TECHNISCHE UNIVERSITÄT WIEN

Energy Economics Group

Understanding the similarities and differences in decarbonization scenarios derived from different building stock models

Ece Özer, Lukas Kranzl, Andreas Müller, Behnam Zakeri, Robin Hasse, Sirin Alibas, Theofano Fotiou

24-27 July 2023, Milan

18th IAEE European Conference

OUTLINE

MOTIVATION and BACKGROUND

- Buildings → 1/3 of total final energy consumption (global) [1]
  → 40% of total global greenhouse gas emissions [2]
- Scenario modelling is crucial for understanding the dynamics of building sector and planning of decarbonization pathways.
- Comparing different model results is important to understand models- specific characteristics.
- Model comparisons are often difficult to perform, if scenario specifications did not take place in a comparable manner.
- Scenario specification and the model-run task has been carried out within the scope of the *European Climate and Energy Modeling Forum (ECEMF)* project.
- ECEMF|H2020→ to establish a European forum to bring together energy and climate researchers and policymakers and deal with how to achieve climate neutrality. [3]

EUROPEAN CLIMATE+ENERGY MODELLING FORUM

nion's

[1] World Energy Outlook 2021, International Energy Agency (IEA)
[2] https://ourworldindata.org/emissions-by-sector
[3] European Climate and Energy Modeling Forum (ECEMF) : https://www.ecemf.eu/

OBJECTIVE

1. to analyze the impact of different building stock model narratives on;
   I. different demand reduction level,
   II. different supply configurations.

2. to address the differences/deviations among the included building stock models.

Key messages:

1. Heat pumps and district heating are the predominant heating systems for decarbonizing buildings.
2. H2 and e-fuels are not economically viable in any scenario.
3. Building renovation and improved envelopes are crucial for a decarbonized building stock.

METHODOLOGY I

1. Scenario Design

2. Involved models

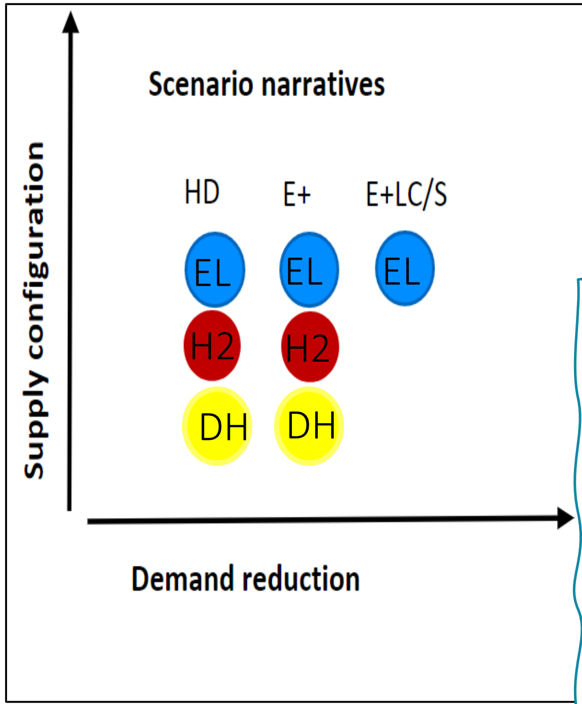
- Invert/EE-Lab
- Invert/Opt
- FORECAST – Buildings
- PRIMES – Buildings
- EDGE/REMIND – Buildings

3. Application of the scenarios

4. Visualization and Interpretation of the results

1) Scenario Design

I. 3 scenarios are focusing on *supply technology*:
   i. High electrification (EL),
   ii. High e-fuels (H2),
   iii. High district heating (DH).
II. 2 levels of *demand reduction focusing on efficiency measures*:
   i. Efficiency high,
   ii. Efficiency moderate.
III. 1 scenario *lifestyle and behavioral change* added.



Scenarios:
HD: High demand
E+: Strong energy efficiency measures
LC/S: Lifestyle change and sharing
EL: High electrification scenario
H2: Hydrogen-based scenario
DH: High district heating scenario

1) High Electrification | Efficiency Moderate
2) High Electrification | Efficiency High
3) High Electrification | Lifestyle and Behavioral Change
4) High H2/e-fuels | Efficiency Moderate
5) High H2/e-fuels | Efficiency High
6) High District Heating | Efficiency Moderate
7) High District Heating | Efficiency High

METHODOLOGY III

2) Involved Models

Model Name	Approach	Spatial Coverage	Temporal Coverage	Technological Coverage
Invert/EE-Lab	Techno-socio-economic bottom-up simulation model, logit approach, building owners represented as agents with distinct decision-making parameters.	EU27	2020-2050, 5-year intervals	Space heating/cooling, domestic hot water. Electrical appliances are aggregated with lighting, and cooking.
Invert/Opt	An economic bottom-up optimization model (deriving overall cost-optimum mix of renovation measures and technology choice for a certain target year).	EU27	2019 - 2050	Space heating/cooling, domestic hot water. Electrical appliances are aggregated with lighting, and cooking.
FORECAST - Buildings	A bottom-up simulation model that considers the dynamics of technologies and socioeconomic drivers for the future energy demand of the buildings sector.	EU27	2010-2050, annual	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.
PRIMES - Buildings	A hybrid economic-engineering optimization model founded on microeconomic theory, built to represent behaviours of consumers, with embedded engineering constraints.	EU27	2005-2050,5-year intervals	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.
EDGE/REMIND - Buildings	A top-down simulation model is driven by projected population, GDP, and climate data. Buildings are embedded as a sector in a global IAM.	EU27	2005-2100, 5-year intervals until 2060, 10 year intervals afterwards	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.

METHODOLOGY III

2) Involved Models

Model Name	Approach	Spatial Coverage	Temporal Coverage	Technological Coverage
Invert/EE-Lab	Techno-socio-economic bottom-up simulation model, logit approach, building owners represented as agents with distinct decision-making parameters.	EU27	2020-2050, 5-year intervals	Space heating/cooling, domestic hot water. Electrical appliances are aggregated with lighting, and cooking.
Invert/Opt	An economic bottom-up optimization model (deriving overall cost-optimum mix of renovation measures and technology choice for a certain target year).	EU27	2019 - 2050	Space heating/cooling, domestic hot water. Electrical appliances are aggregated with lighting, and cooking.
FORECAST - Buildings	A bottom-up simulation model that considers the dynamics of technologies and socioeconomic drivers for the future energy demand of the buildings sector.	EU27	2010-2050, annual	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.
PRIMES - Buildings	A hybrid economic-engineering optimization model founded on microeconomic theory, built to represent behaviours of consumers, with embedded engineering constraints.	EU27	2005-2050,5-year intervals	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.
EDGE/REMIND - Buildings	A top-down simulation model is driven by projected population, GDP, and climate data. Buildings are embedded as a sector in a global IAM.	EU27	2005-2100, 5-year intervals until 2060, 10 year intervals afterwards	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.

METHODOLOGY III

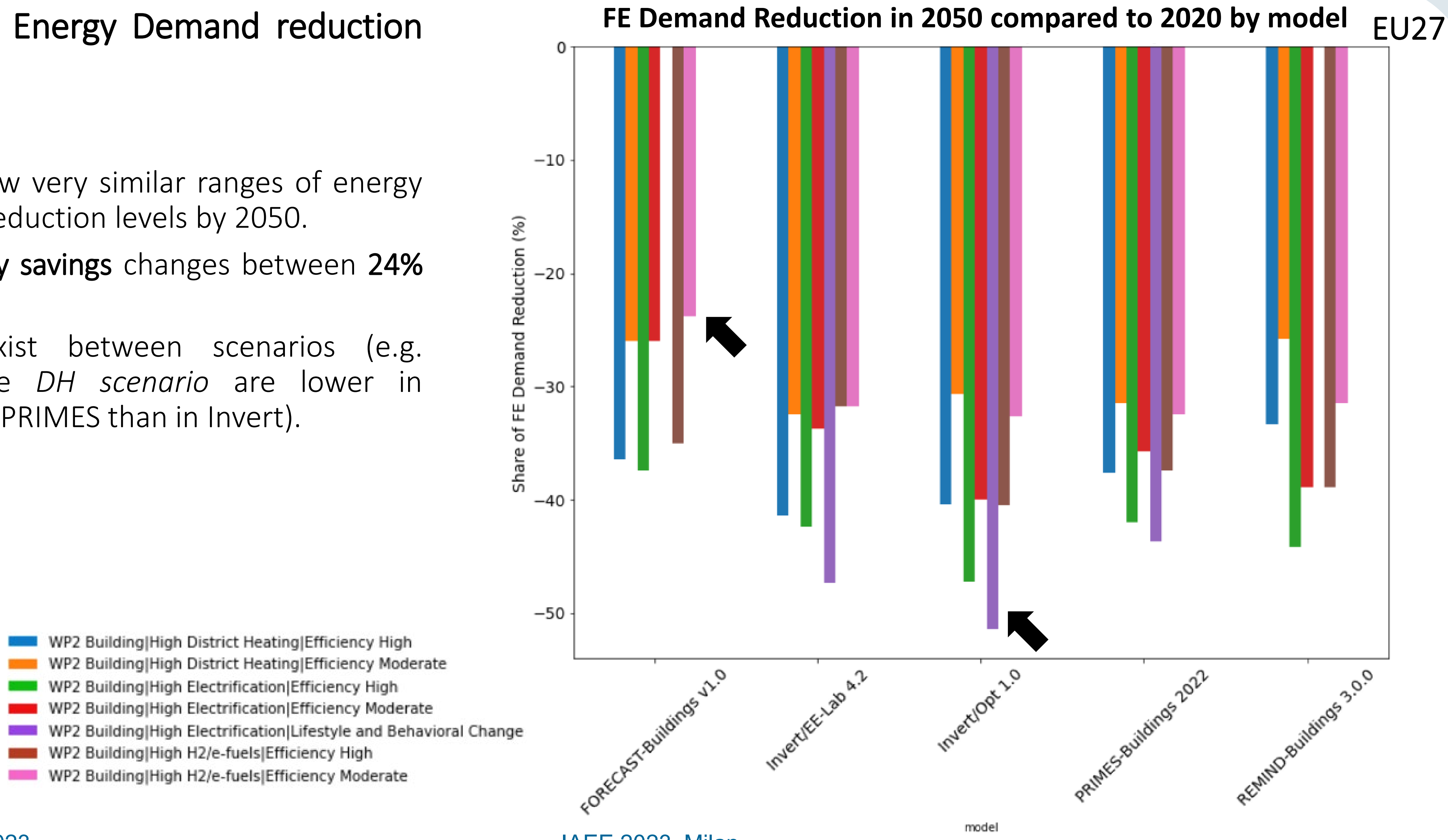
2) Involved Models

Model Name	Approach	Spatial Coverage	Temporal Coverage	Technological Coverage
Invert/EE-Lab	Techno-socio-economic bottom-up simulation model, logit approach, building owners represented as agents with distinct decision-making parameters.	EU27	2020-2050, 5-year intervals	Space heating/cooling, domestic hot water. Electrical appliances are aggregated with lighting, and cooking.
Invert/Opt	An economic bottom-up optimization model (deriving overall cost-optimum mix of renovation measures and technology choice for a certain target year).	EU27	2019 - 2050	Space heating/cooling, domestic hot water. Electrical appliances are aggregated with lighting, and cooking.
FORECAST - Buildings	A bottom-up simulation model that considers the dynamics of technologies and socioeconomic drivers for the future energy demand of the buildings sector.	EU27	2010-2050, annual	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.
PRIMES - Buildings	A hybrid economic-engineering optimization model founded on microeconomic theory, built to represent behaviours of consumers, with embedded engineering constraints.	EU27	2005-2050,5-year intervals	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.
EDGE/REMIND - Buildings	A top-down simulation model is driven by projected population, GDP, and climate data. Buildings are embedded as a sector in a global IAM.	EU27	2005-2100, 5-year intervals until 2060, 10 year intervals afterwards	Space heating/cooling, domestic hot water, electrical appliances, lighting, cooking.

RESULTS I

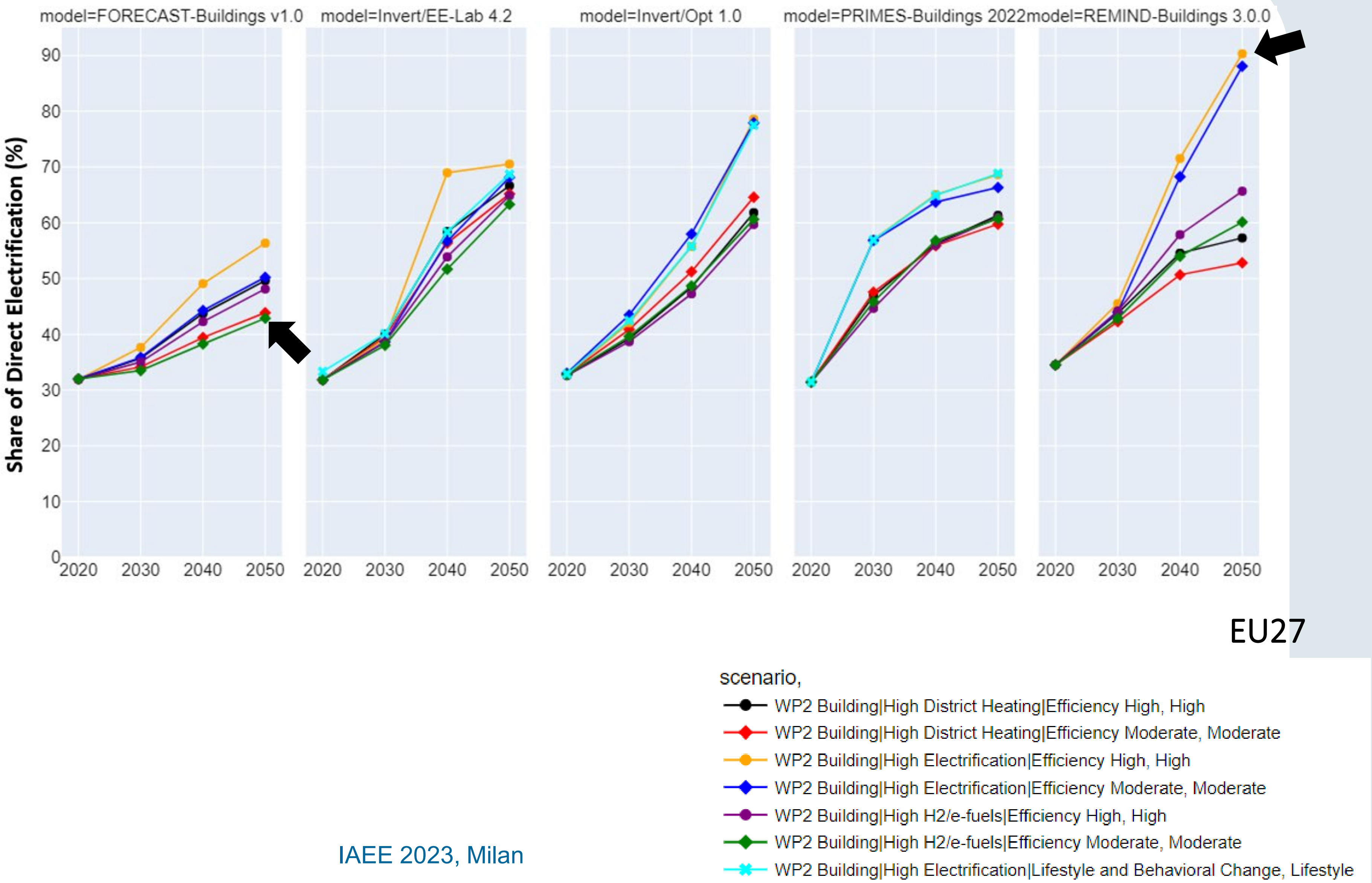
▪ Share of Final Energy Demand reduction in 2050

- All models show very similar ranges of energy consumption reduction levels by 2050.
- **Share of energy savings** changes between **24% to 51%.**
- Differences exist between scenarios (e.g. savings in the *DH scenario* are lower in FORECAST and PRIMES than in Invert).



Share of direct electrification

- **Share of direct electrification** changes from **43% to 90%.**
- Highest shares of electrification via heat pumps were achieved in REMIND.

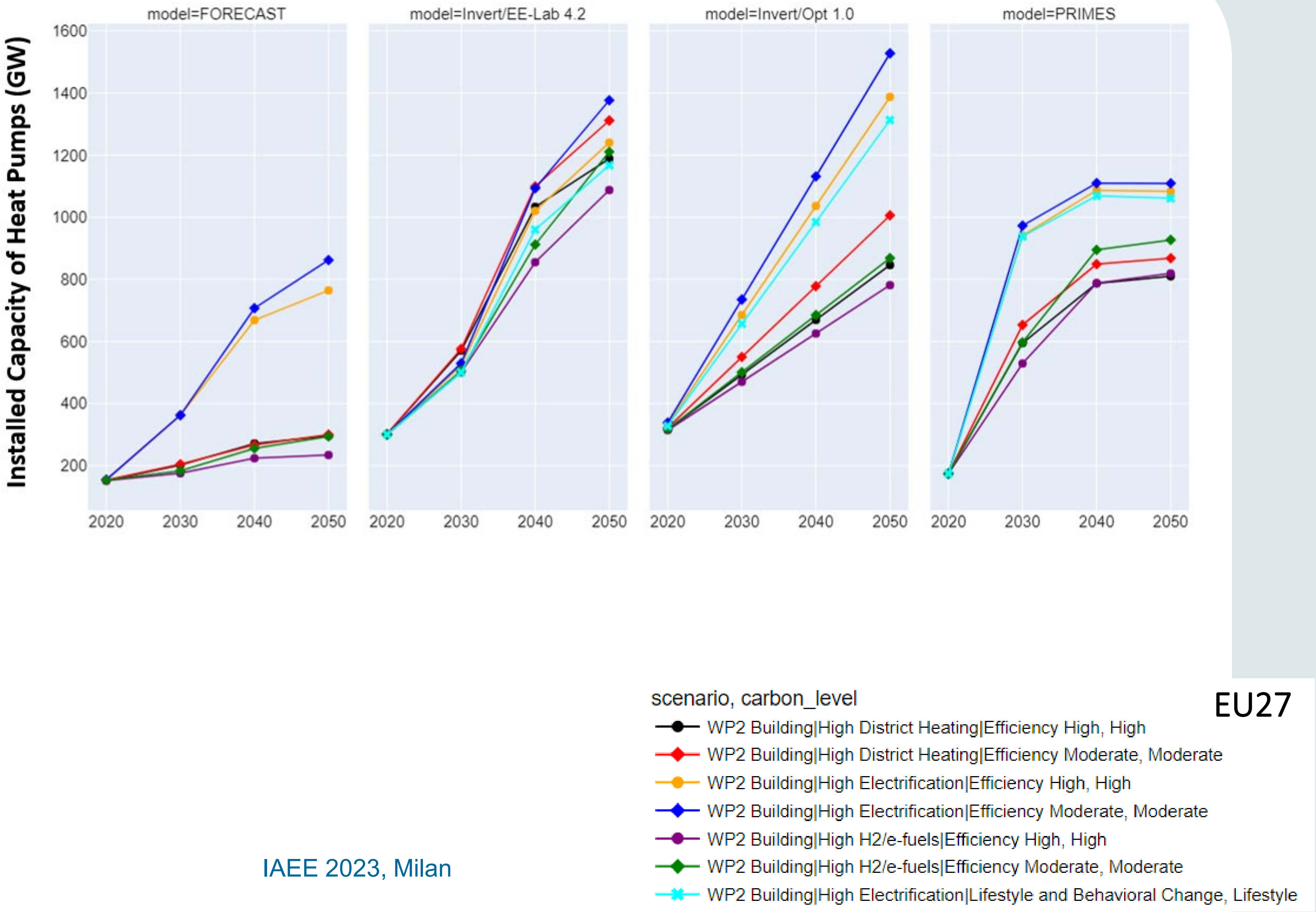


Share of direct electrification in Space and Water Heating

- **Share of direct electrification in Space and Water Heating** is changing from **18.5% to 45.2%.**
- **Highest shares of electrification** via heat pumps in Space and Water Heating were achieved in **Invert/EE-Lab**.

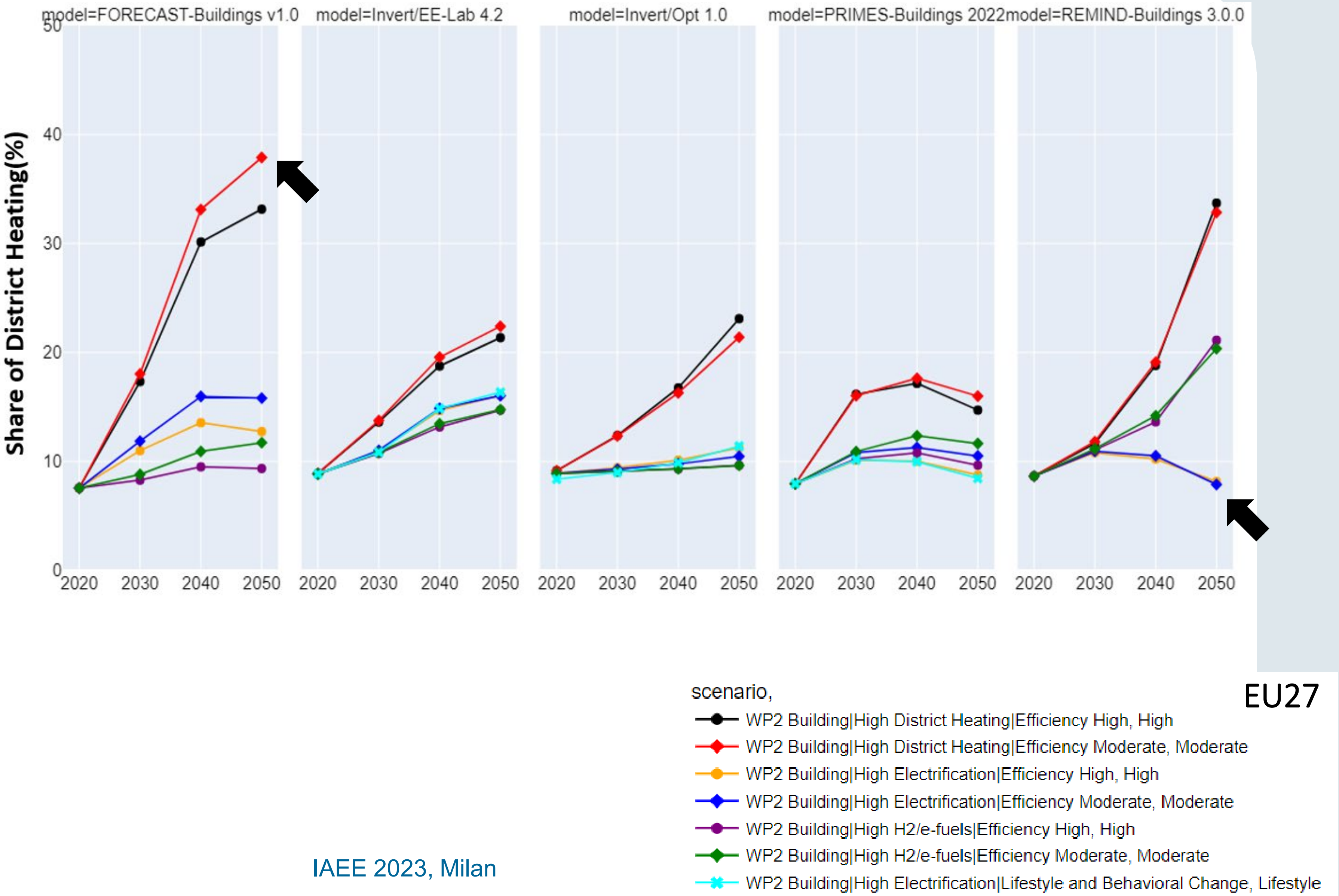
Installed capacity of heat pumps

- Most models and scenarios indicate a 3-5-fold increase in the installed capacity of heat pumps, reaching **700-1500 GW**.
- **FORECAST-Buildings** projects a minor increase in heat pump capacity for **H2/e-fuels and High District Heating scenarios**, estimating it to be around **234-300 GW**.
- The **highest installed capacity of heat pumps** is observed in the **Invert/Opt** scenario with the **High Electrification|Efficiency Moderate** scenario.



Share of district heating

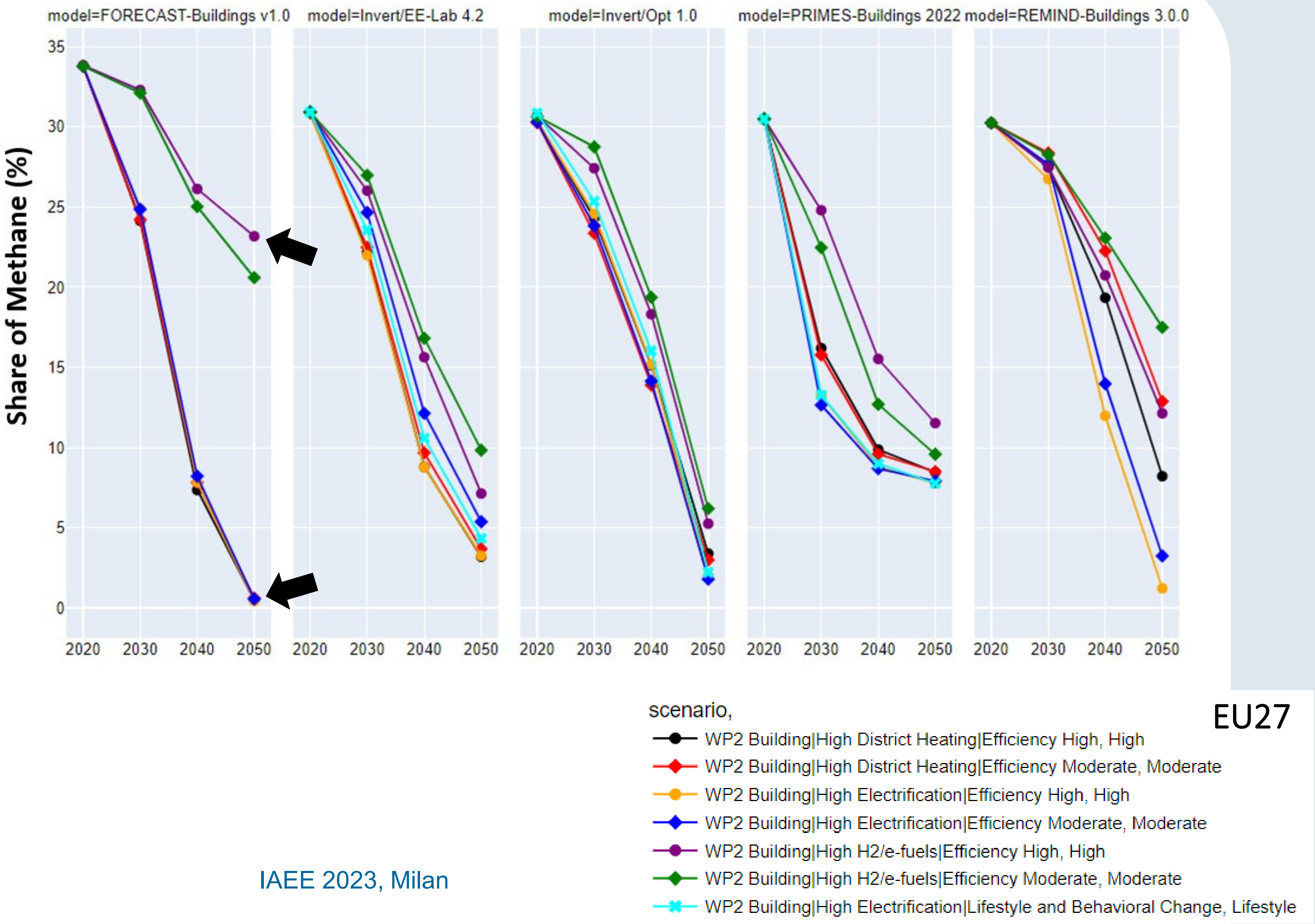
- **Share of district heating** varies from **8% to 38%.**
- Highest shares of DH achieved in FORECAST and REMIND.
- FORECAST-Buildings utilizes more *district heating* compared to other models due to the *lower* investment and operation costs of these heating systems.
- PRIMES shows the lowest variation (and growth) in district heating across all scenarios.



RESULTS IV

Share of methane

- **Share of methane** (fossil and biogases) varies from **0% to 23%.**
- **All models and scenarios lead to a strongly reduced share of gases**, even in the H2-scenarios.
- In 2020, FORECAST-Buildings shows a higher methane share, which can be explained by the variations in the base year between the heating module and appliances module of the model.



Renovation rate of the building envelope

- Renovation rate → **refurbished floor area (m2, annual) divided by the total available floor area**, ranging from **0.7% to 2.8%.**
- **The highest renovation rate** is observed in **PRIMES-Buildings** with the **High Electrification|Lifestyle and Behavioral Change** scenario.
- **Renovation rate and the decrease in final energy demand are not directly proportional**, warranting further analysis of renovation depths in each model.

CONCLUSION

- ✓ Substantial **enhancement of building renovation** and related **improvement of the building envelope** is key for a *decarbonized building stock*.
- ✓ **Heat pumps** play a crucial role in the supply mix of all scenarios.
- ✓ **H2 and e-fuels** do not turn out to be an efficient and economically viable solution in any of the models, even not in the dedicated H2/e-fuels scenarios.
- ✓ **District heating** is important for the *decarbonization process*, but models show different intensities of district heating expansion.

NEXT STEPS

- MS-level analysis
- Understanding the reasons for the deviations between models
  - Modeling approach
  - Scenario settings

TU WIEN TECHNISCHE UNIVERSITÄT WIEN

THANK YOU FOR YOUR ATTENTION!

Ece Özer
oezer@eeg.tuwien.ac.at