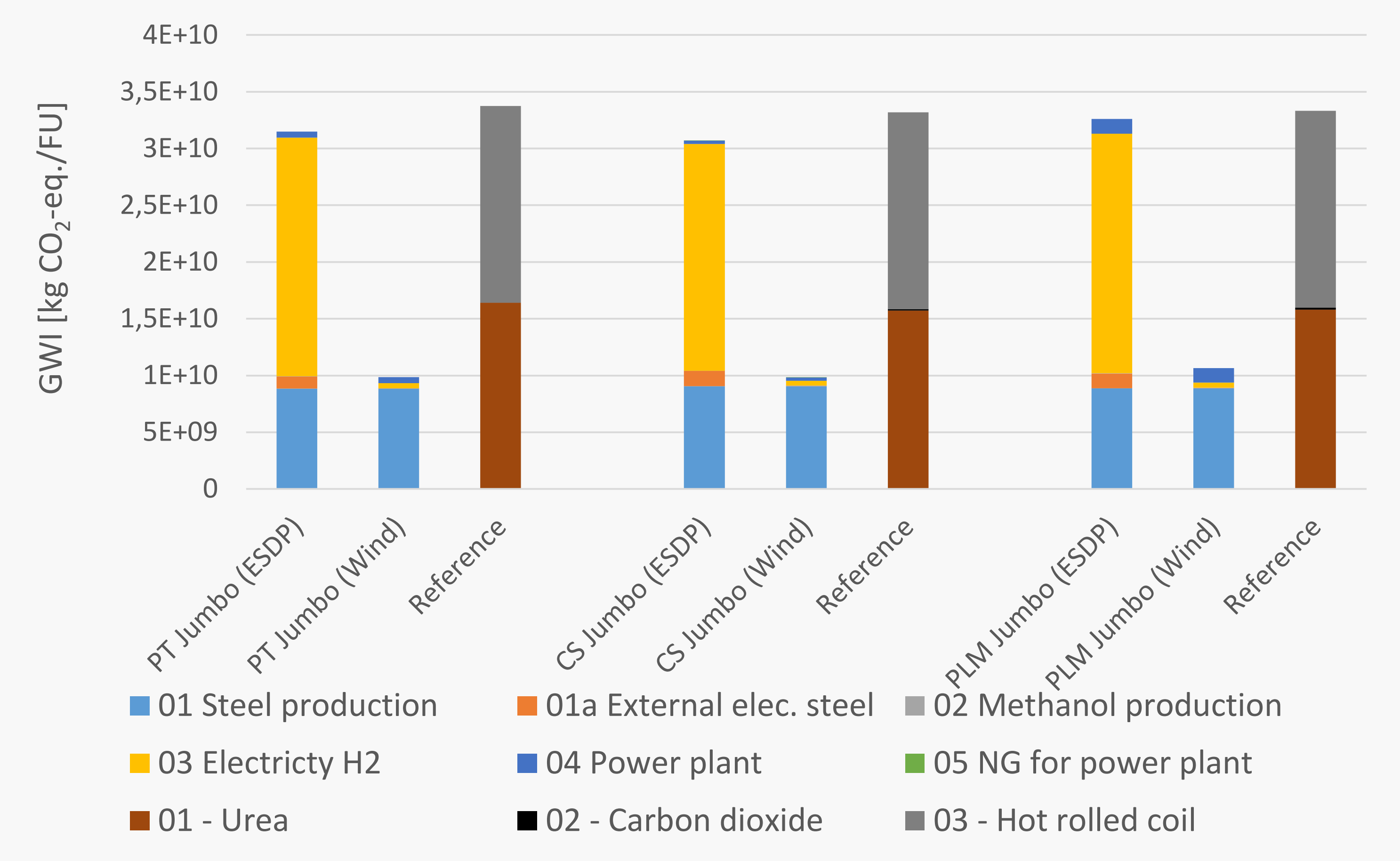
Results for urea
Global warming impact

- Products
  - ~ 10 Mio. t urea and 8.4 Mio. t steel
- Cooling was not modelled due to lacking data
- GWI of urea production smaller than reference
- In the case of ESPD, electricity contributes to approx. 65 % of the GWI
- GWI of urea production with wind power approx. 1/3 of GWI



GWI = Global Warming Impact

PT = Process-technology model
CS = Co-Simulation
PLM = Process-logistics model

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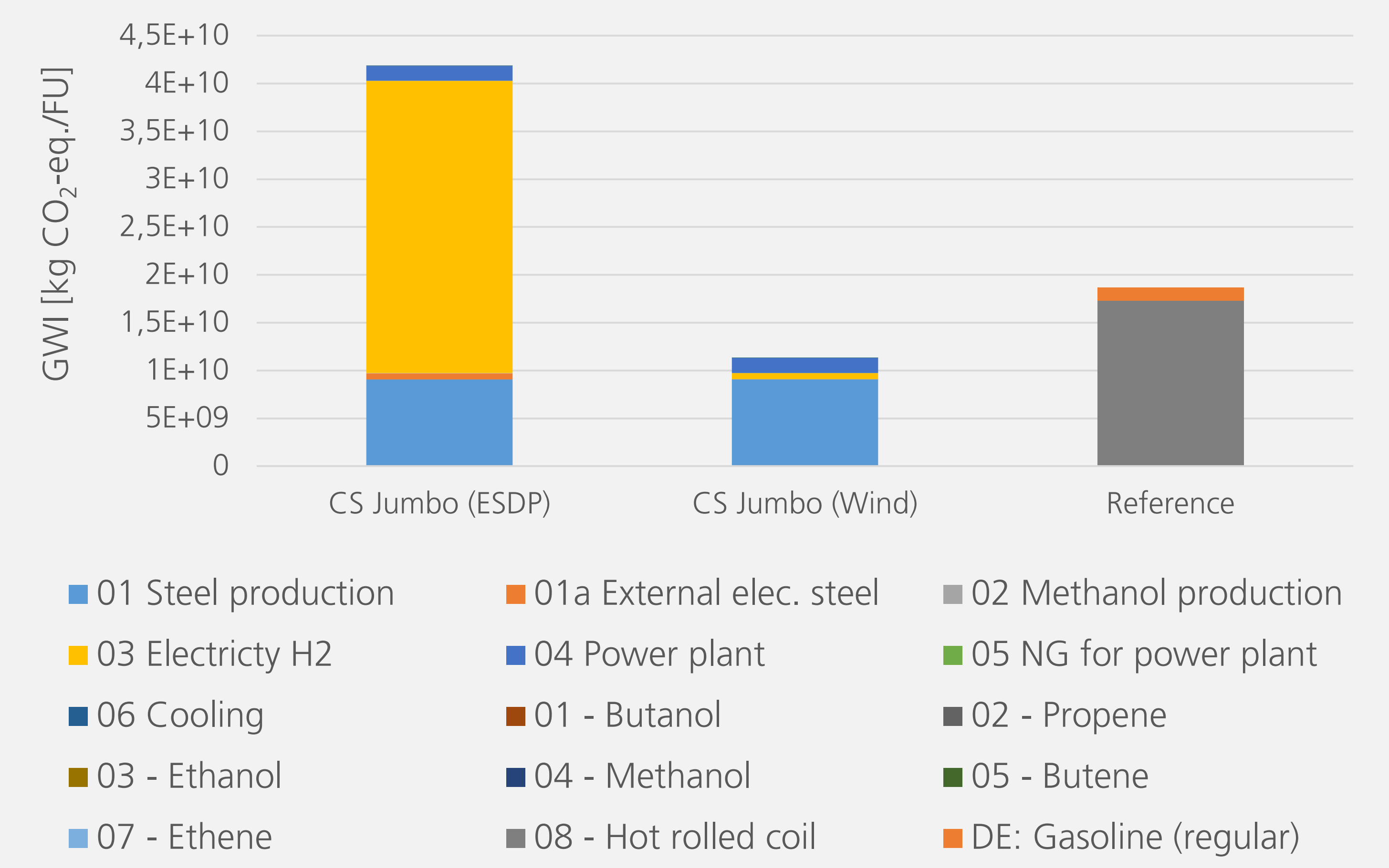
Results for higher alcohols
Global warming impact

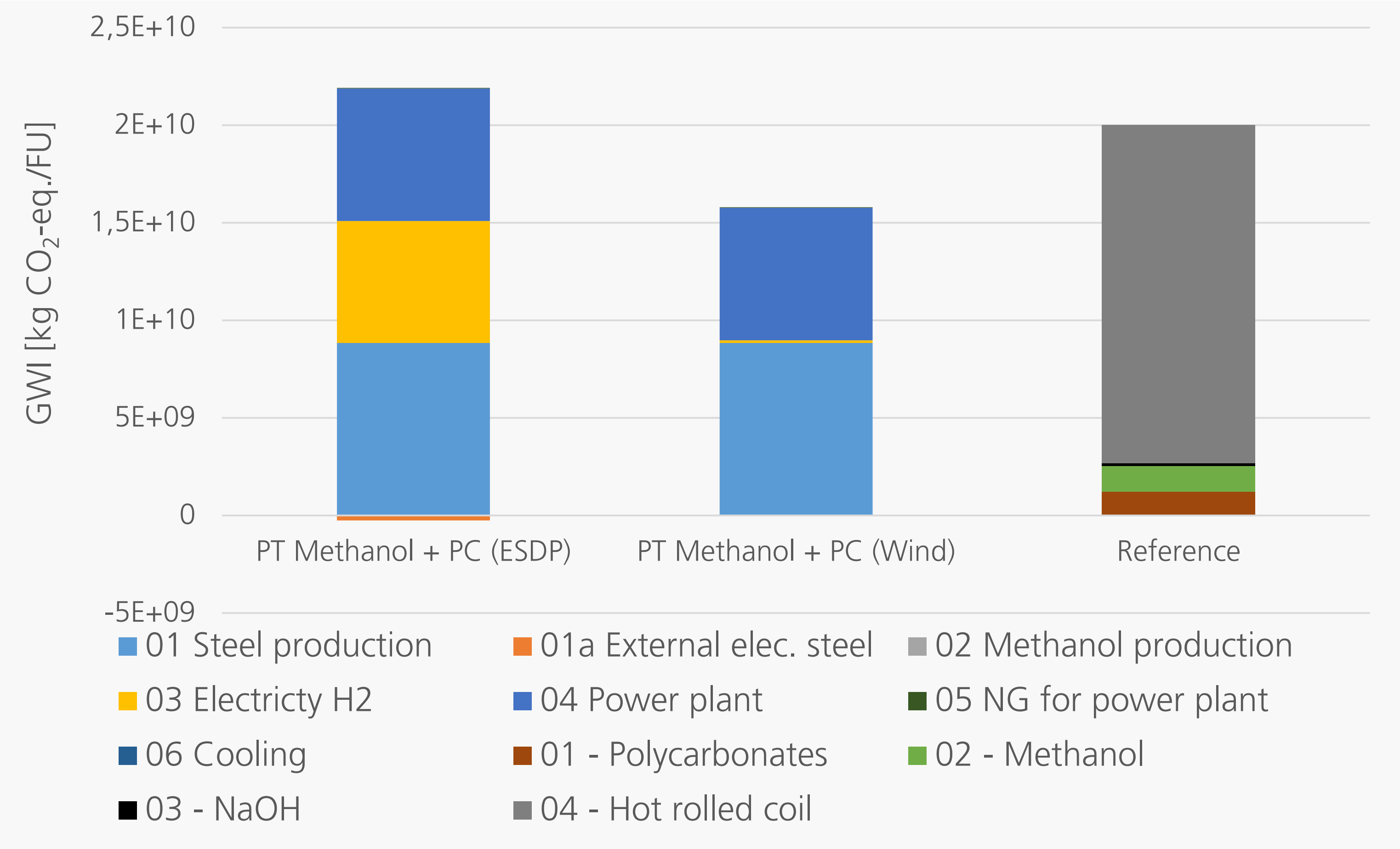
- Products
  - 3.3 Mio. t petrol and 8.4 Mio. t steel
- Total hydration of alkenes to higher alcohols
- GWI of integrated production approx. 2 times higher than reference (ESDP)
- Only approx. 1/2 of GWI with wind power



GWI = Global Warming Impact

Results for polycarbonates and methanol
Global warming impact

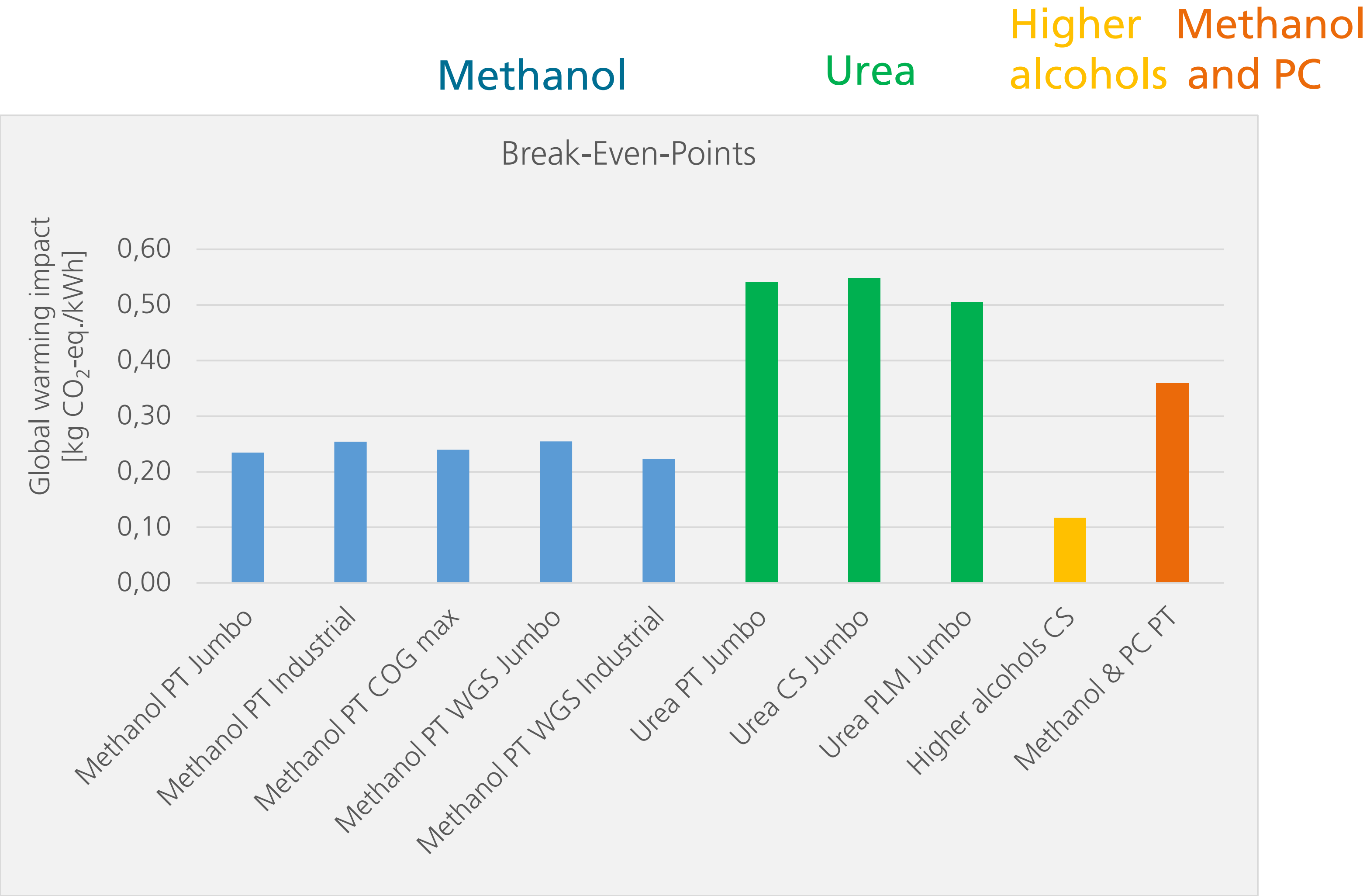
- Products
  - Methanol 1.5 Mio. t
  - NaOH 0.1 Mio. t
  - Polycarbonates 0.3 Mio. t
  - 8.4 Mio. t steel
- ESDP mix: 8 % higher than reference
- Wind power: 21 % smaller GWI



GWI = Global Warming Impact

Comparison of Break-Even-Points

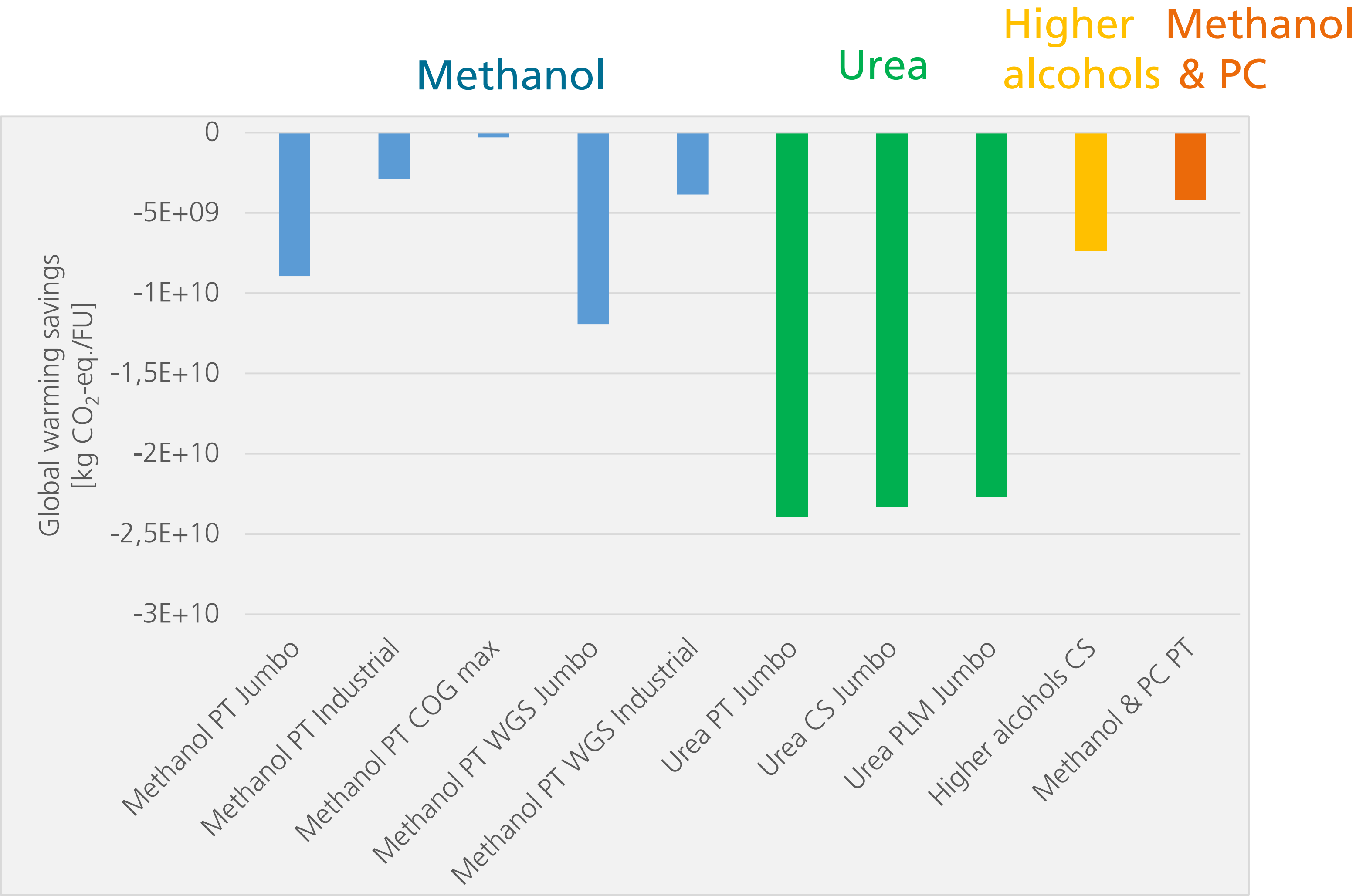
- Urea production leads to the highest Break-Even-Point (BEP)
  - GHG savings can be achieved today
- Methanol & polycarbonate production associated with higher BEP as methanol alone
- Higher alcohol production related to a BEP of about 0.1 kg CO_2-eq./kWh



GWI = Global Warming Impact
PC = Poly Carbonate

Absolute GHG savings using wind power

- Wind power
- Urea shows highest savings
- Methanol: Jumbo scenarios show much higher savings than industrial or COG scenarios
- Higher alcohols also lead to considerable savings
- Combination of PC and methanol can lead to higher GHG savings than methanol alone



Interpretation (I)

- The integrated production of steel and chemicals allows GHG reductions compared to stand-alone production
- The global warming impact mainly depends on two drivers:
  1. Power demand for hydrogen production
     - Lowest hydrogen demand is needed for urea production, highest for higher alcohols
  2. The product yields
     - Urea production scenario has the highest product yield (mass balance) followed by methanol and higher alcohols

Interpretation (II)

- The break-even-point is a suitable indicator to show at which carbon intensity of power generation the integrated production of steel and chemicals becomes beneficial
  - Depending on the target product and the production conditions, the BEP lies between approximately 0.2 and 0.5 kg CO_2-eq./kWh
  - In 2019, the carbon intensity of the German power production was about 0.5 kg CO_2-eq./kWh [Umweltbundesamt-2020]
  - For urea, already today GHG savings can be achieved
- In the case of using wind power all scenarios lead to GHG savings
  - Total GHG emissions can be reduced by 5 to 25 Mio. t CO_2 per year (one site)

BEP = Break Even Point

LCA Publications in Carbon2Chem®

Applied Energy 263 (2020) 114599

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

ELSEVIER

Environmental impacts of CO_2-based chemical production: A systematic literature review and meta-analysis

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Chemie Ingenieur Technik Research Article 1

Handling of Multi-Functionality in Life Cycle Assessments for Steel Mill Gas Based Chemical Production

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DOI: 10.1002/cite.201800025

Supporting Information available online

Energy & Environmental Science

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal

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Cite this: DOI: 10.1039/c9ee00914k

Consequential life cycle assessment of carbon capture and utilization technologies within the chemical industry†

Nils Thonemann *[a] and Massimo Pizzol [b]

Ingenieur Technik Research Article 1

Life Cycle Assessment of Steel Mill Gas-Based Methanol Production within the Carbon2Chem® Project

Nils Thonemann* and Daniel Maga

DOI: 10.1002/cite.202000051

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Görge Deerberg
Eckhard Weidner

Location Planning for the Production of CO_2-Based Chemicals Using the Example of Olefin Production

A methodology for identifying suitable locations for the CO_2-based production of olefins in Germany is presented. Based on electricity and CO_2 requirements, locations are identified that can provide sufficient CO_2 and renewable energy for the conversion of CO_2 to olefins. In addition, the use of existing infrastructures is tak-

Chemie Ingenieur Technik Research Article 1

Integration of Results from the Energy System Development Plan into Life Cycle Assessment

Nils Thonemann[1,*], Daniel Maga[1], and Cornelia Petermann[2]

DOI: 10.1002/cite.201800117

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Outlook on Carbon2Chem® Phase 2

- Analysis of promising configurations
  - Also considering technical and economical limitations
- Analysis of further impact categories and trade-offs
- Consideration of further CO_2 sources
  - Cement plant, municipal waste incineration
- Comparison of CCU to direct reduction process for steel production
- Dynamic LCA-Model
  - Integration of LCA data into simulation tools to support decision making and plant control
  - Higher resolution of environmental footprint of CCU based chemical production
  - Identification of optimal solutions from an environmental point of view

CCU: Carbon capture and utilization

MANY THANKS FOR YOUR ATTENTION

Looking forward to a good cooperation!

Present information on Life Cycle Assessment are available here:
https://www.umsicht.fraunhofer.de/en/research-for-the-market/life-cycle-assessment.html

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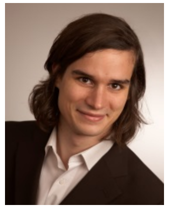

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Thank you for your attention!