Impact of hydrogen import prices, cross-border exchange and transport sector flexibility in net-neutral Europe

A case study of the openENTRANCE project

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Contents

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Chapter 01

Introduction
Motivation, objective and methodological approach

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The case study has two objectives: (1) simulate the expansion and operation of pan-European energy systems and (2) demonstrate coupling models of via the openENTRANCE platform

Case study motivation in the openENTRANCE project

- **Low-carbon energy systems** in Europe need to be **based on cross-sectoral integration** to meet energy & climate policy goals
- **Cost-efficient coupling** of the electricity with industry, building, and transport sectors **implies additional demands for renewable electricity** but integrating technologies at the interfaces between those sectors **may also provide a valuable source of flexibility**
- Multiple studies have been carried out on a one-node-per-country level – but how does the **integration of cross-sectoral technologies play out in the local but interconnected domain**?

Objectives

Simulate the **expansion** and **operation** of **the pan-European power and energy system**, while **integrating all relevant flexibility assets**, **network costs** and **constraints** on a **local and decentralised level**

Original plan	*Extended scope*	
Transport sector flexibility	*Cross-border integration*	*Hydrogen import prices*

Combine a **proprietary integrated energy system modelling framework** (SCOPE SD at Fraunhofer IEE) with an **open-source power sector modelling framework** (plan4EU at EDF) via the **openENTRANCE platform**

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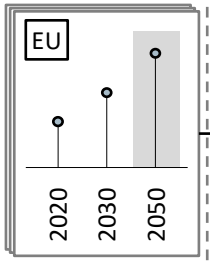
Methodological approach involves linking IEE's SCOPE SD and EDF's plan4EU modelling frameworks via the openENTRANCE platform to use its "Techno-friendly" pathway as a basis

Scenario Framework (GENeSYS-MOD)



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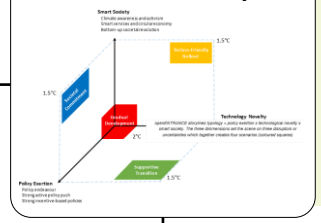
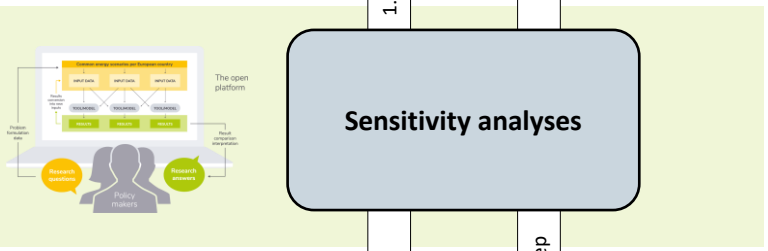
Model	Model type and problem	Spatial focus	Temporal focus
SCOPE Scenario Development	■ Static deterministic partial equilibrium techno-economic bottom-up mathematical optimization model ■ Cross-sectoral Capacity Expansion Planning (CEP) ■ With/ without expansion decisions (pure system operation model/ or only sector-specific expansion)	■ EU27+NOR/CHE/UK ■ One node per country ■ Subnational regions for Germany and France (based on eHighWay2050 network clusters)	■ Full-year (historical meteorological year) ■ Hourly resolution ■ Only single scenario years (no pathway)
plan4EU	■ SSV+EUC plan4EU models (stochastic optimization) ■ Without expansion decisions ■ Electricity sector	■ EU27+NOR/CHE/UK ■ Regional resolution	■ Full-year (historical meteorological year) ■ Hourly resolution ■ Only single scenario years (no pathway)

Techno-Friendly





1. step

Sensitivity analyses

2. step

Focus on increased regional resolution in core regions of Germany and France

Single-stage focus of both models matches well

Deterministic vs. stochastic approach

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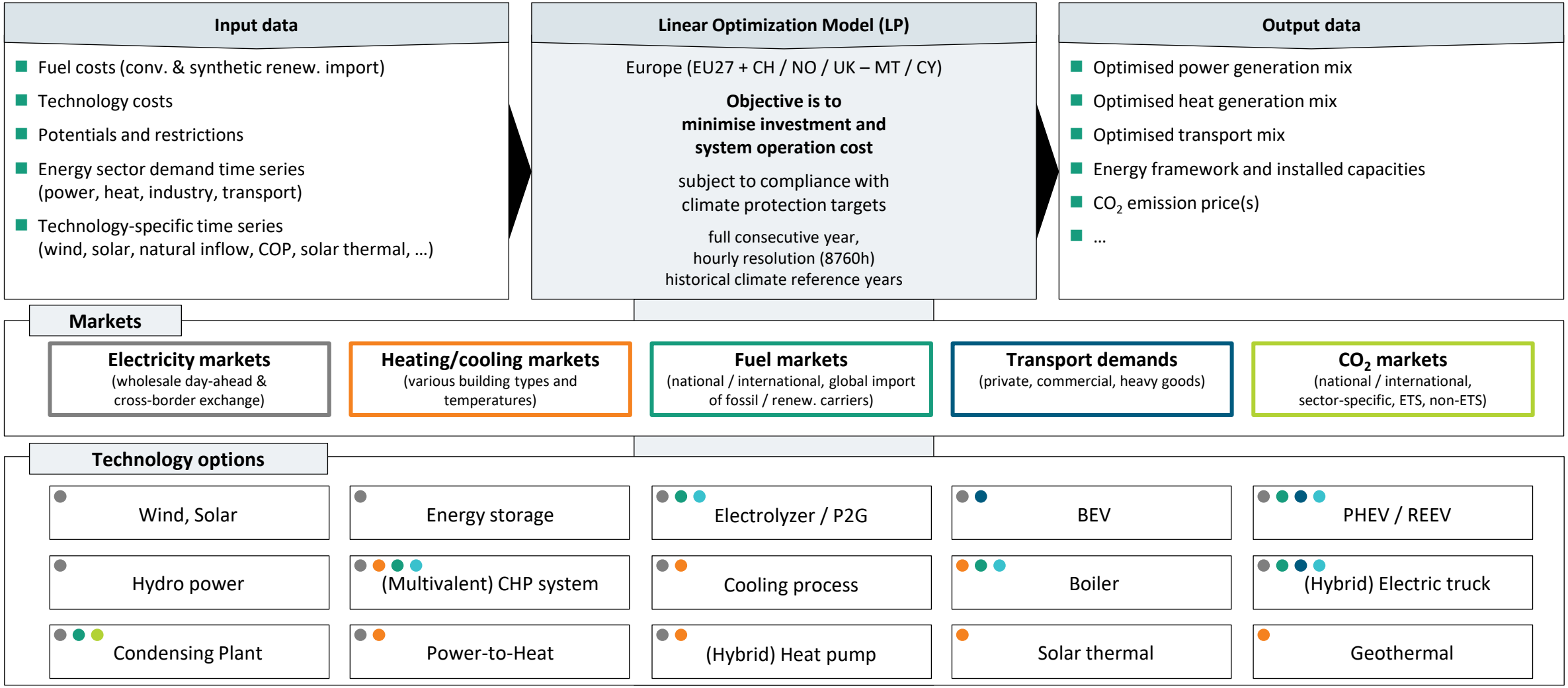
SCOPE Scenario Development (SD) plans cost-optimised scenarios of integrated energy sys-tems with energy & climate policy targets – captures wide range of technology combinations



Recent formulations can be found in: 10.1109/TPWRS.2020.3023474, 10.1016/j.energy.2021.121598, 10.1016/j.eneco.2021.105709, 10.1109/EEM.2018.8469846, 10.3390/en10111841

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Chapter 02

Case study
Case study setup and results

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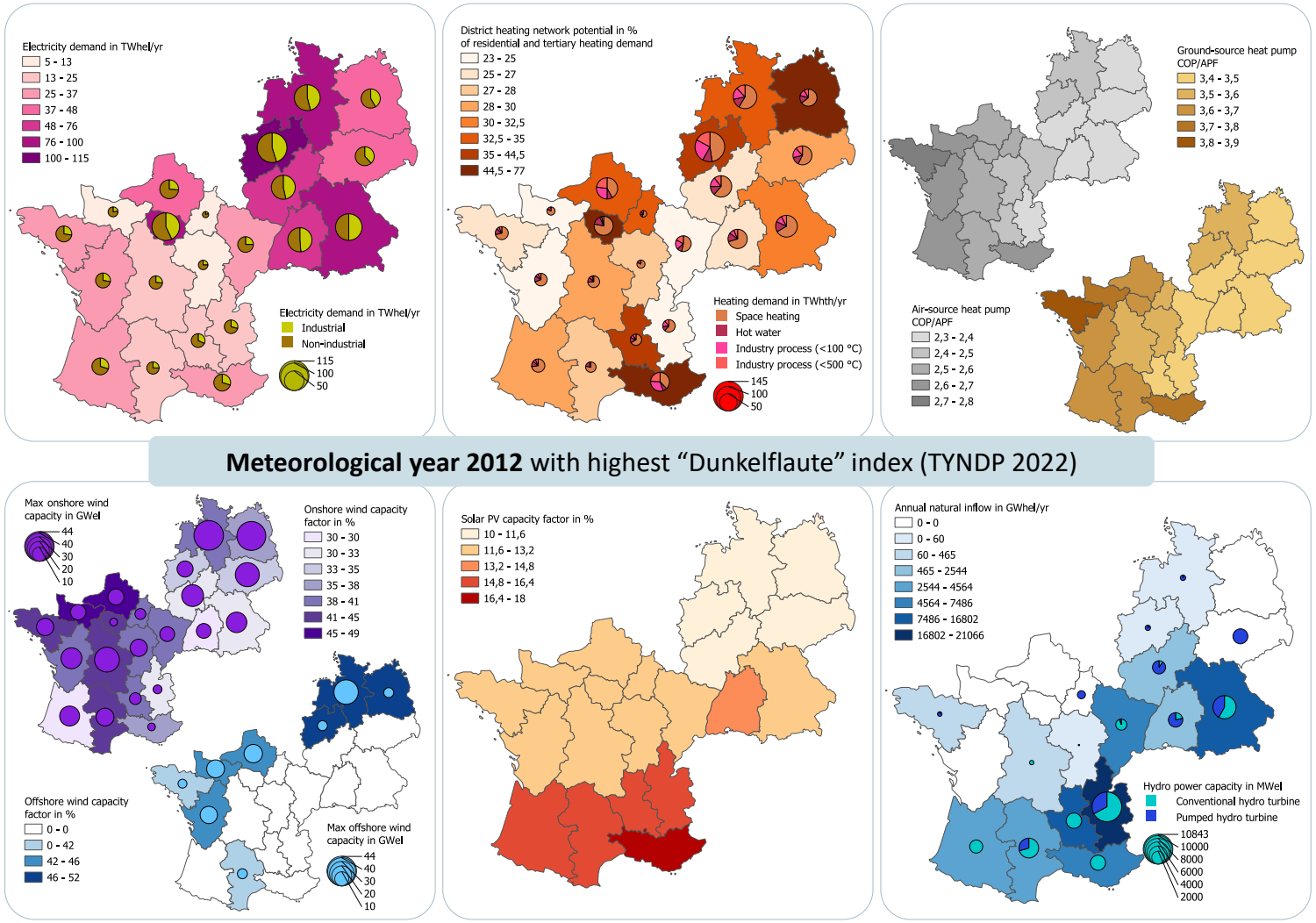
Geographical coverage with increased focus on grid regions in Germany and France requires regionalised data in all technology and end-use domains of an integrated energy system

Geographical coverage

EU27 + NOR / CHE / GBR
- EST / LTU / LVA
- HUN / ROU / BGR / HRV
- GRC / CYP / MLT

Reductions required due to computational tractability issues



Meteorological year 2012 with highest “Dunkelflaute” index (TYNDP 2022)

Sources: European cluster model of the Pan-European transmission grid (e-HighWay 2050), openENTRANCE Nomenclature

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Focusing on transport sector flexibility, cross-border integration, and hydrogen import prices, the case study simulates the expansion and operation of pan-European energy systems

Criteria		**Sensitivities** (low and high)	
Cross-border electricity exchange (XB) capacity	×	**Low cross-border exchange capacity expansion (XB↓)** **Europe 118.5 GW** (w/o internal) DEU 101.1 GW (internal only) FRA 110.2 GW (internal only)	**High cross-border exchange capacity expansion (XB↑)** **Europe 229.9 GW** (w/o internal) DEU 108.2 GW (internal only) FRA 133.3 GW (internal only)
Share of electric vehicles (EV) with a flexible charging policy	×	**Low electric vehicle charging flexibility (EV↓)** **10%** of all electric vehicles (BEV, PHEV, REEV) allowed to charge in a system-friendly manner	**High electric vehicle charging flexibility (EV↑)** **90%** of all electric vehicles (BEV, PHEV, REEV) allowed to charge in a system-friendly manner
Import price for hydrogen (H_2) from global markets	PtX global ATLAS	**Low hydrogen import price (H_2↓)** **45.1 EUR/MWh$_{th}$** (~1.5 EUR/kg LHV)	**High hydrogen import price (H_2↑)** **85.0 EUR/MWh$_{th}$** (~2.82 EUR/kg LHV)

Source: : European cluster model of the Pan-European transmission grid (e-HighWay 2050), TYNDP 2020, NEP 2022, Fraunhofer CINES 2022, https://maps.iee.fraunhofer.de/ptx-atlas/

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Results focus on two aspects of the SCOPE SD modelling results today: an aggregate view on the European energy system development & a short dive into French and German prices

European energy system development

France / Germany

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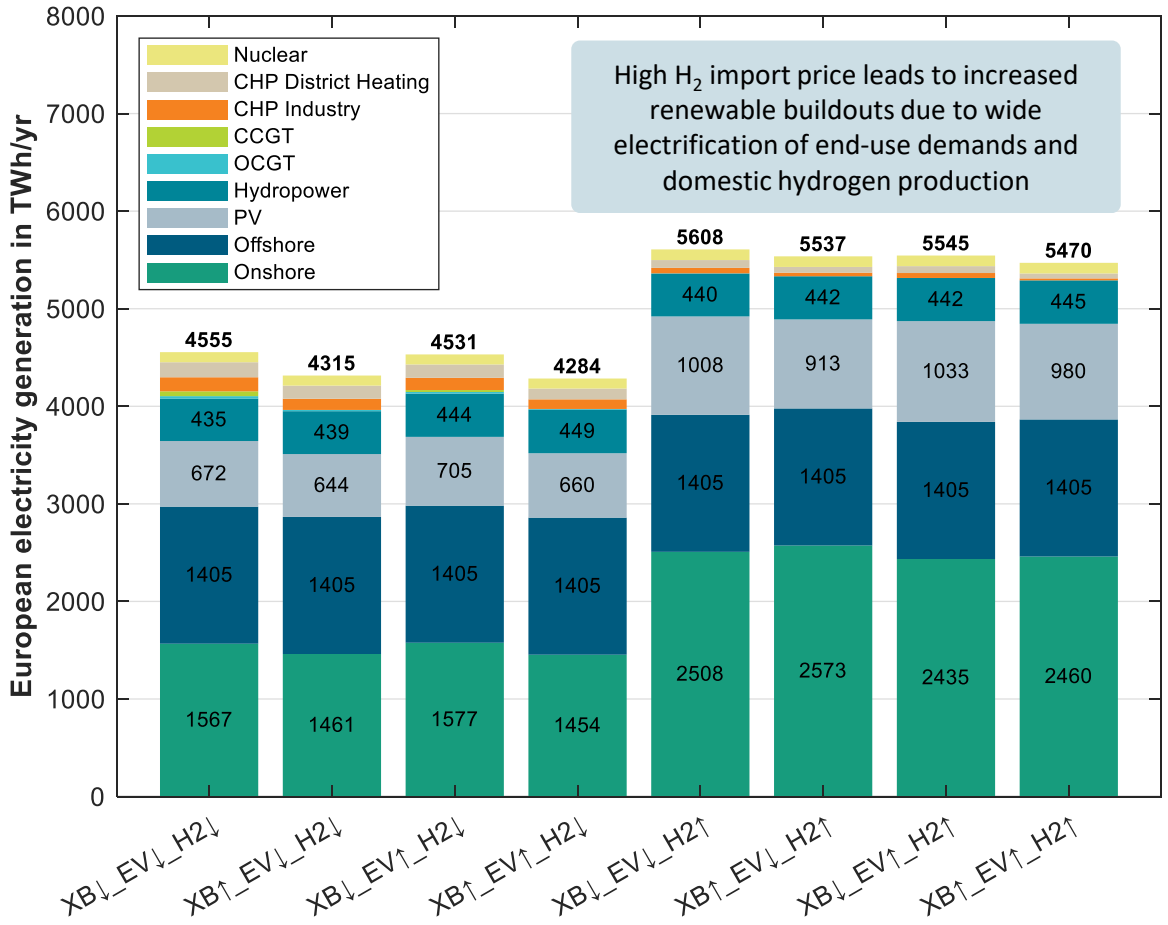
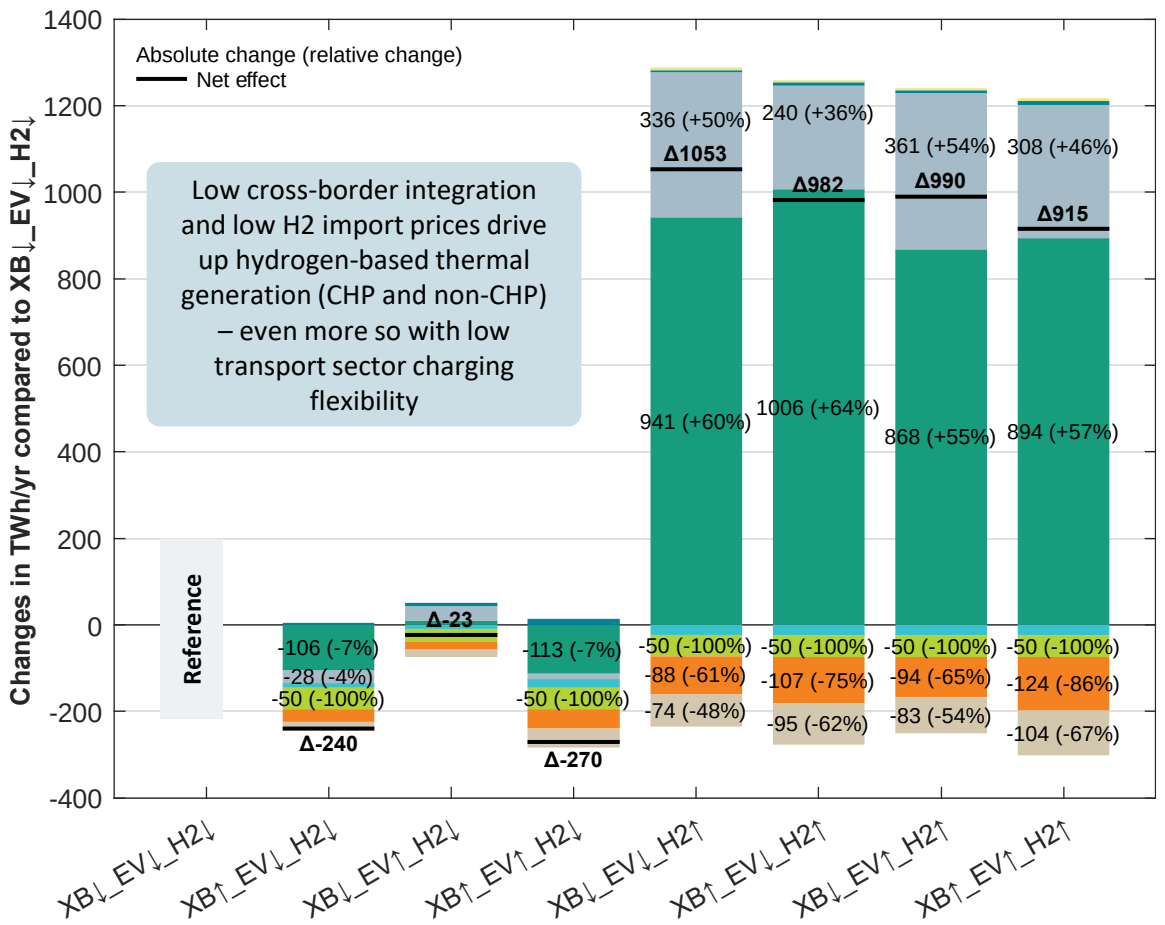
Hydrogen import price demonstrates strongest effect on European electricity generation –for renewable generation, changes directly correspond to capacity expansion decisions

European energy system



France / Germany



Note that "European" refers to the geographical coverage: EU27 + NOR / CHE / GBR - EST / LTU / LVA / HUN / ROU / BGR / HRV / GRC / CYP / MLT

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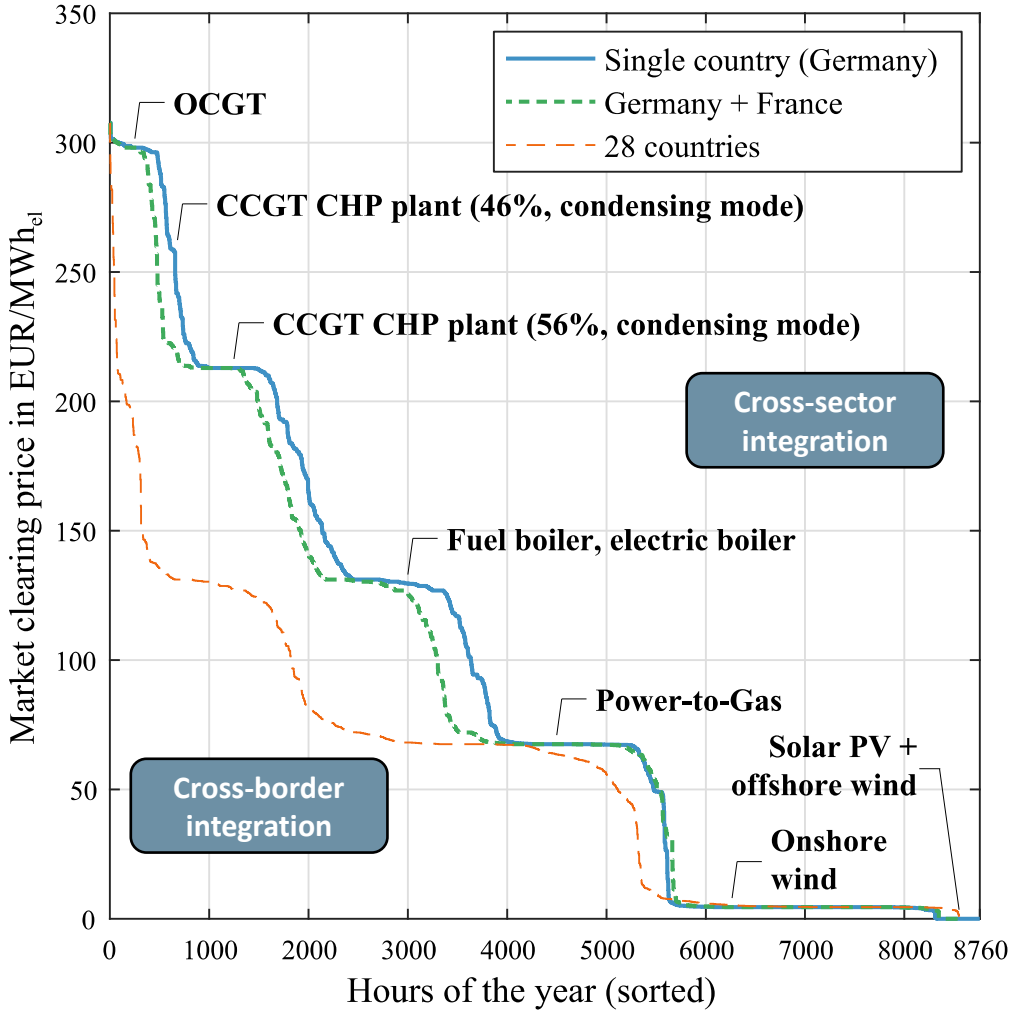
Background on potential market clearing effects in future wholesale power markets of net-zero systems can be found in two publications

How do we extract market clearing prices from the energy system modelling framework?

Why do we see the prices that we see?

How do hybrid technology and electrolyser bids influence the electricity market outcomes?



D. Böttger, P. Härtel, "On Wholesale Electricity Prices and Market Values in a Carbon-Neutral Energy System," Energy Economics, 105709, 2022. doi: 10.1016/j.eneco.2021.105709.
P. Härtel, M. Korpås, "Demystifying market clearing and price setting effects in low-carbon energy systems," Energy Economics, 105051, 2021. doi: 10.1016/j.eneco.2020.105051

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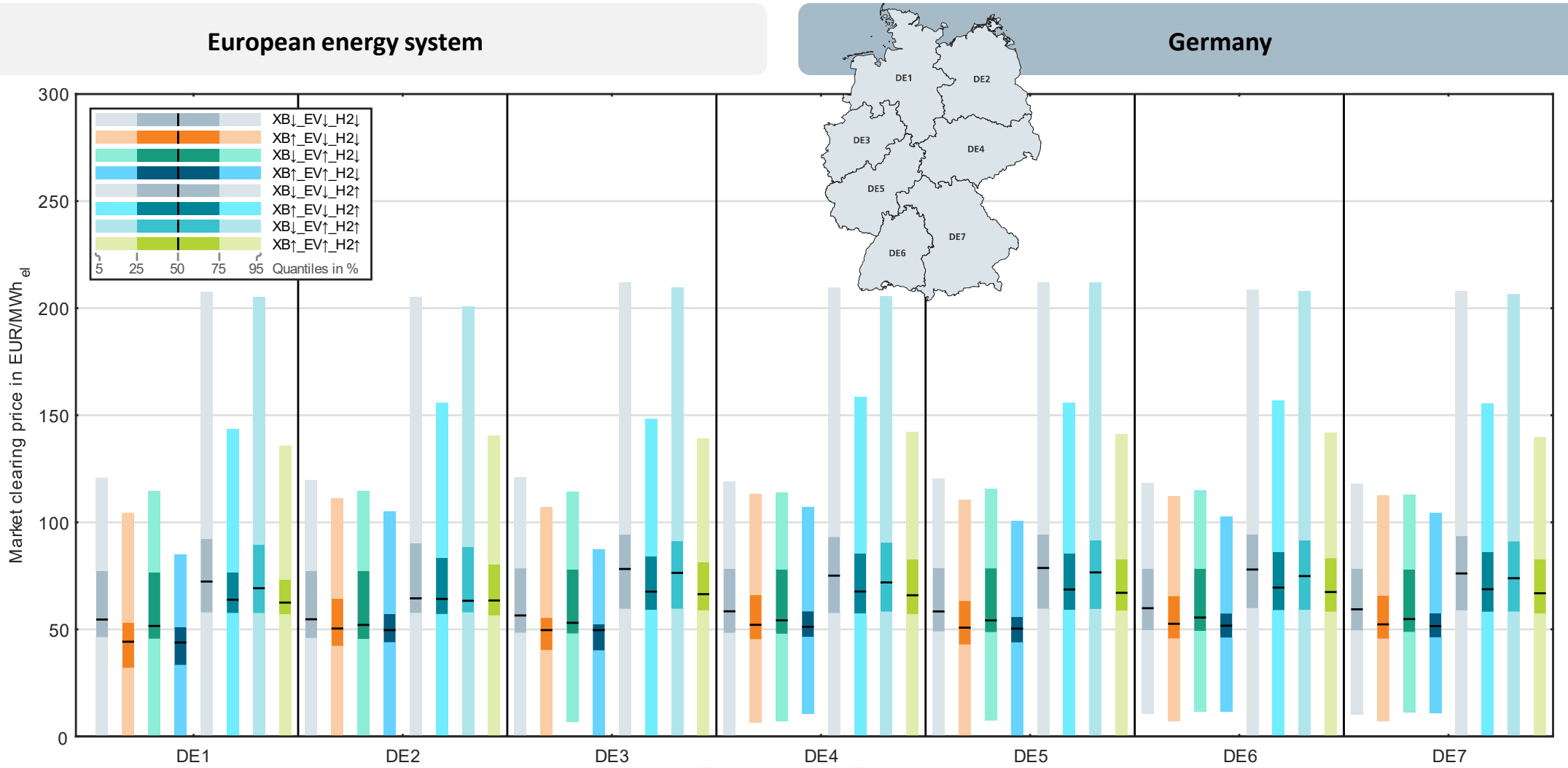
Impacts on wholesale market clearing prices in Germany show strong impacts of high H_2 import prices – volatility primarily depends on XB availability, less so on EV flexibility

European energy system

Germany



For the market clearing price, the dual variable (LP) of the nodal market clearing constraint is used as a proxy (based on total costs).

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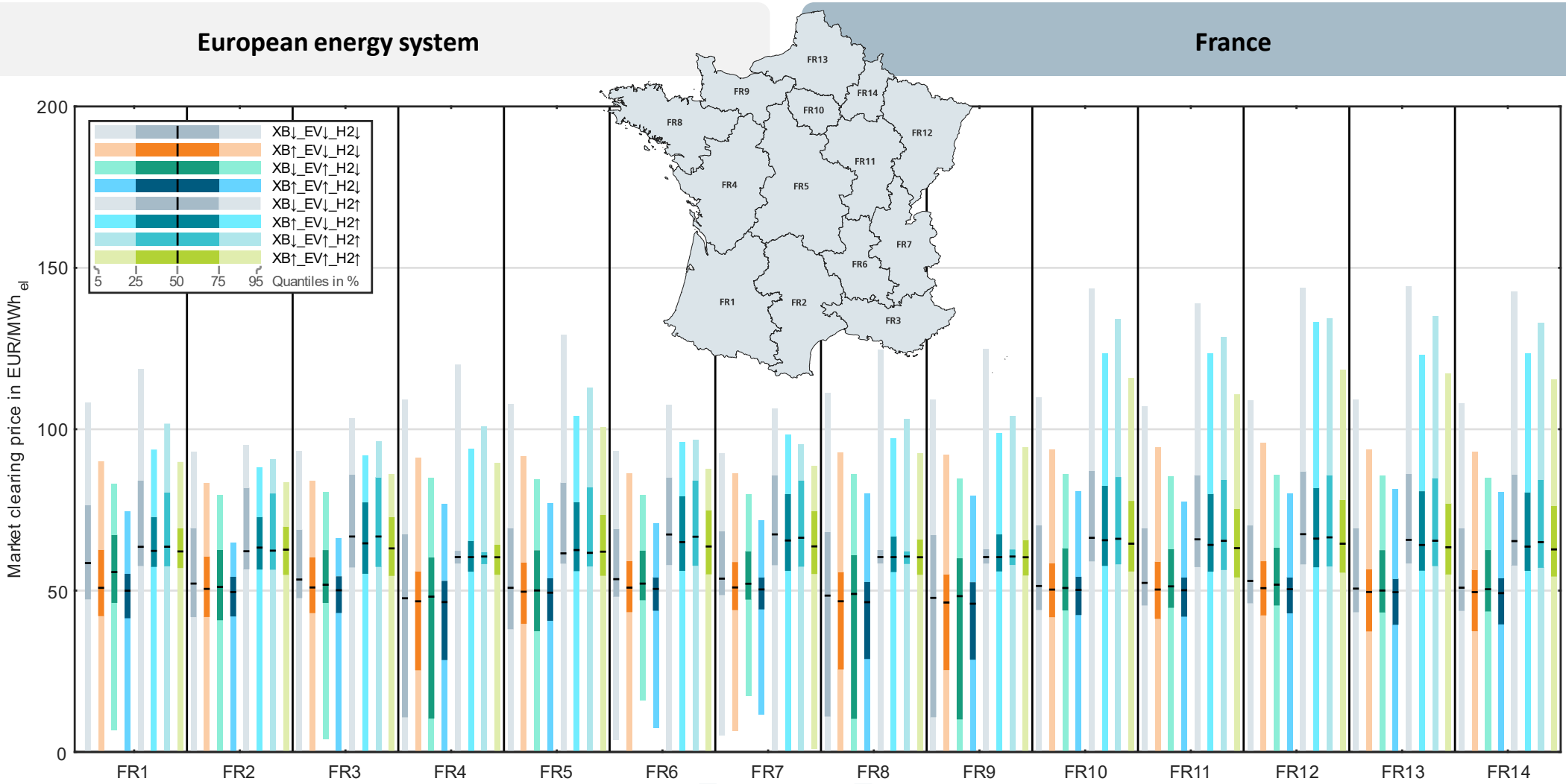
French prices show a more heterogeneous picture with similar impacts of different criteria – generally lower than German prices that permeate in the Northeastern regions

European energy system | **France**



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Chapter 03

Conclusion
Summary and some take-away messages

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Some takeaways

- **Case study is a sensitivity analysis** based on openENTRANCE's "Techno-Friendly 1.5°C" pathway, looking into **low and high materialisations** of **future transport flexibility**, **cross-border exchange**, and **H_2 import prices**
- Coupling of GENeSYS-MOD (TU Berlin) ⇨ SCOPE SD (Fraunhofer IEE) ⇔ plan4EU (EDF) demonstrates that both **open and proprietary modelling frameworks can be linked via the openENTRANCE platform**
- **Hydrogen import price is responsible for the largest energy system changes** in the climate-neutral system and **determines Europe's energy import dependency** – low prices lead to higher hydrogen demand and high share of imports from global markets
- **Higher cross-border exchange capabilities and transport sector charging flexibility have moderate effects**, i.e. they increase direct use of renewable electricity and reduce need for indirect electrification applications (i.e. hydrogen demand)
- **Hydrogen import prices** exhibit **strongest impact** on regional **electricity price** distributions – **Cross-border trade** and **electric vehicle flexibility rather affect the volatility** in the distribution tails
- **General limitations** include **gas infrastructure representation** (only pan-European fuel markets considered w/o infrastructure ⇨ new IMAGINE model) and **pathway dependencies** (partly alleviated through openENTRANCE's pathway development)

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Thank you very much for your attention!

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