# Regional impacts of electricity system transition in Central Europe until 2035

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IAEE Online Conference

# Vision to radically transform European electricity system: providing clean electricity and economic growth for all

## European clean energy vision


Source: EC. *Going Climate-Neutral by 2050* (European Commission (EC), Luxembourg, 2019).

## Two of the key elements of this vision

**Large-scale cost-efficient deployment of renewables**

**Consistent with Paris Agreement targets**

**Inclusive and equitable transition for all regions**

**Consistent with Sustainable Development Goals**

# This vision requires a large-scale deployment of renewable capacities
# So far, renewable capacities are unevenly deployed across regions

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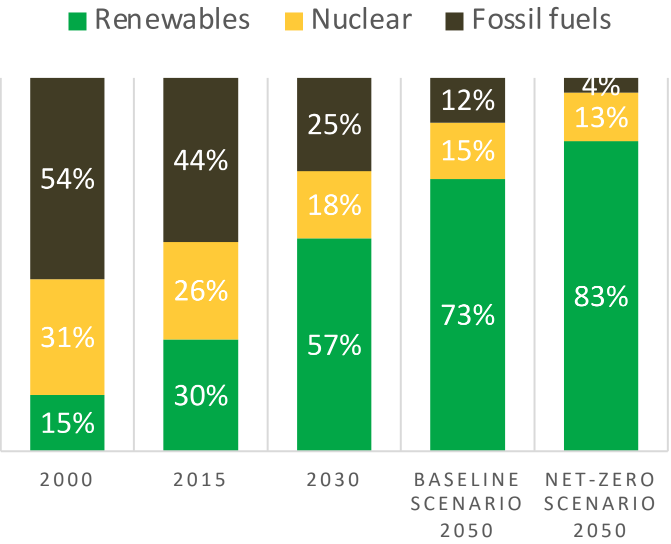
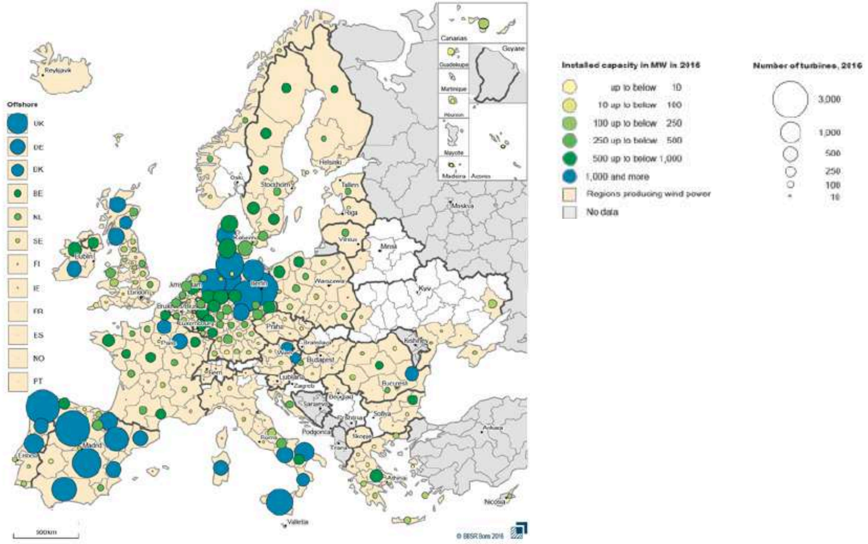
## Shares in electricity generation




Source: EC. *Going Climate-Neutral by 2050* (European Commission (EC), Luxembourg, 2019).

## Example: Regionally uneven wind capacity




Source: BBSR. *The Windpower Dataset* (BBSR, Bonn, 2016).

# Associated regional impacts might not be evenly distributed as well

| Regional benefits | Regional burdens |
|---|---|
| Chances for economic development | Increased electricity costs and prices |
| New employment | Ecosystem and wildlife impacts |
| Tax revenue for communities | Visual impacts and sound annoyance |
| Reduced air pollution | Job losses (e.g., phasing out coal) |
| Improved human health | Land use conflicts (e.g., agriculture) |
| Decreased dependence on fossil fuels | Decreased property values |

Based on: Wolske et al. (2017), Rand et al. (2017), Carlisle et al. (2014), Chmutina et al. (2013), Wiesma et al. (2014), Langer et al. (2016), Tsoutsos et al. (2005), Lehr et al. (2012), Knoblauch et al. (2018), Kraft et al. (2009).

# Research questions

What are the **regional impacts** of reaching **renewable electricity targets in Central Europe by 2035** in terms of:

- **Total system costs**
- Life-cycle **employment**
- Direct **greenhouse gas emissions**
- Direct **particulate matter emissions**
- Direct **land use**

as compared to the current (2018) electricity system?

How equally are these regional impacts distributed and what are the trade-offs between

- **Minimizing total system costs**,
- **Maximizing regional equality**,
- **Maximizing renewable electricity generation**?

# Model: Soft-linked electricity system model EXPANSE-PyPSA

**Spatial resolution**: NUTS-3 regions (AT, CH, DE, DK, FR, PL)
**Temporal resolution:** hourly (single-year 2035)

## Key features

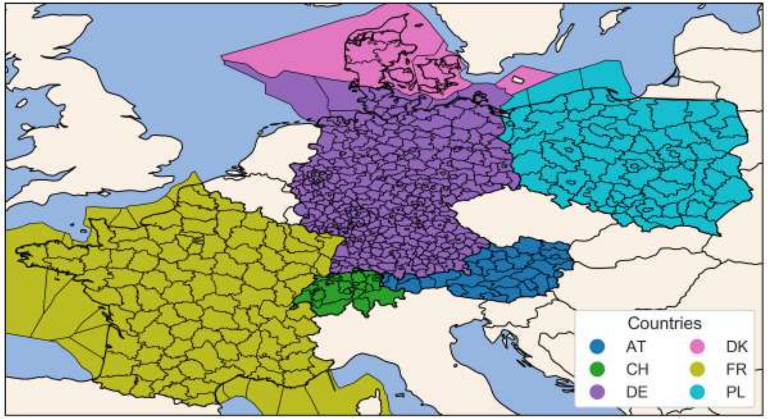
- High spatial resolution (NUTS-3 regions)
- **Regional impacts:** system costs, employment, greenhouse gas emissions, particulate matter emissions, and land use
- **Regional equality of impacts** measured with Gini index
- Cost-optimal and near-optimal spatial allocation scenarios with **Modeling to Generate Alternatives (MGA)** method
- Includes storage and transmission
- Hourly operation and capacity investment

## Model overview

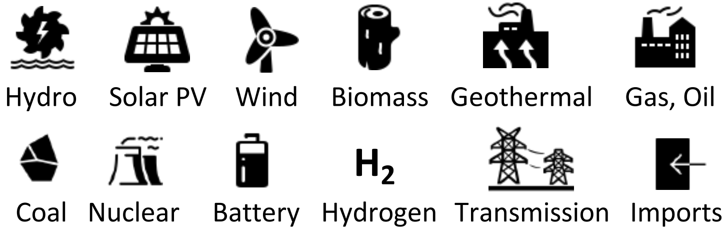
**Open-source data** → **EXPANSE model** → **PyPSA model** → **Regional impacts**

**EXPANSE -> near-optimal spatial allocation of electricity generation capacity**
**Near-optimal = up to 20% higher total LCOE than cost-optimal LCOE**
**PyPSA -> post hoc cost-optimization of hourly generation, storage, and transmission**

## Modeled regions




## Modeled technologies




References: Trutnevyte, E. (2013); Sasse, JP., Trutnevyte, E. (2019); Brown, T. et al. (2018).

# Scenario definitions and electricity supply targets

## Definition

**100 MGA scenarios**
Scenarios with cost-optimal and near-optimal total system costs

**Frozen generation capacity scenario**
*Electricity generation capacity*: same as in 2018.
*Electricity demand*: same 8% increase as for all other scenarios.

**Min. system cost scenario**
Scenario with least total electricity system costs

**Max. regional equality scenario**
Most regionally equal system costs per capita

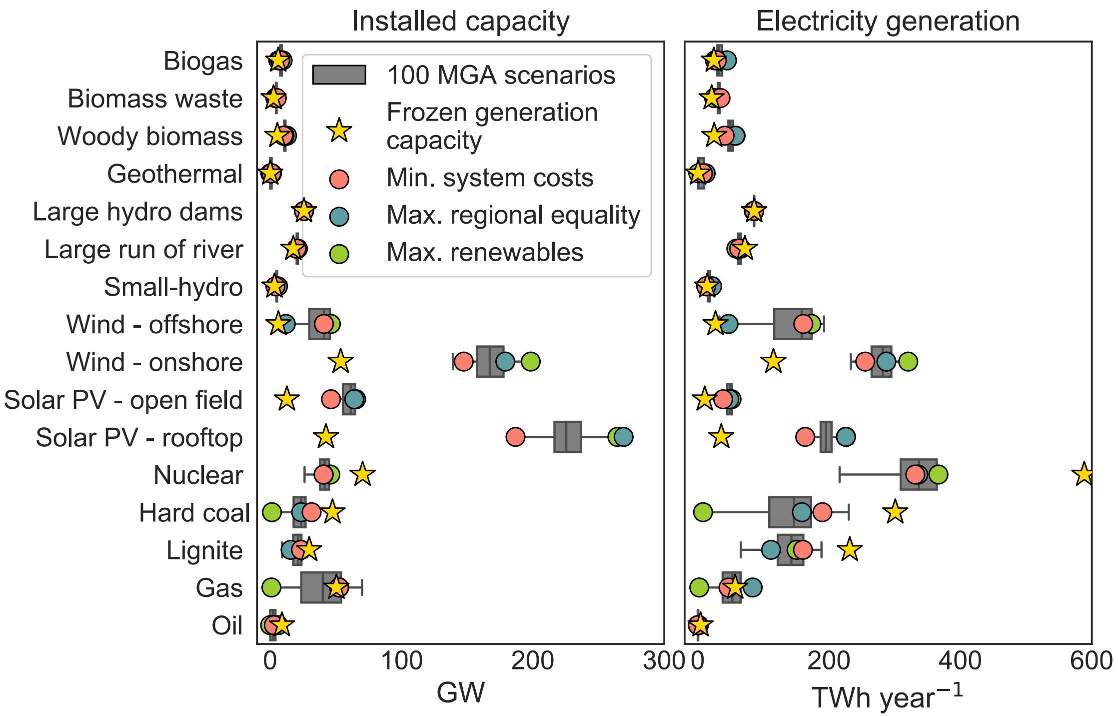
**Max. renewables scenario**
Maximum annual renewable electricity generation

## Modeled targets (except for Frozen generation capacity scenario)

| Country | Country-level targets (2035) |
|---|---|
| Austria | 100% renewable electricity supply |
| Denmark | 100% renewable electricity supply |
| France | < 50% nuclear electricity supply |
| Germany | > 70% renewable electricity supply |
| Poland | < 40% electricity from coal |
| Switzerland | > 11.4 TWh electricity from wind, solar, biomass and geothermal |

Country targets are derived based on: NECP for Austria (2019), NECP for Denmark (2019), NECP for France (2019), Koalitionsvertrag for Germany (2018), NECP for Poland (2019), Erneuerbare Energiegesetz for Switzerland (2016).

# Results: Near-optimal MGA scenarios of the electricity system in 2035

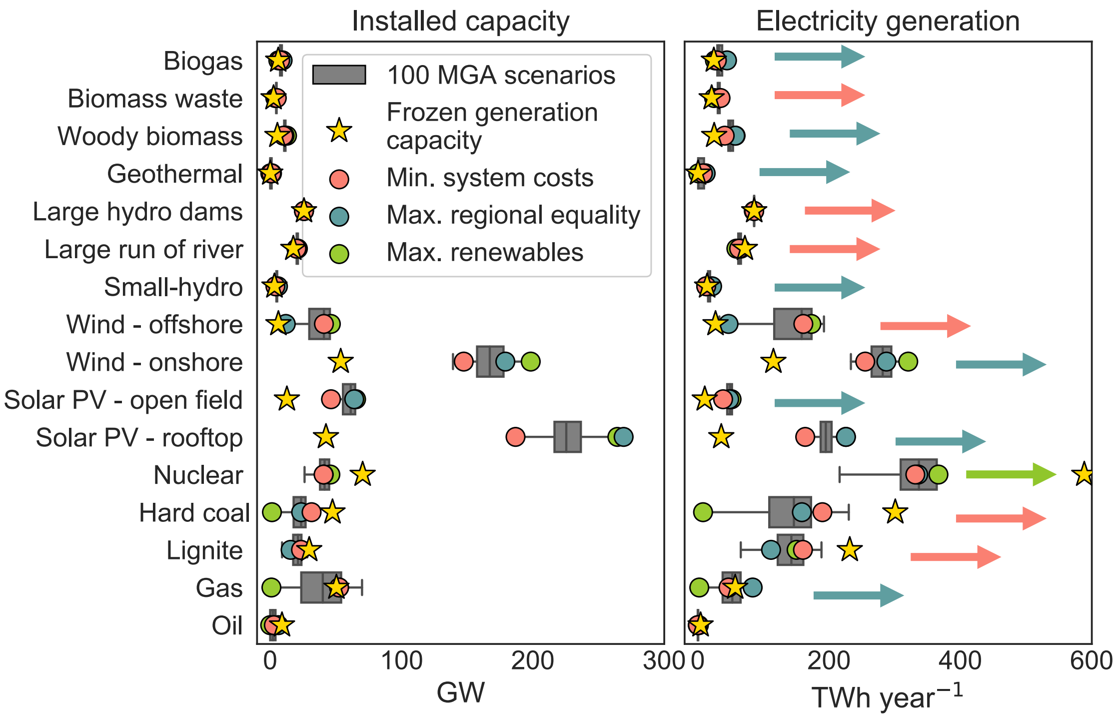



**Frozen generation capacity scenario**
Same generation capacity as in 2018.

**Max. renewables scenario**
Maximum renewable electricity generation

Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Results: Near-optimal MGA scenarios of the electricity system in 2035




Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

**Frozen generation capacity scenario**
Same generation capacity as in 2018.

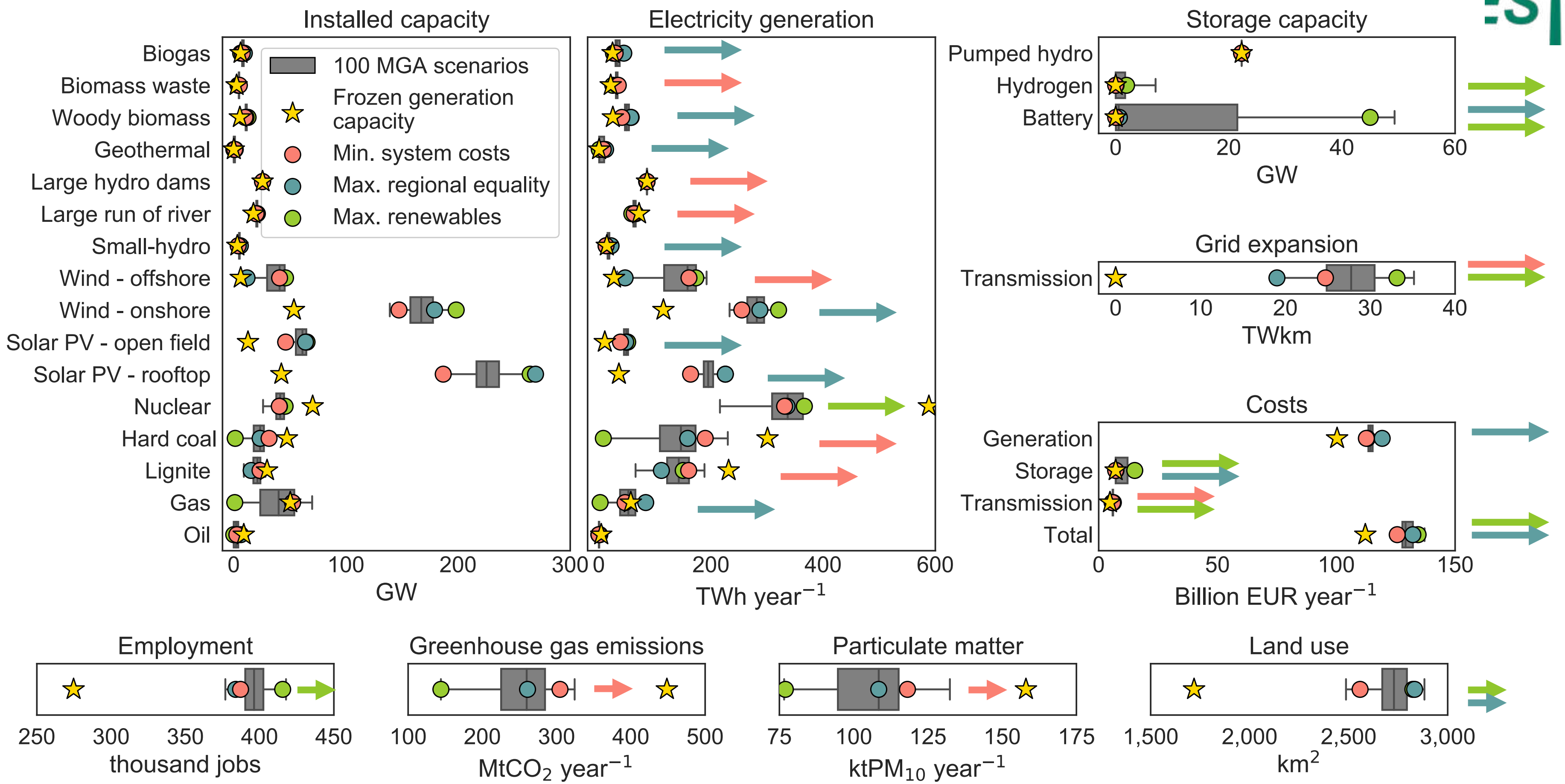
**Max. renewables scenario**
Maximum renewable electricity generation

**Improves regional equality**

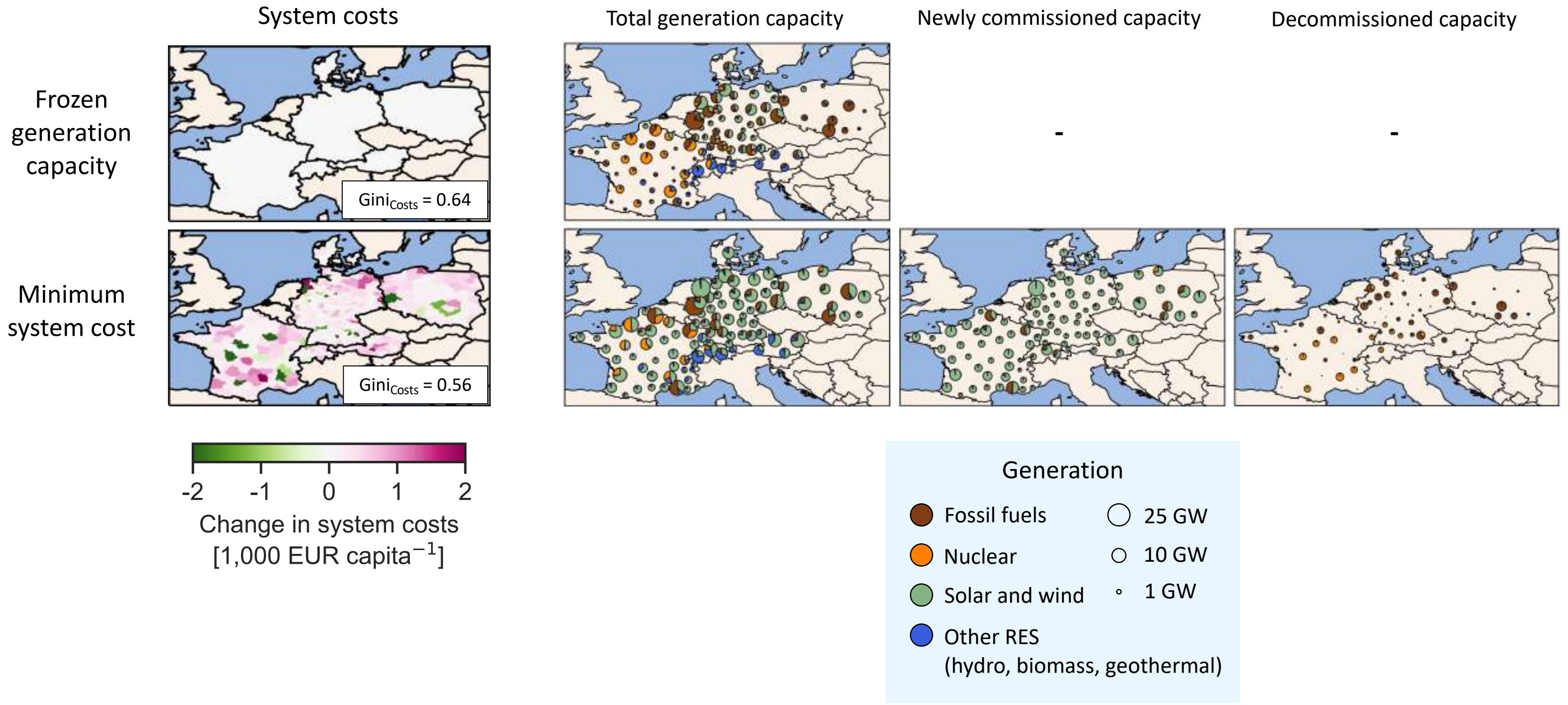
**Improves cost-efficiency**

**Improves renewable electricity integration**

# Results: Near-optimal MGA scenarios of the electricity system in 2035



# Results: Regional impacts of electricity system infrastructure




Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

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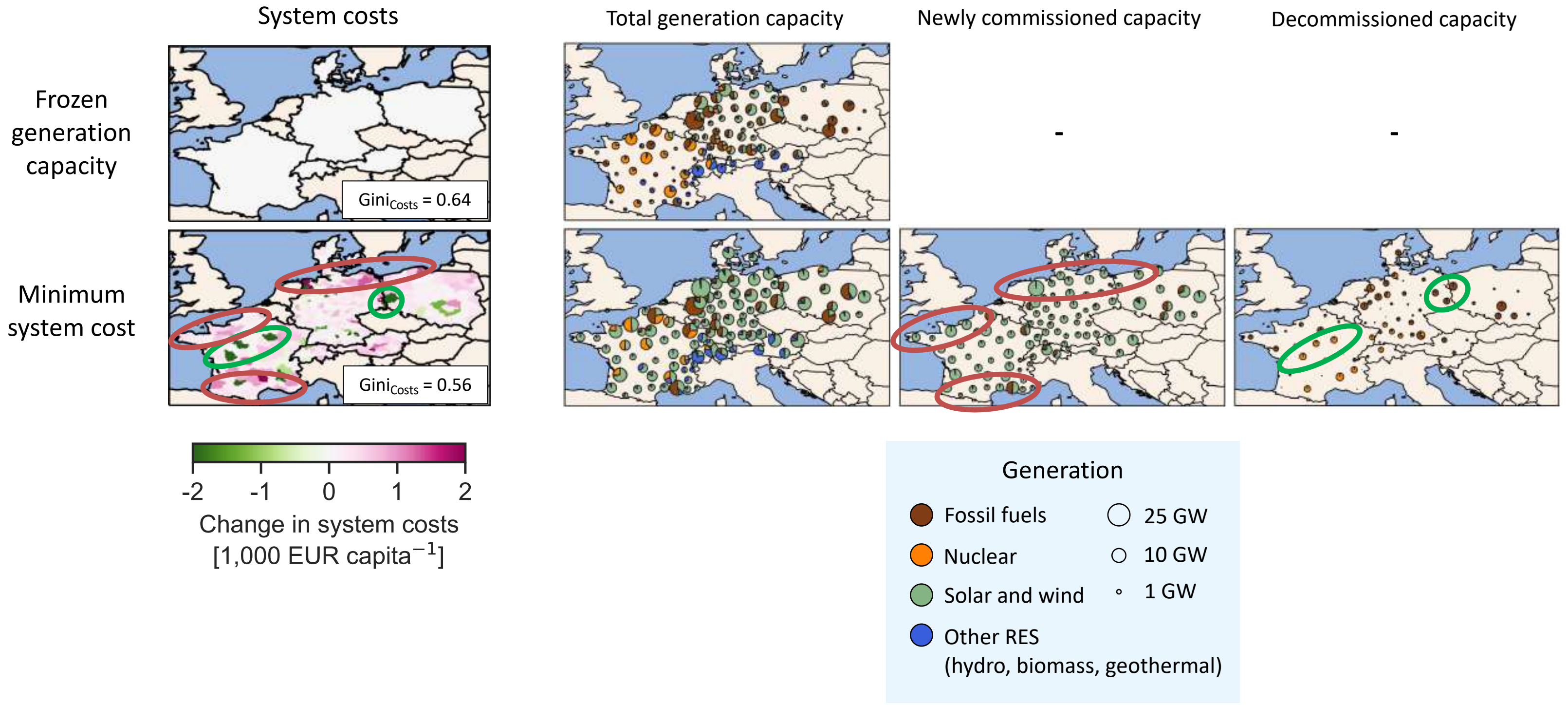


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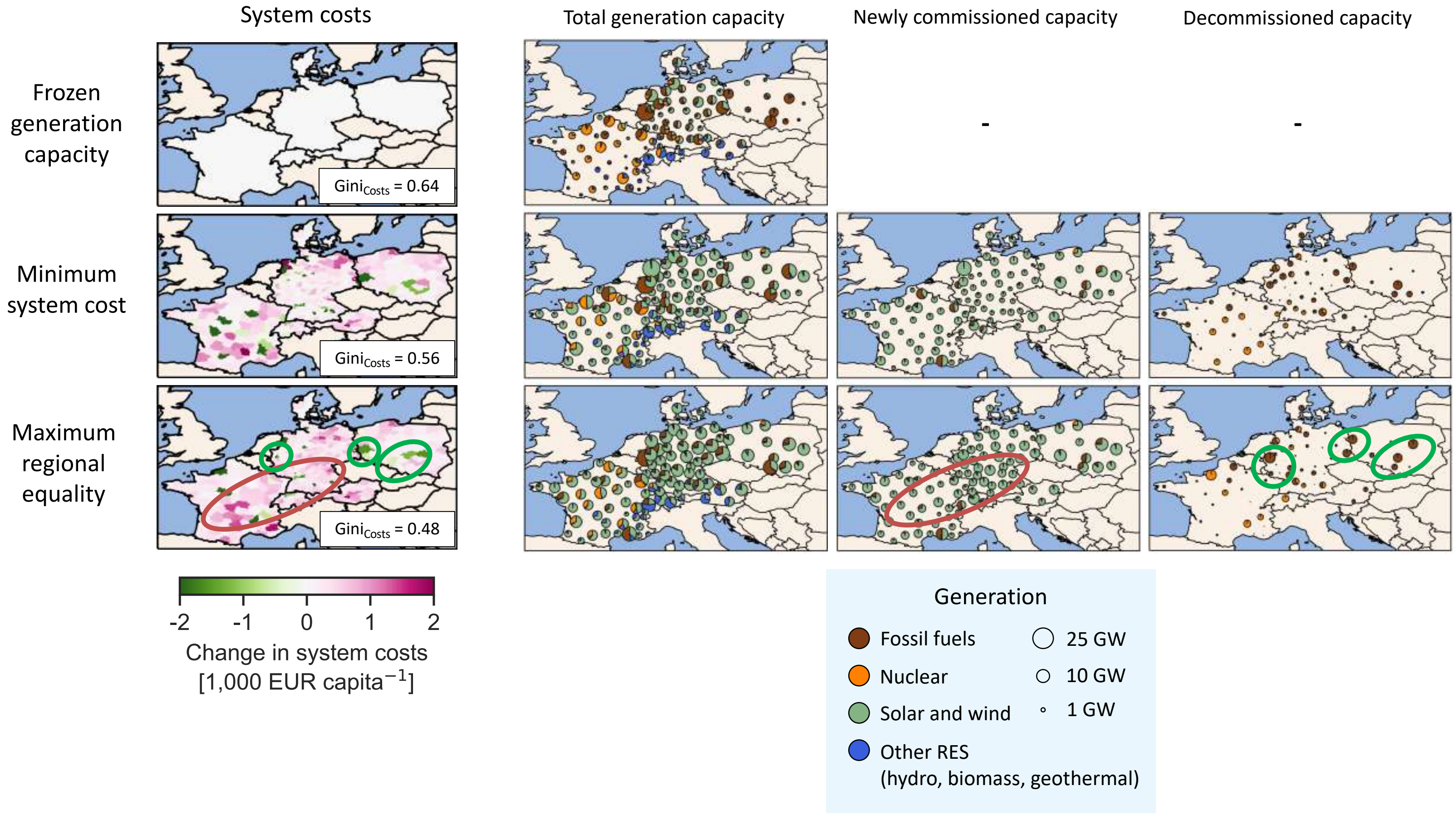


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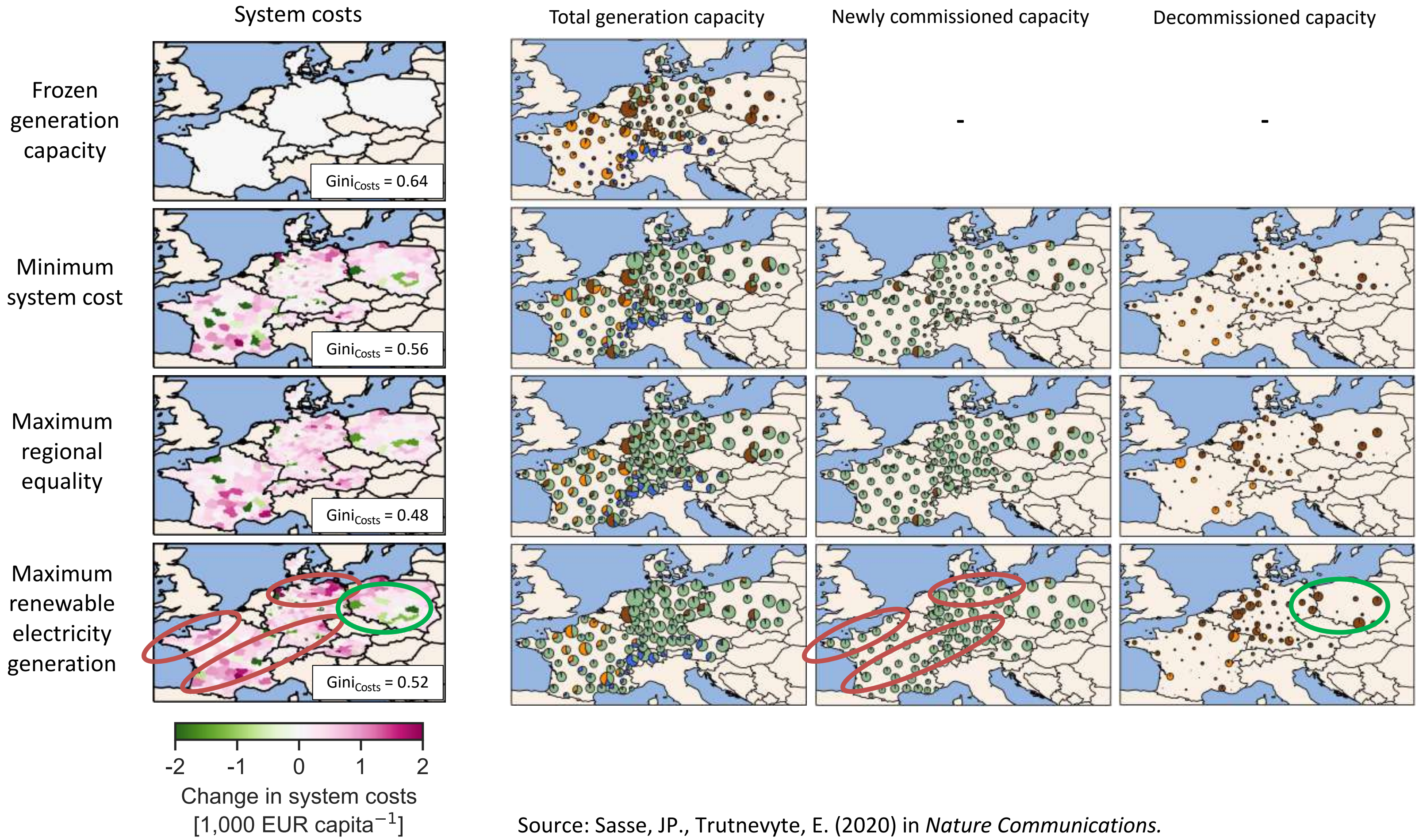


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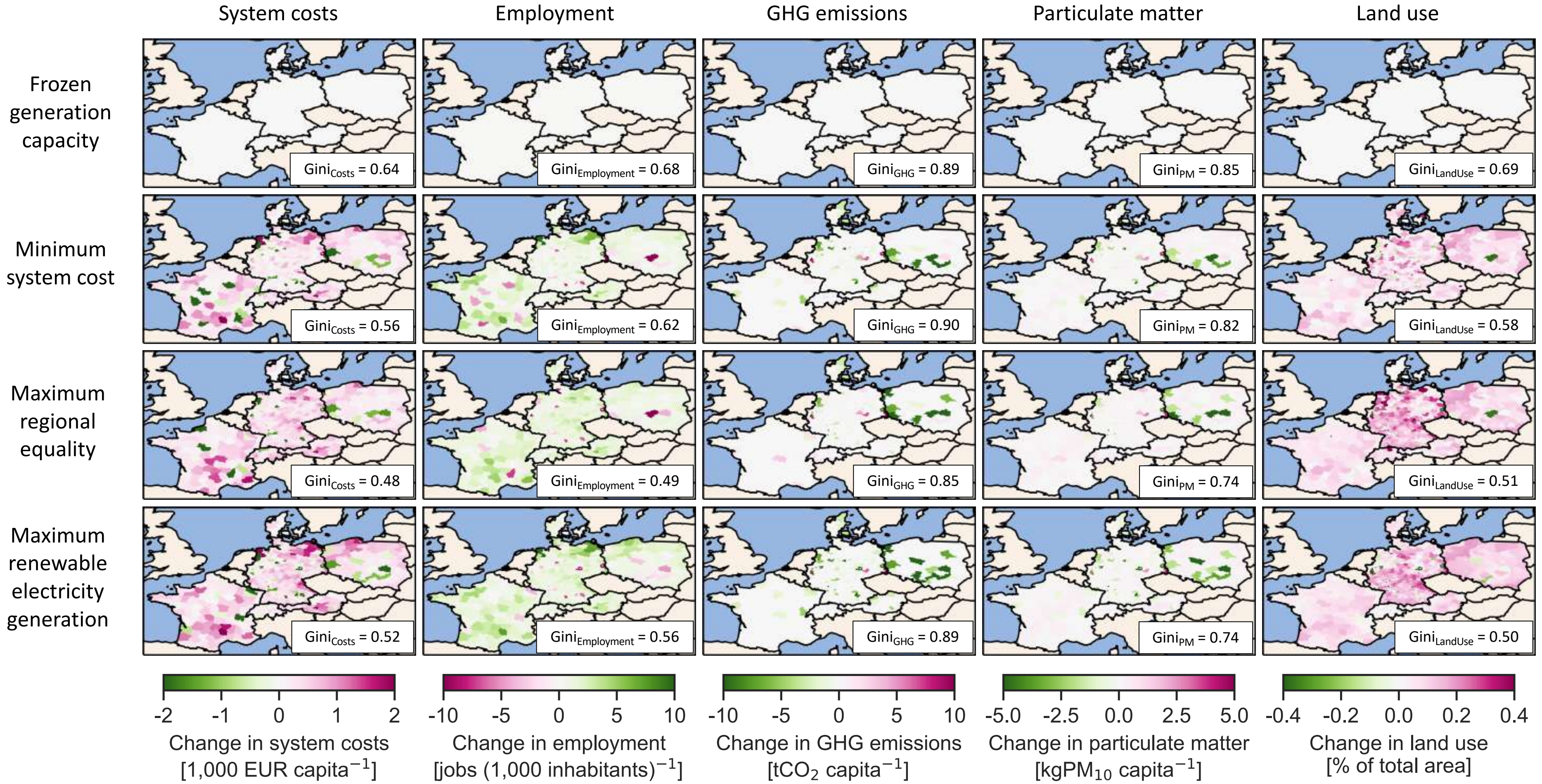
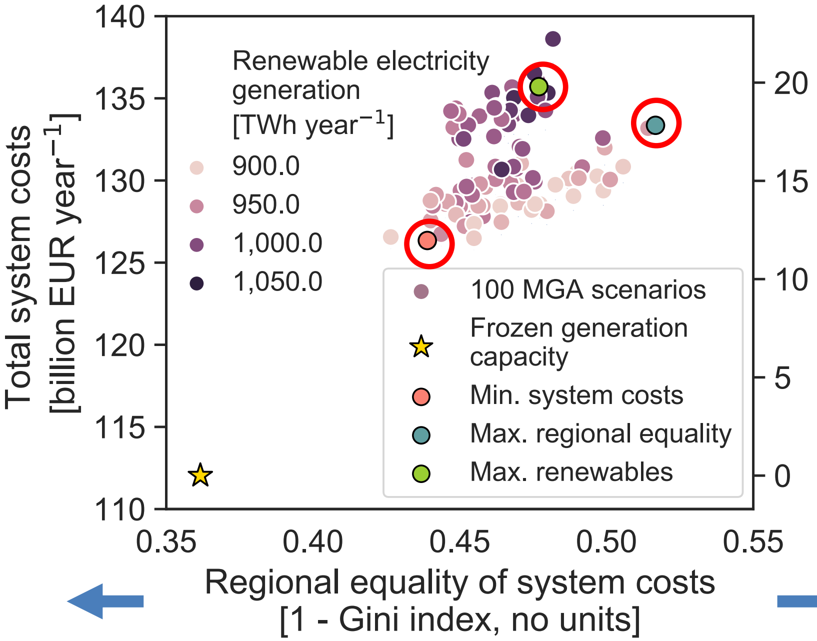


# Results: Trade-off between costs, equality, and renewable electricity



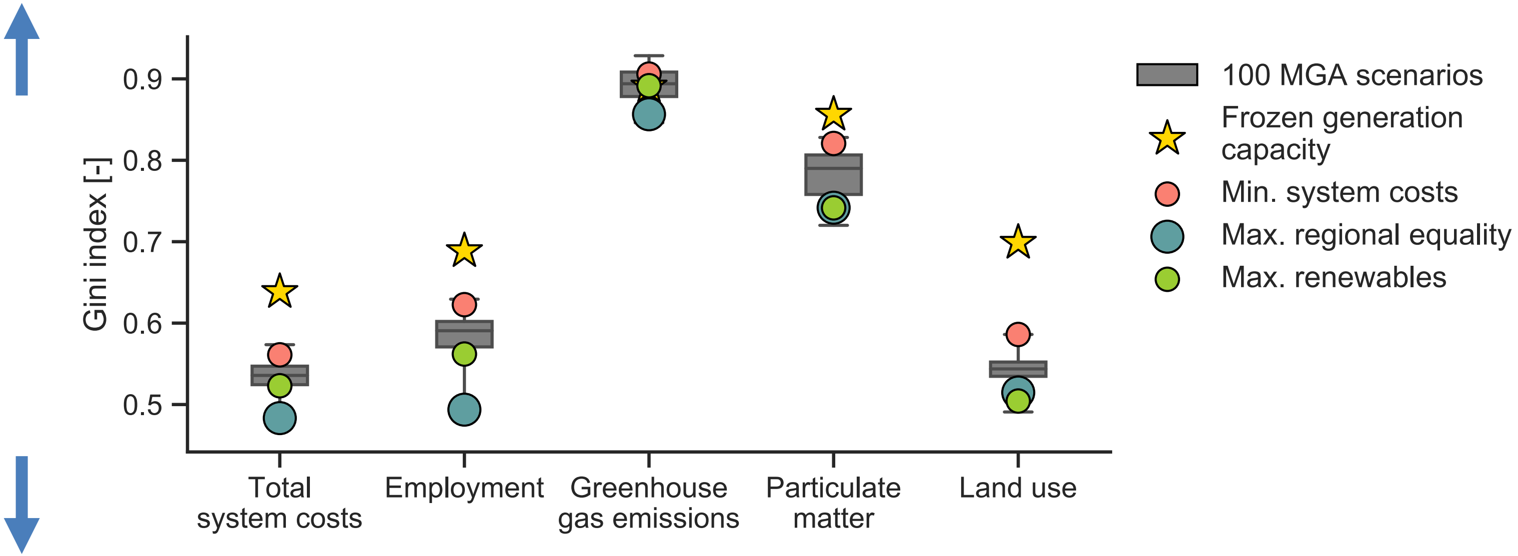

**Less equality**

**More equality**

Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Results: Regional equality of impacts

**Less equal impacts**




**More equal impacts**

Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Conclusions

Compared to 2018, Central European electricity targets of 2035

- increase **system costs** by **12–22%**,
- increase **regional equality** of system costs by **18–43%**,
- increase **renewable electricity generation** by **97–140%**

**Regional impacts** of system costs, employment, greenhouse gas and particulate matter emissions, and land use are mostly **driven by** changes in generation capacity from **solar PV, wind, nuclear, coal, and gas**.

The aims of improving cost-efficiency, regional equality, and renewable electricity generation have vastly different implementation pathways and cannot be reached simultaneously.

| | | |
|---|---|---|
| **Min. system costs** | -> | **encourages regional inequalities for all impacts** |
| **Max. regional equality of costs** | -> | **encourages regional equalities,** but with **higher impacts** |
| **Max. renewable electricity generation** | -> | **reduces regional inequalities**, with **high costs** and **land use impacts** |

# Thank you!

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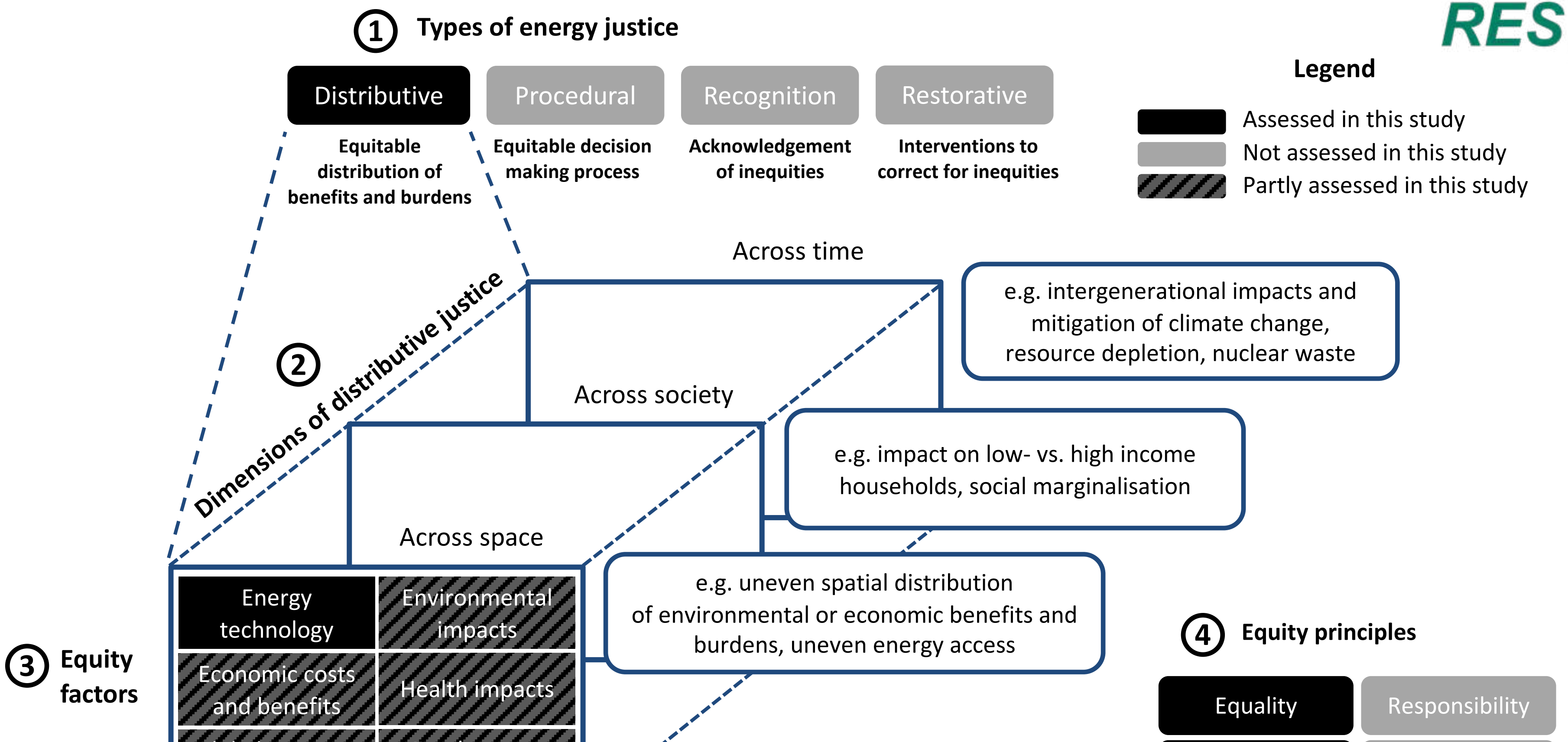
# Method: Energy justice framework




Adapted from:
Sasse, JP., Trutnevyte, E. (2019).

# Technology-specific impact factors

| Technology | Regional life-cycle employment (Jobs/MW) | Direct greenhouse gas emissions ($tCO_{2\text{-eq}}/MWh_{el}$) | Direct particulate matter formation ($gPM_{10\text{-eq}}/MWh_{el}$) | Direct land-use ($m^2/MWh_{el}$) |
|---|---|---|---|---|
| *Renewable electricity generation* | | | | |
| Wind (onshore) | 0.395 (Kis et al., 2018) | - | - | 2.280 (Fthenakis and Kim, 2009) |
| Wind (offshore) | 1.343 (Kis et al., 2018) | - | - | - |
| Solar PV (open field) | 0.336 (Kis et al., 2018) | - | - | 0.700 (Fthenakis and Kim, 2009) |
| Solar PV (rooftop) | 0.336 (Kis et al., 2018) | - | - | - |
| Large hydro dams | 0.857 (Kis et al., 2018) | - | - | 4.100 (Fthenakis and Kim, 2009) |
| Large run of river | 1.326 (Kis et al., 2018) | - | - | 0.003 (Fthenakis and Kim, 2009) |
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Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Impact definitions

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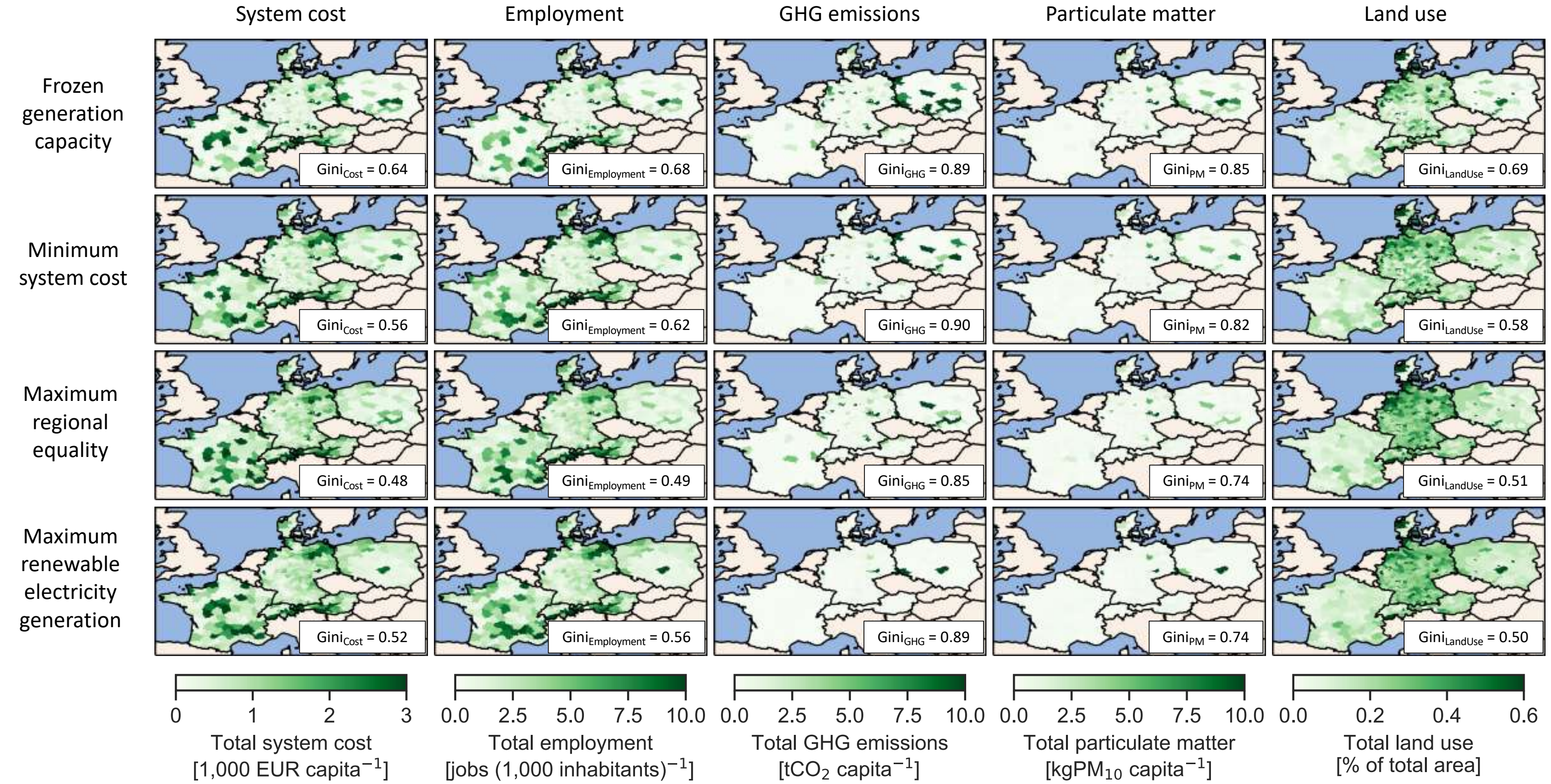
| Impact category | Regional impact | Definition | Unit |
|---|---|---|---|
| **Technical impact** | Electricity system infrastructure | Electricity generation, storage, and transmission capacity | MW |
| **Economic impact** | Total system costs | Annual capital and variable costs (i.e. fuel, operation and maintenance) for electricity generation, storage and transmission | EUR per year |
| **Social impact** | Employment | Annual direct life-cycle jobs for electricity generation and storage. For all technologies, we include jobs in construction, installation, operation, maintenance, and decommissioning. For biomass, coal and lignite, we additionally include jobs in fuel extraction and transport. | Jobs per year |
| **Climate change impact** | Greenhouse gas emissions | Annual direct greenhouse gas emissions from fuel combustion for electricity generation | tons $CO_{2\text{-eq}}$ per year |
| **Health impact** | Particulate matter | Annual direct particulate matter formation from fuel combustion for electricity generation | tons $PM_{10\text{-eq}}$ per year |
| **Environmental impact** | Land use | Direct land use for electricity generation | $km^2$ |

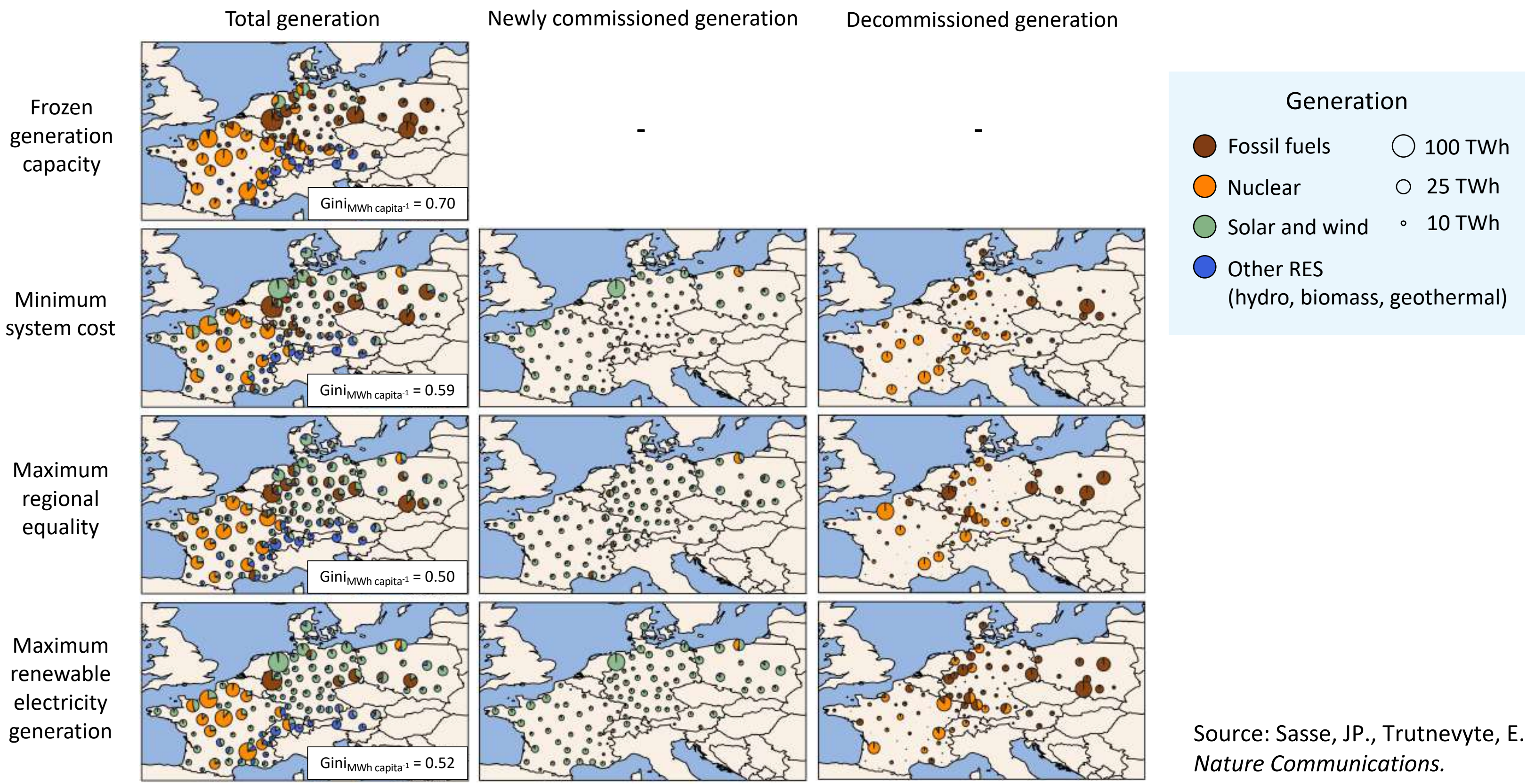
Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Total regional impacts



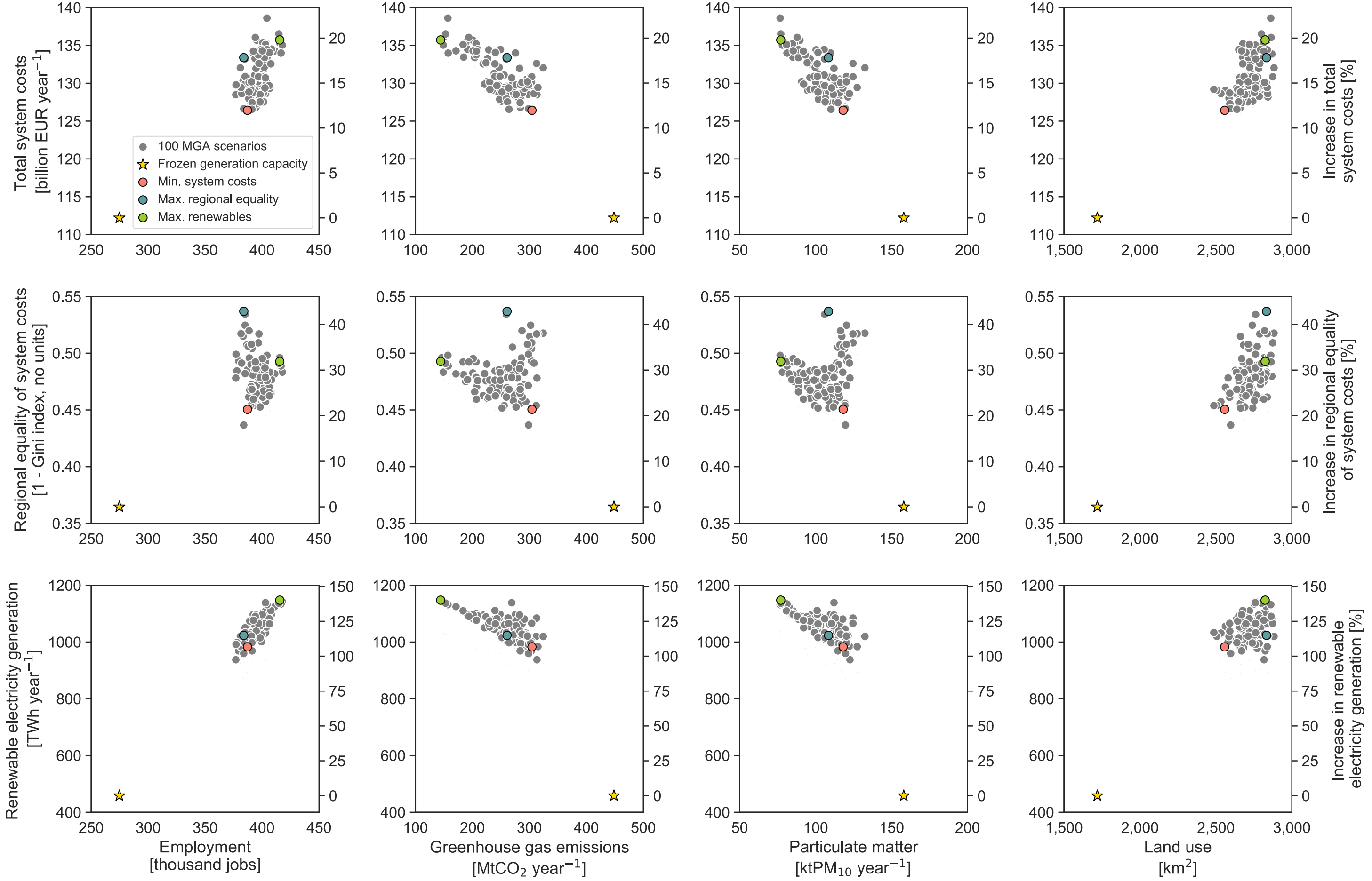

Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Spatial distribution of electricity generation




Source: Sasse, JP., Trutnevyte, E. (2020) in *Nature Communications.*

# Trade-off curves

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