Image source: Bing Image Creator

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Chair of Energy Systems & Energy Economics

OR 2024 IN MUNICH

Using the **flexibility** of the thermal mass of buildings to assess **emission reduction potentials**—a case study for Ireland and Germany

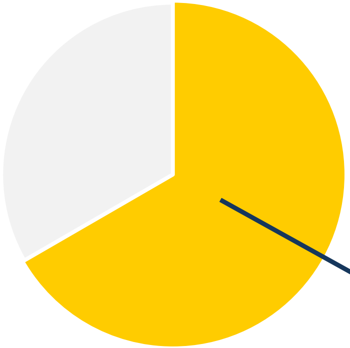
Christine Nowak

Agenda

- Introduction
  - Motivation
  - Related Literature
  - Research Questions
- Methods
  - Setup of Building Models
  - Archetype Buildings
  - Input Data
- Results
  - Thermal Flexibility
  - Emission Reductions
- Limitations & Outlook

Motivation

- major energy demand in **residential stock**



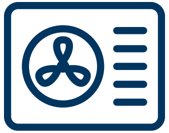
60–70% of final energy consumption
in residential buildings
for **space heating**
in Ireland and Germany (2020) [1, 2]

→ however: shift to **renewable heating technologies** still slow

[1] Sustainable Energy Authority of Ireland (2022). Residential.
[2] Statista (2022). Share of final energy consumption [...].
Image source: work in progress by KUSNIYAH

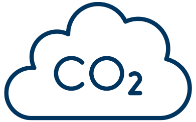
Motivation

What?



heat pumps in residential buildings

- primary **renewable-based** technology
- **topical** in both Ireland and Germany [1, 2]
- still contribute to **carbon emissions**



own review paper: **emission reductions** when using energy demand **flexibility**

- emission reduction potentials can be **significant** (Ø 17.8%)
- often **no focus** on employing energy demand flexibility for environmental reasons

How?

thermal flexibility

- mass of buildings as thermal storage
- shift energy demand
- to **reduce emissions**

Where?

Ireland and **Germany**

- weather (maritime vs. continental)
- building structure (insulation, cellars, …)
- energy system (isolation of grid vs. connected grid)

[1] Sustainable Energy Authority of Ireland (2022). National Heat Study.
[2] Statistisches Bundesamt (2022). *Press Release No. 226*.
Image sources: heat pump by Lomaxy, CO2 by Circlon Tech, thermometer by Adrien Coquet, map by Wikipedia

Related Literature

Ref.	Building scales	Germany/ Ireland	Modelling of the thermal mass	Target year	Energy system model method	Emission reduction potential[1]
Leerbeck et al. (2020)	family house & office building	— (Denmark)	***RC-model*** & state-space model	***2017–2018***	control (MPC) with ***emission-optimisation***	✓
Huckebrink & Bertsch (2022)	urban neighbourhood with 130 houses (aggregated)	***✓(Germany)***	***RC-model***	***2020***	cost-optimisation	—
Rasku & Kiviluoma (2019)	Finnish housing stock (aggregated)	— (Finland)	***RC-model***	2030	cost-optimisation	—
Sperber et al. (2020)	***German building stock (single & aggregated)***	***✓(Germany)***	TRNSYS & ***RC-model***	2040	simulation	—
this study	**Irish & German building stock (single & aggregated)**	**✓ (Ireland & Germany)**	**RC-model**	**2019**	**emission-optimisation**	**✓**

[1] by using the thermal mass as a thermal storage

Leerbeck K. et al. (2020). https://doi.org/10.3390/en13112851.
Huckebrink D. & Bertsch V. (2022). https://doi.org/10.1016/j.energy.2022.124605.
Rasku T. & Kiviluoma J. (2019). https://doi.org/10.3390/en12010005.
Sperber E., Frey U. & Bertsch V. (2020). https://doi.org/10.1016/j.enbuild.2020.110144.

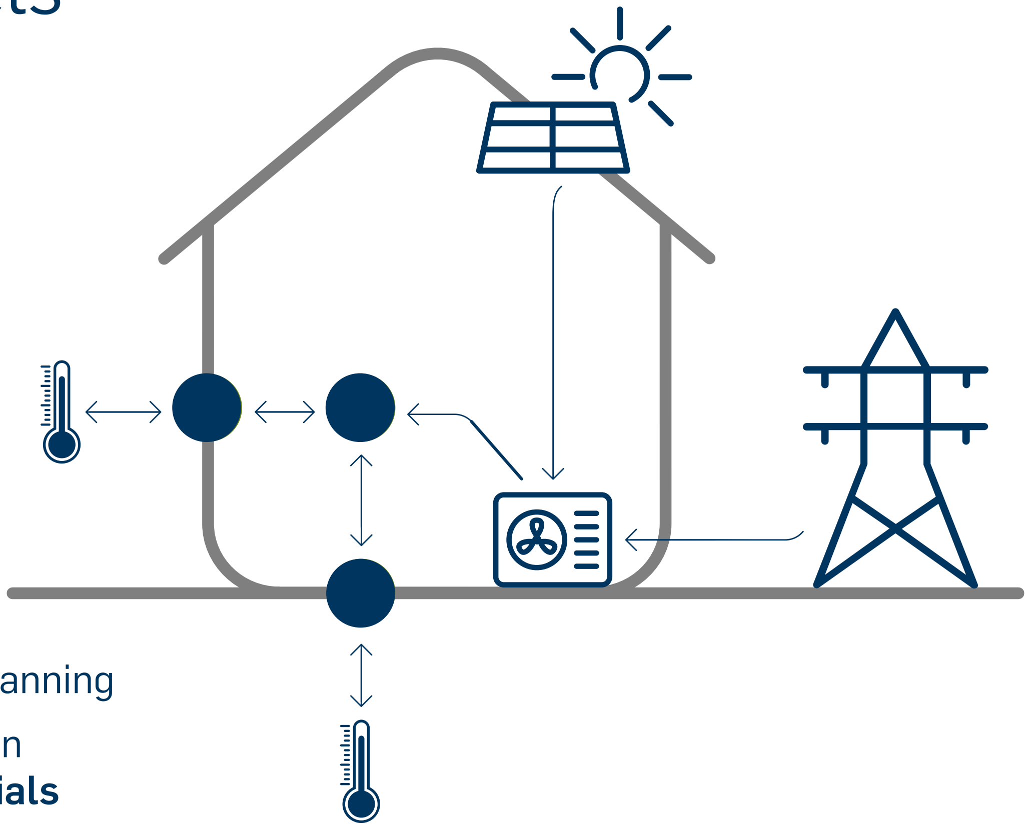
Research Questions

- How…
  - many **emissions** can be reduced
  - by **decoupling** energy demand and supply when operating **heat pumps**
  - by using **passive thermal storage** (mass of buildings)?

- Additionally, what is the impact of **geographical variation** on the potential for emission reductions?

Setup of Building Models

- based on *Backbone*
  with **building model method by** [1, 2]



→
- **scheduling** and **investment** planning
- cost and **emission** minimisation
  → **emission reduction potentials**

[1] Rasku T. & Kiviluoma J. (2019). https://doi.org/10.3390/en12010005.
[2] Huckebrink D. & Bertsch V. (2022). https://doi.org/10.1016/j.energy.2022.124605.
Image sources: heat pump by Lomaxy, thermometer by Adrien Coquet, PV module, sun and transmission tower by Alex Quinto

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Setup of Building Models

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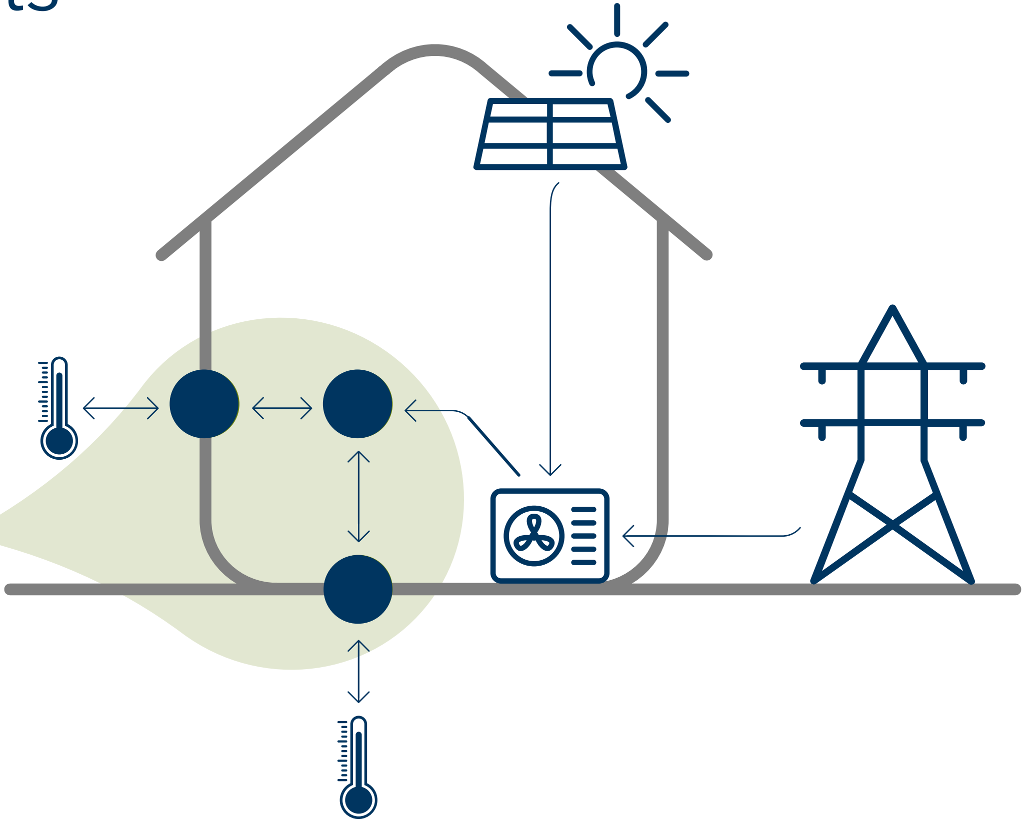

- **reduced order model**
  (2R3C)
- **building parameters**
  (U-values, areas,
  heat capacities)

[1] Rasku T. & Kiviluoma J. (2019). https://doi.org/10.3390/en12010005.
[2] Huckebrink D. & Bertsch V. (2022). https://doi.org/10.1016/j.energy.2022.124605.

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Setup of Building Models

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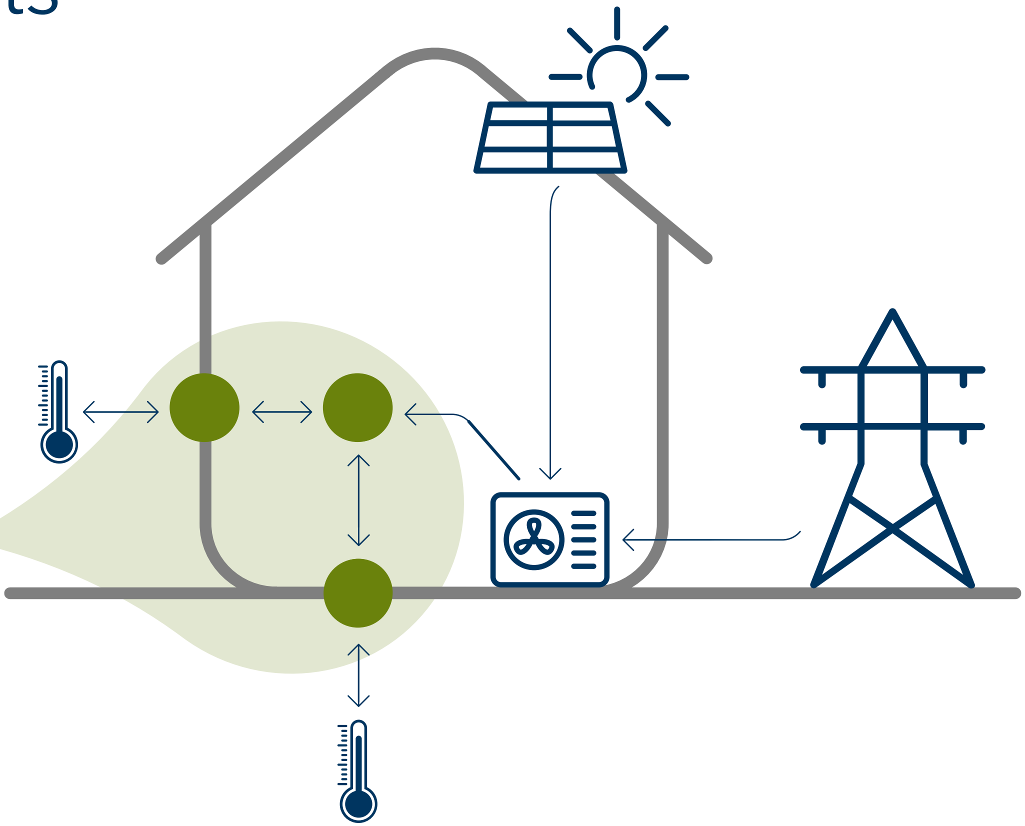

- **endogenous** heating demand
- **thermal flexibility**
  by indoor temperature band
  ⟶ building masses as a
  thermal storage

[1] Rasku T. & Kiviluoma J. (2019). https://doi.org/10.3390/en12010005.
[2] Huckebrink D. & Bertsch V. (2022). https://doi.org/10.1016/j.energy.2022.124605.
Image sources: heat pump by Lomaxy, thermometer by Adrien Coquet, PV module, sun and transmission tower by Alex Quinto

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Archetype Buildings

- **residential archetype buildings**

- building parameters for **Ireland** [1]:
  - **EnergyPlus small-scale models**
  - for typical Irish building archetypes
  - detached houses,
    40% of the Irish building stock

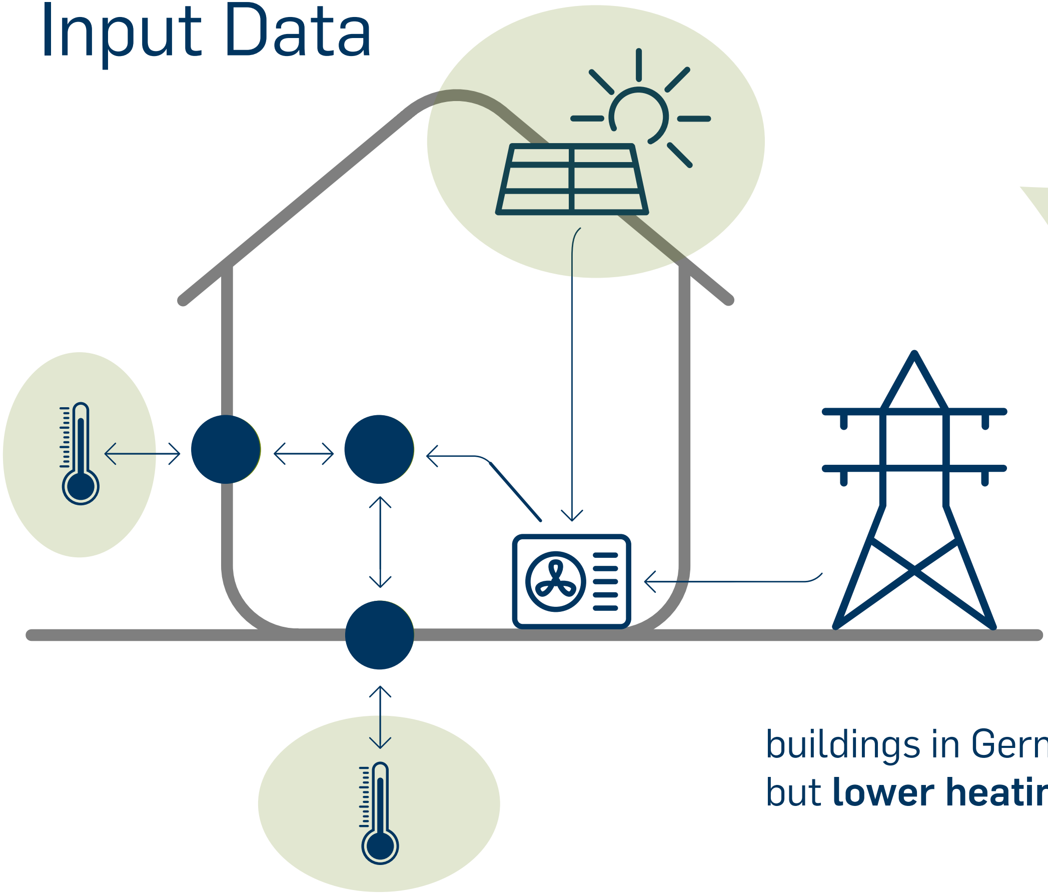
Figure: Detached house used in Irish model [1]

- building parameters for **Germany** [2]:
  - **TRNSYS/reduced-order small-scale models**
  - for typical single-family houses in Germany
  - single-family houses,
    66% of the German building stock

Figure: Single-family house used in German model [1] (based on TABULA [3])

[1] Ali U. et al. (2019). https://doi.org/10.1016/j.enbuild.2019.109364.
[2] Sperber E., Frey U. & Bertsch V. (2020). https://doi.org/10.1016/j.enbuild.2020.110144.
[3] TABULA (2014). https://doi.org/10.1016/j.enpol.2014.01.027.

Input Data



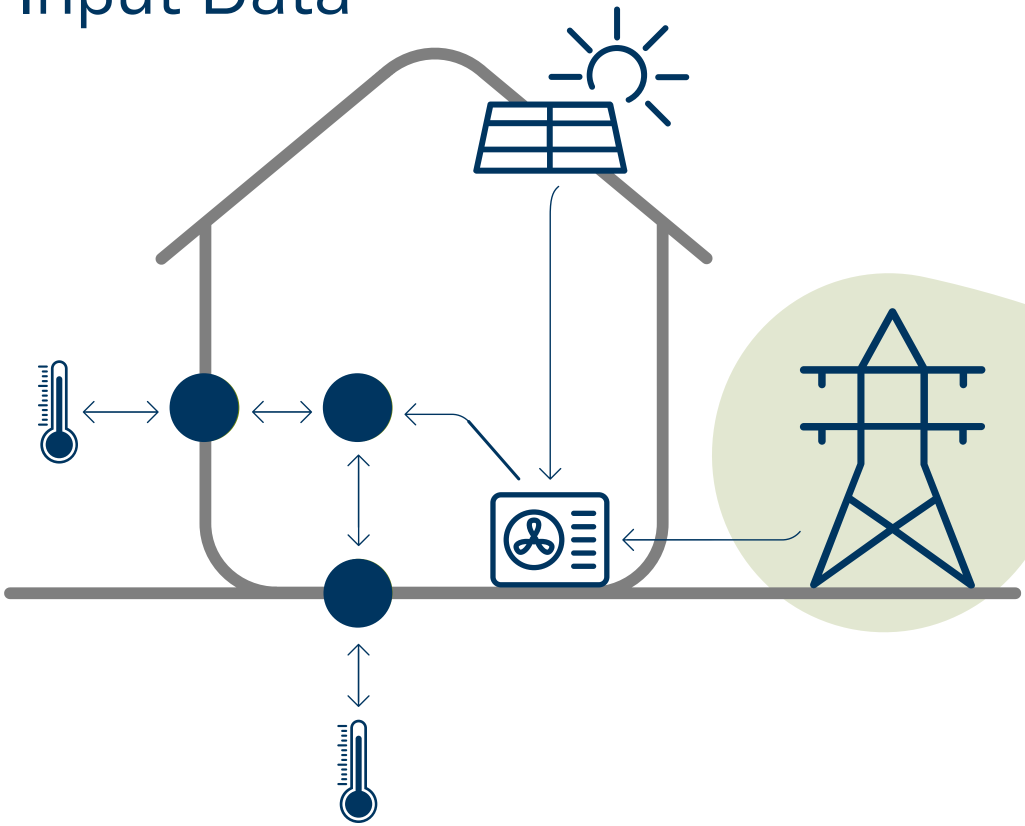
data for **2019**

- **weather data**
  for Berlin & Dublin

buildings in Germany **better insulated**,
but **lower heating demand** in Ireland due to milder winters

Image sources: heat pump by Lomaxy, thermometer by Adrien Coquet, PV module, sun and transmission tower by Alex Quinto

Input Data



data for **2019**

- **variable emission factors** for the upstream grid

- fuel and electricity **costs**

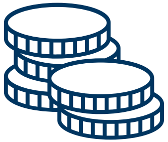
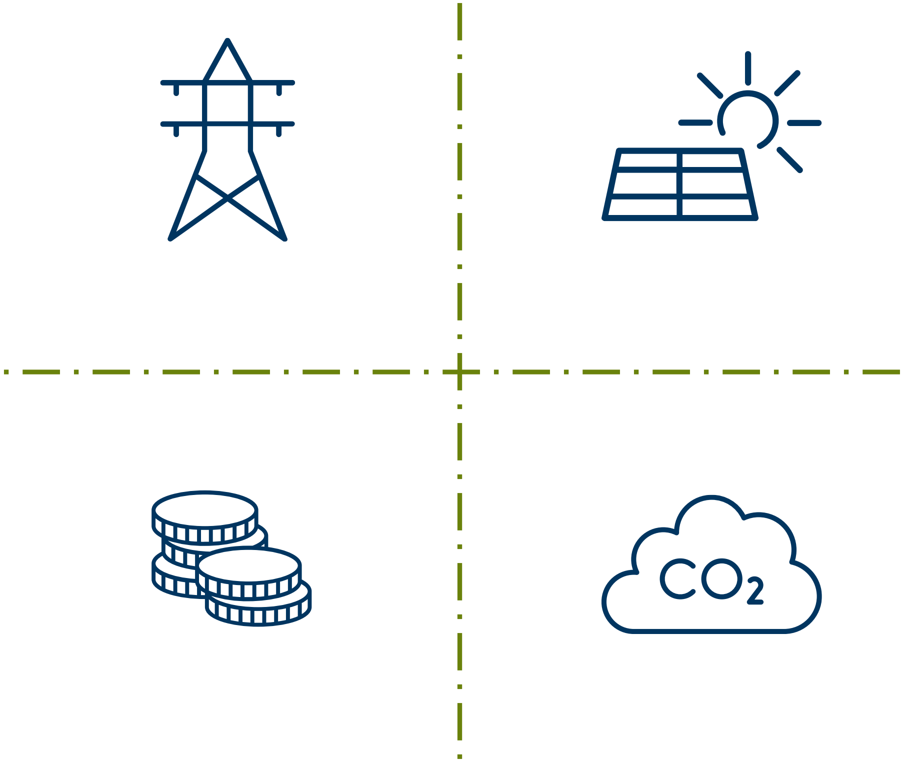


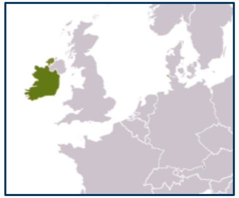
Image sources: heat pump by Lomaxy, thermometer by Adrien Coquet, PV module, sun and transmission tower by Alex Quinto, CO2 by Circlon Tech

Scenarios

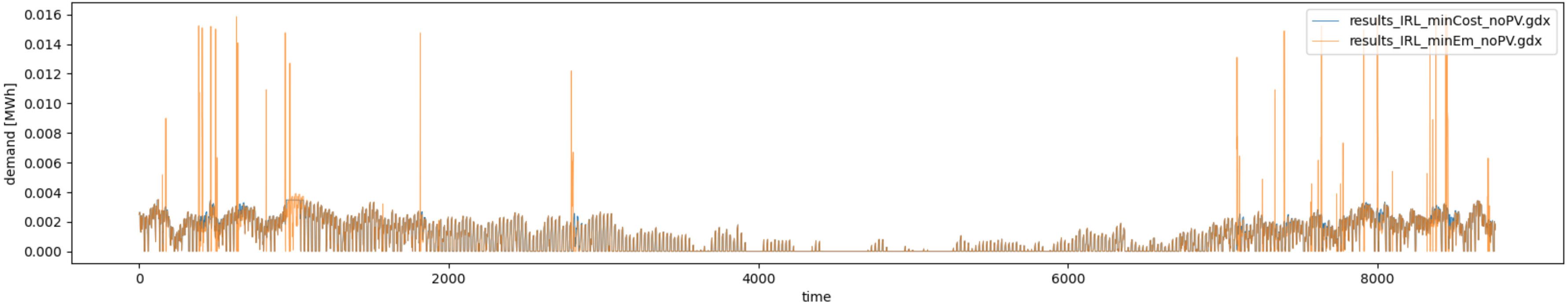
emission reduction potentials



Results – Thermal Flexibility



flexibility of thermal mass
slightly used



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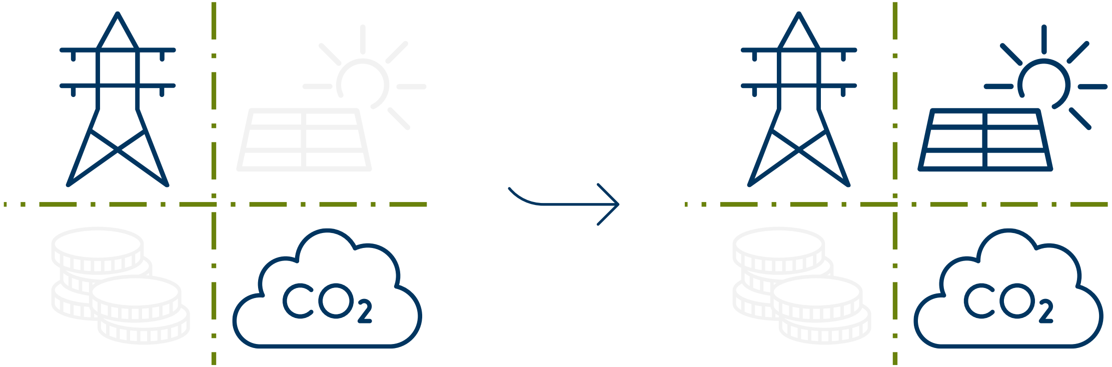
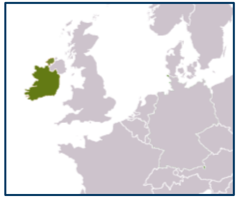
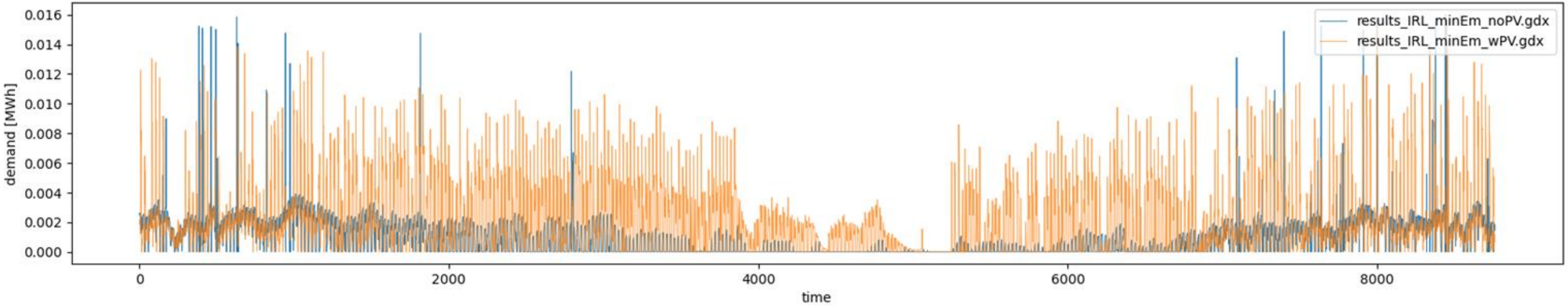
Results – Thermal Flexibility

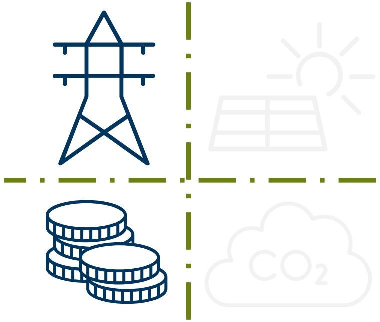




flexibility of thermal mass
thoroughly used

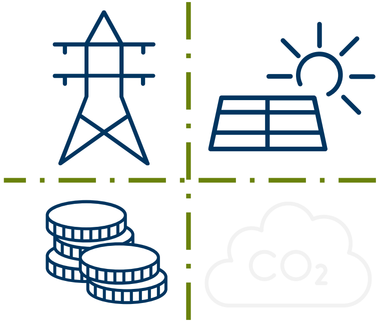


Results – Emission Reductions



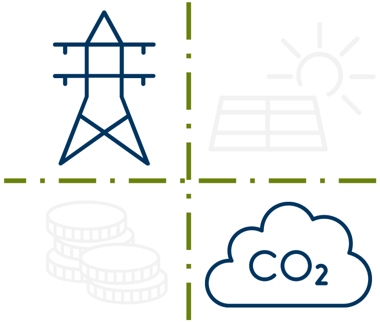
reference case

no flexibility used



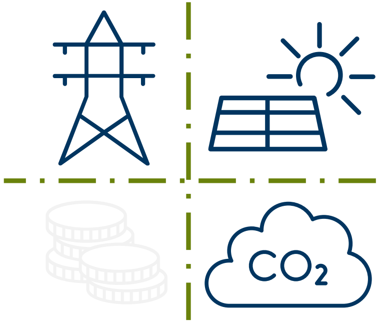
5% 24%

emission reduction potentials



1% 0.2%

emission reduction potentials



56% 44%

emission reduction potentials

Limitations

- RC-model used—possibly not as accurate as computational-intensive white-box-models but considerably faster

Outlook

- inclusion of all **archetype building types** for Ireland and Germany
- **upscaling** of buildings for each country and comparison
- spatial diversion of **weather data** for each country

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thank you

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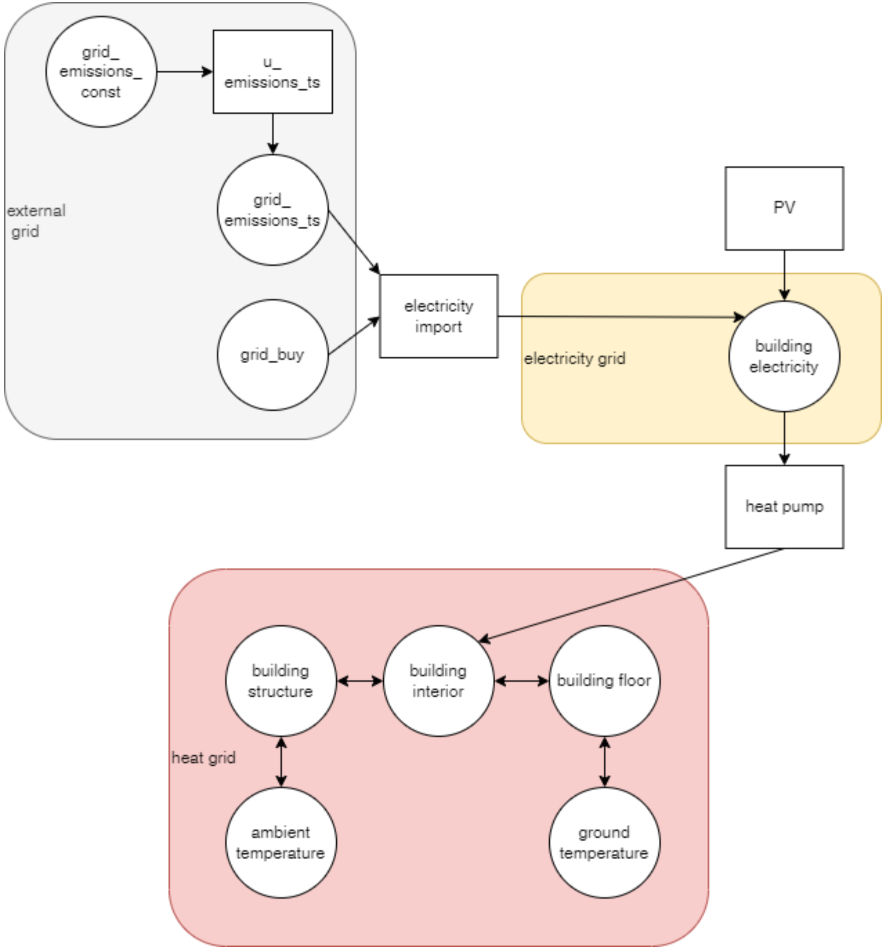
Setup of Building Models

Figure: Own model structure of the building model in Backbone



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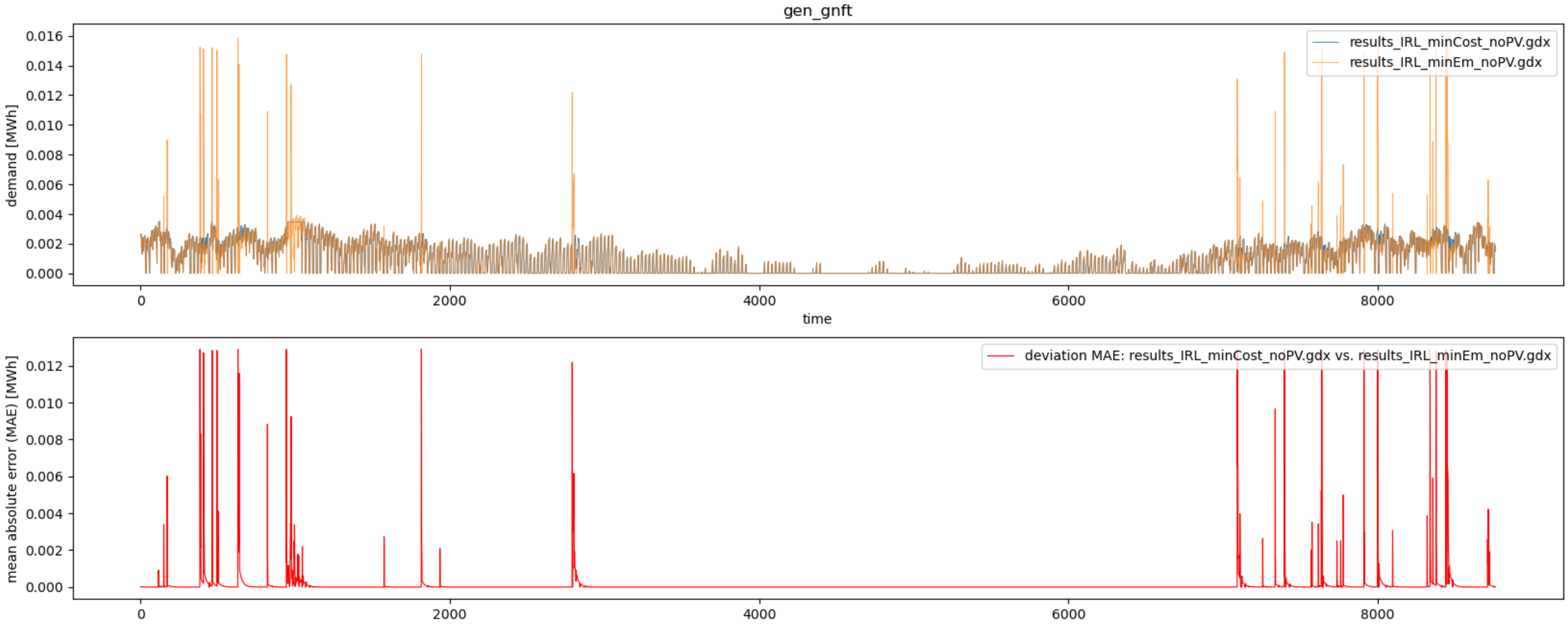
Results

- **min cost** vs. **min emissions** (**w/o PV**): flexibility is slightly used



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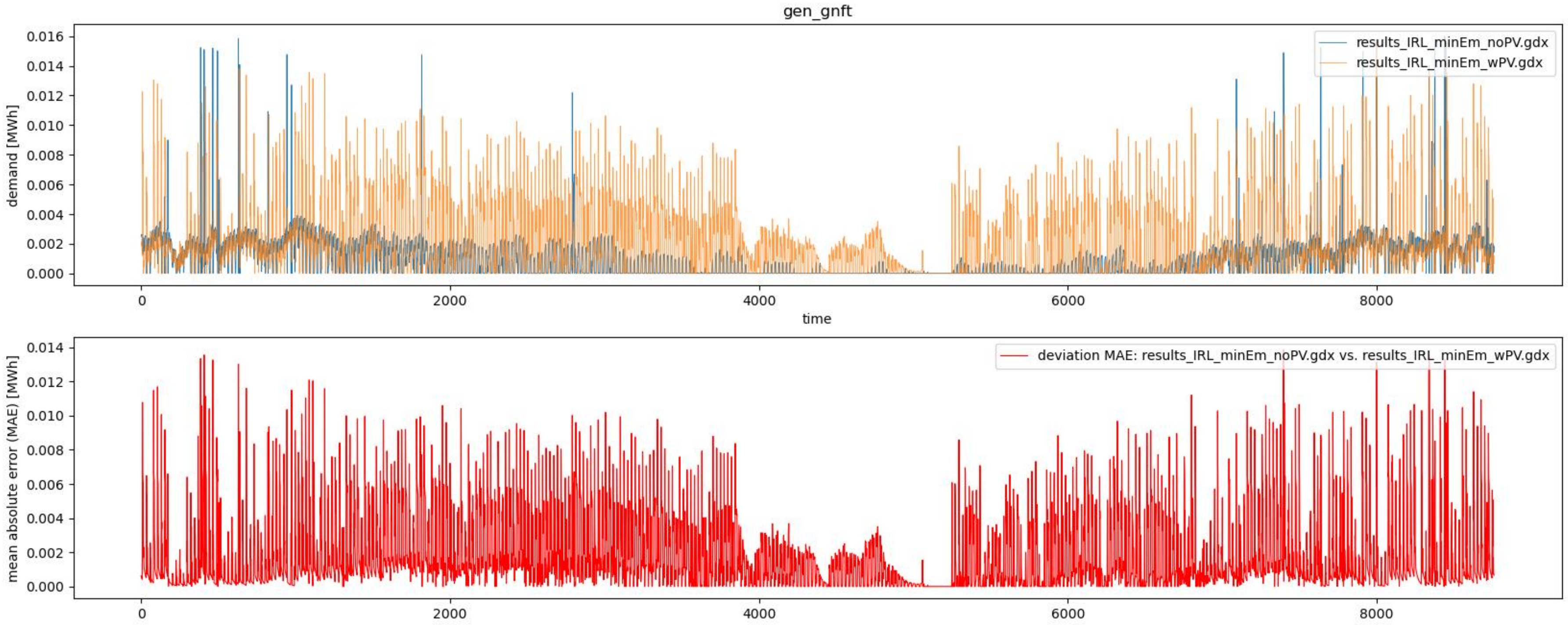
Results

- **min emissions** — **w/o PV** vs. **with PV**: flexibility is thoroughly used



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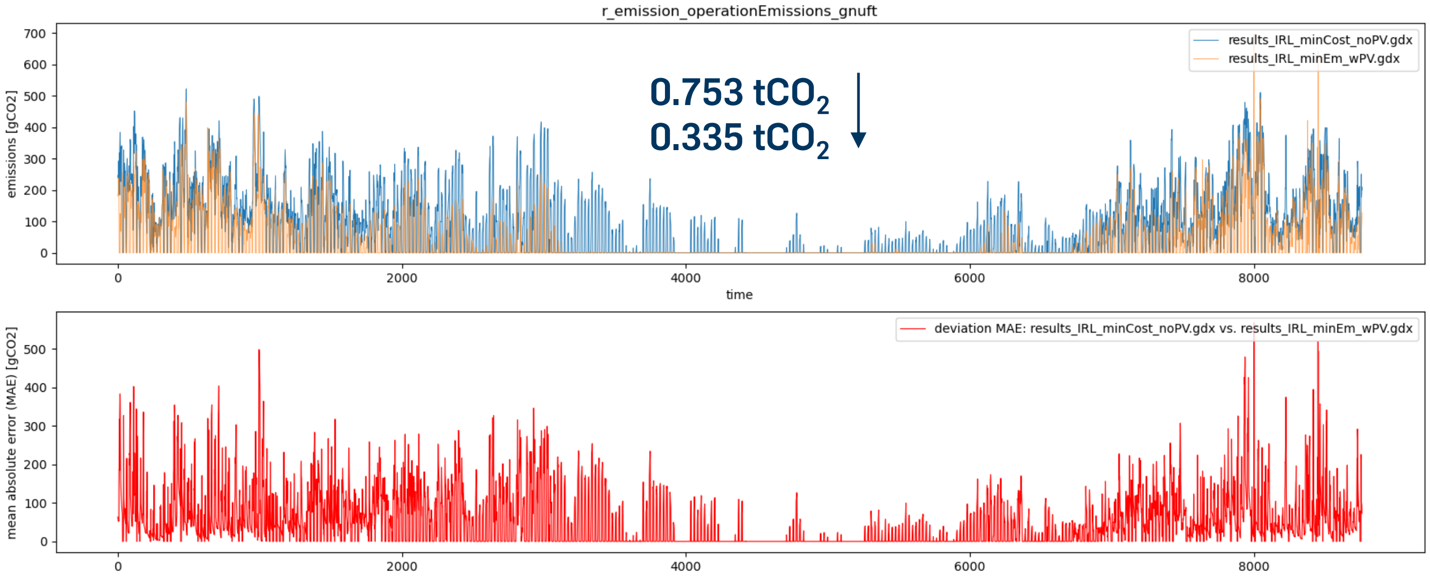
Results

- goal: assessing the **emission-reduction potential** of the **thermal flexibility measures**
- **min cost w/o PV** vs. **min emissions with PV**:



relative deviation: 55.5% (max)

comparison:

- w/o PV — min cost vs. min emissions: **1.0%** emission reduction (min)
- with PV — min cost vs. min emissions: **53.2%** emission reduction

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Results

- **min emissions — w/o PV** vs. **with PV**: flexibility is thoroughly used