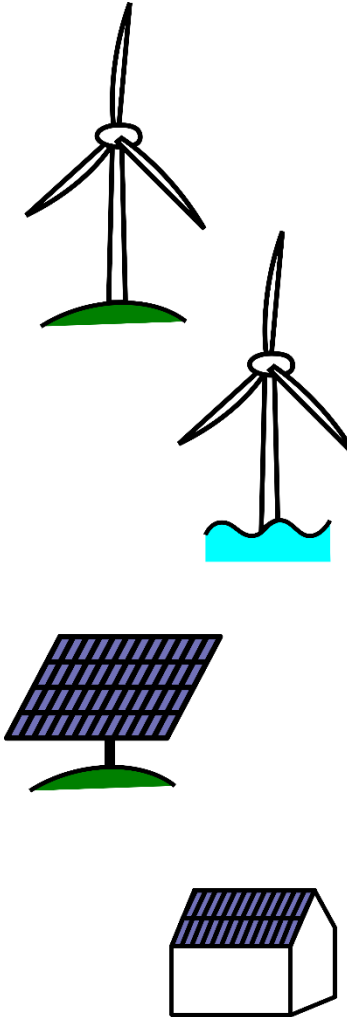


Renewable generation capacity expansion: Can we fairly balance system cost and land-use inequality across Europe?

Jann Launer, Stefan Pfenninger-Lee

Conference talk at ECEMP

Brussels, 17.10.2025



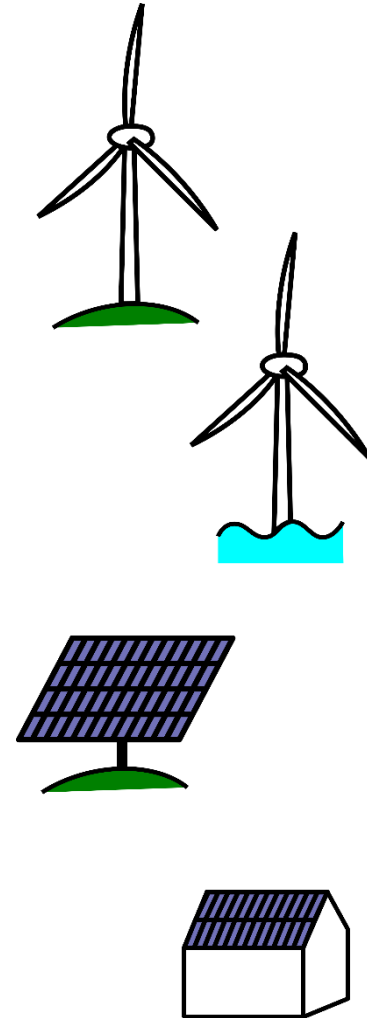
Funded by the European Union
Grant Agreement 101083936

Decarbonisation of energy systems in Europe

For a just transition, we need to address questions of spatial distributive justice [1].

Can we build the infrastructure to electrify and decarbonize energy consumption, while balancing benefits and burdens between regions?

[1] Lehmann et al. 2024. Spatial distributive justice has many faces: The case of siting renewable energy infrastructures. Energy Research & Social Science 118, 103769.



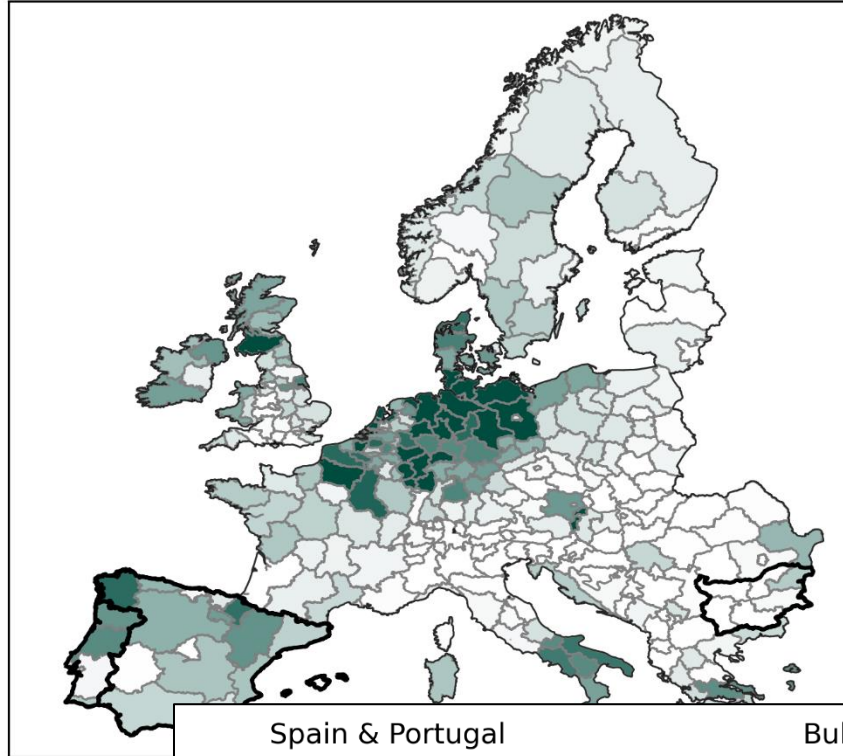
Can we fairly balance
system cost and land-use
inequality across Europe?

**How much land use is necessary
to generate renewable electricity
in a cost-effective way?**

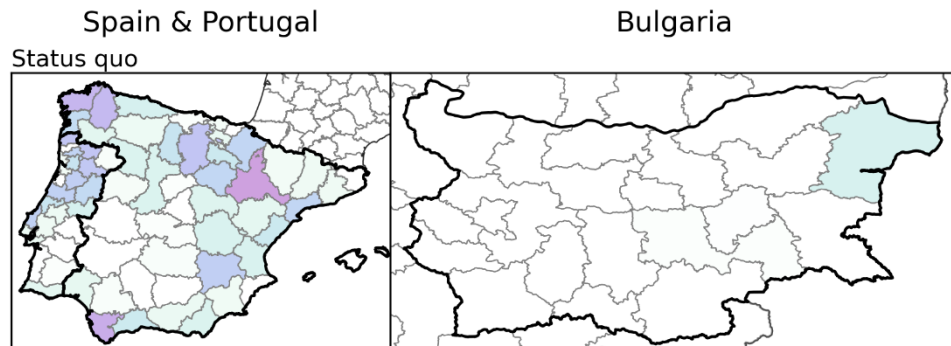
**How much land use can be
avoided by system design?**

**To what extent can system design
mitigate land-use inequality?**

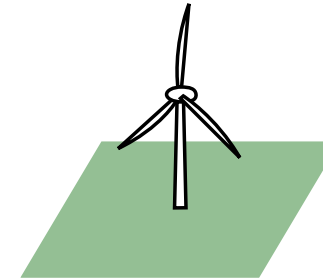
Current land use distribution



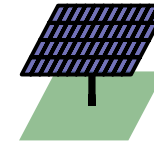
Simple
estimate for
Europe
0.57 % of total
land used for
onshore wind
and PV



Assume a power density



8 MW/km²
onshore wind



80 MW/km²
open-field PV

Gini land use =

0.54 in Portugal + Spain

0 means perfect equality,

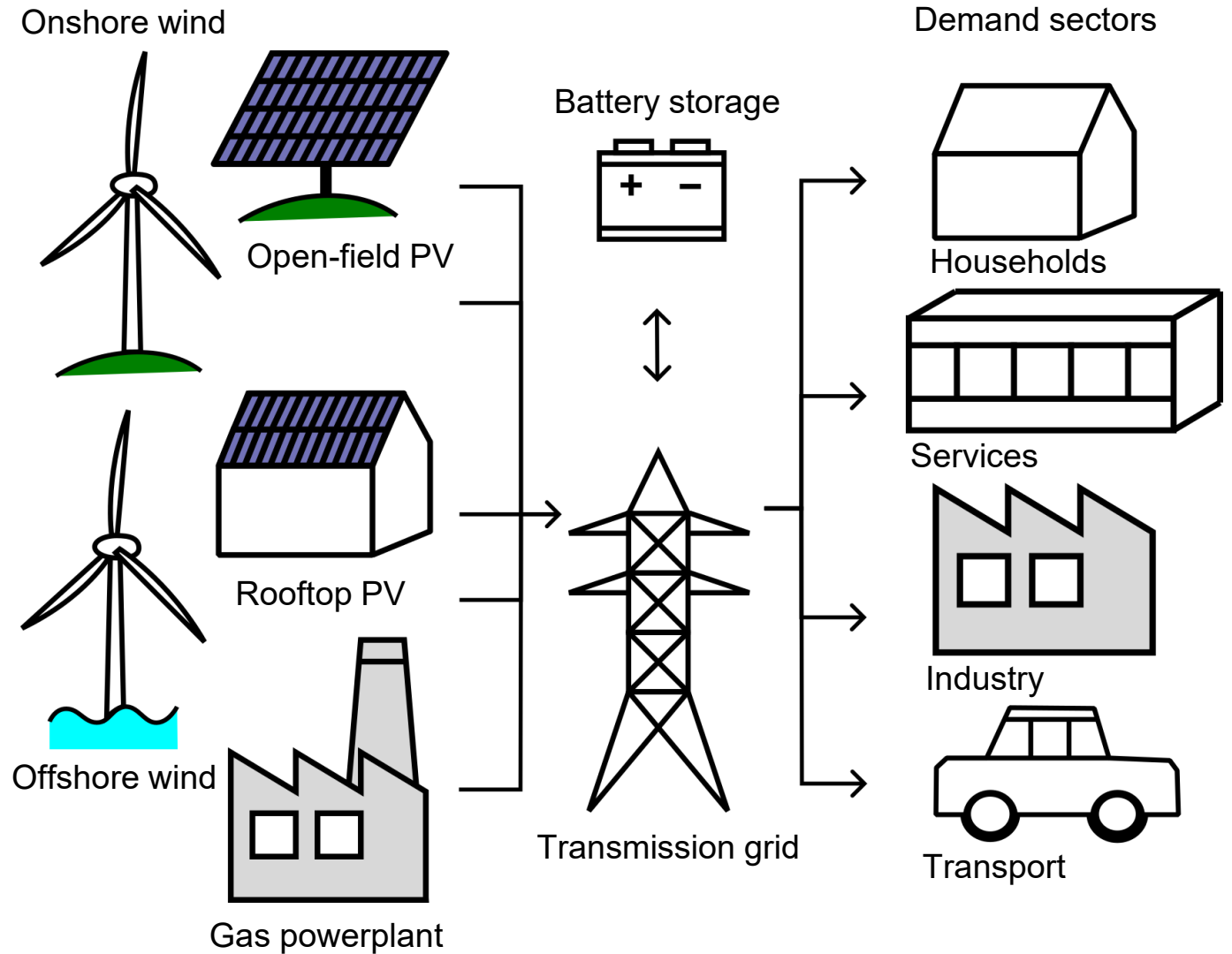
1 means perfect inequality

Portugal +
Spain:
0.79 % of total
land used.

Energy system model

Electricity only
Brown-field
Capacity expansion
1 year
1-hour resolution
Perfect foresight

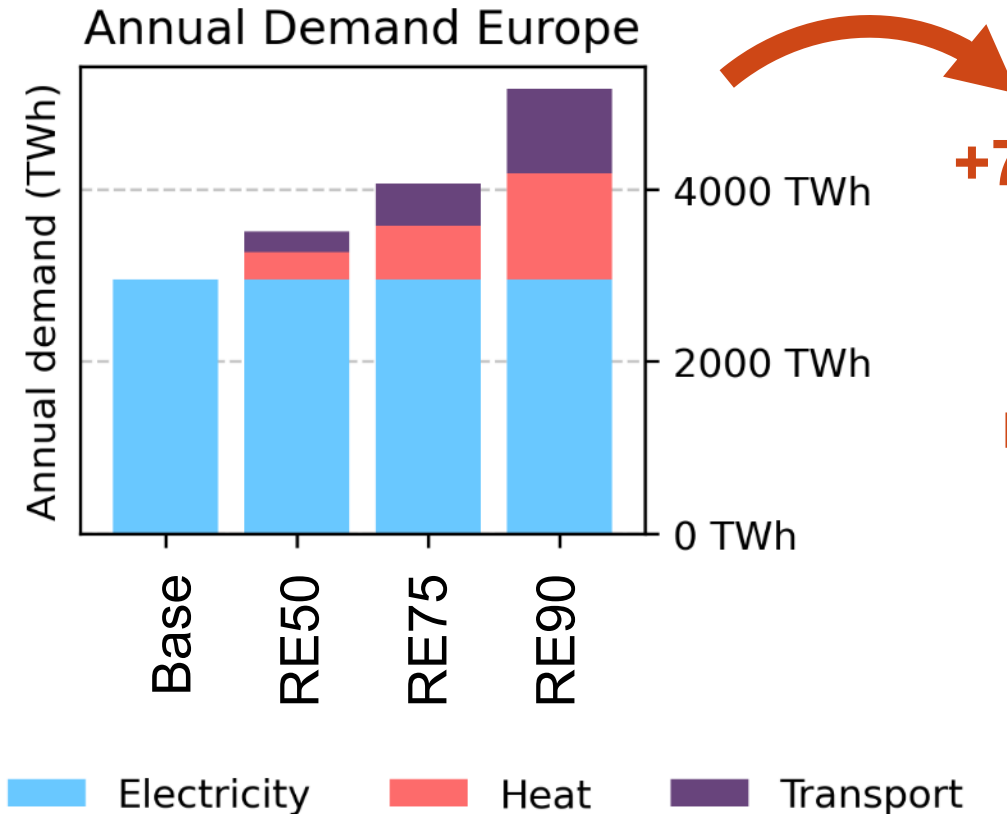
Calliope for optimisation,
Clio data modules,
Gregor for disaggregation.



A growing need for renewable electricity

Assume demand for electric road transport and heat pumps.

| Scenario | Min. RE share | Electrification |
|----------|---------------|-----------------|
| RE50 | 50 % | 25 % |
| RE75 | 75 % | 50 % |
| RE90 | 90 % | 100 % |



+75% in RE 90

For reference:
+35 to +50%
projected for 2050
in TYNDP 2024

Method: Generate options for system design

By using one
of the following
5 objectives

Min. cost

Min. land use

**Min. land use
inequality**

**Min. offshore
wind**

**Max. onshore
wind**

Allow total
system cost to
increase by no
more than 10%

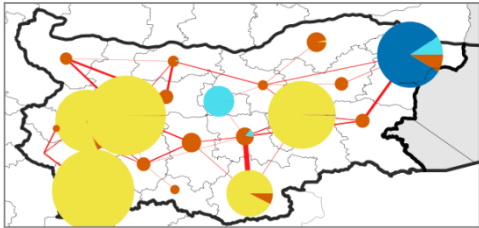
In contrast to sampling-
based MGA (e.g. [2]), our
method directly extremises
several designs objectives.

[2] Vågerö, O., Jackson Inderberg, T.H., Zeyringer, M., 2024. The effects of fair allocation principles on energy system model designs. Environ. Res.: Energy 1, 045011.

Options for system design

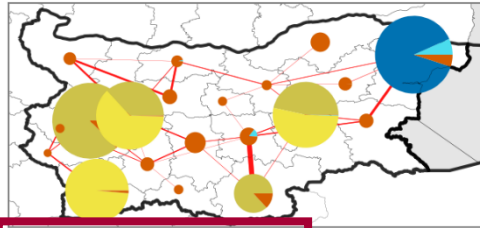
Scenario RE 90
10% cost tolerance

Min.
cost



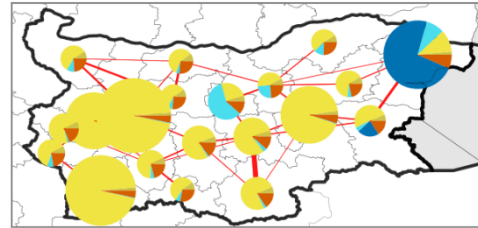
L = 0.63 %,
G = 0.86

Min.
land use



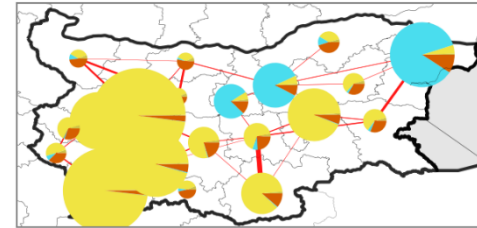
L = 0.23 %,
G = 0.9

Min. diff.
land use



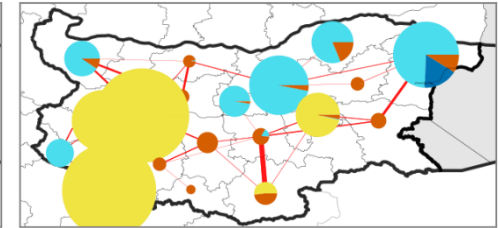
L = 0.75 %,
G = 0.61

Min.
offshore wind



L = 1.63 %,
G = 0.83

Max.
onshore wind



L = 2.27 %,
G = 0.85

- Onshore wind
- Offshore wind
- Rooftop PV
- Open-field PV
- Gas power plant
- Transmission

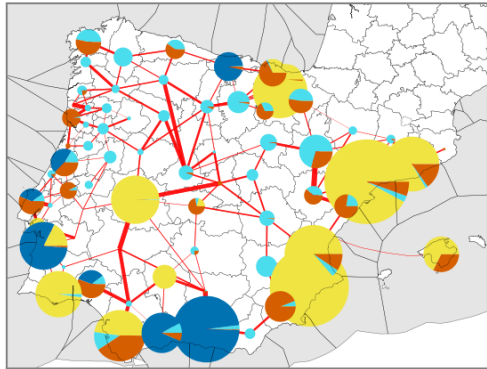
L: Land use share

G: Gini land use

Options for system design

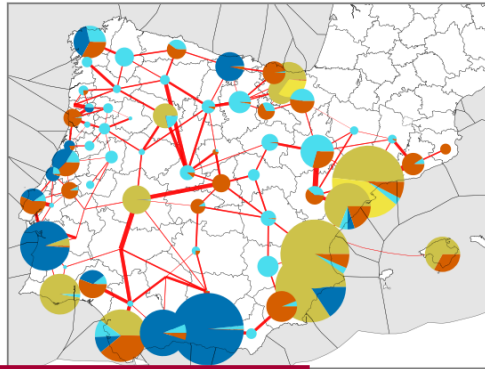
Scenario RE 90
10% cost tolerance

Min.
cost



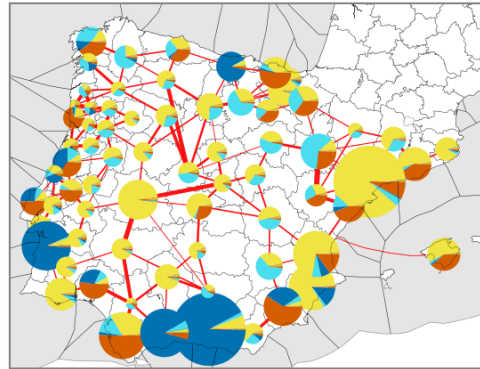
$L = 1.11 \%$,
 $G = 0.76$

Min.
land use



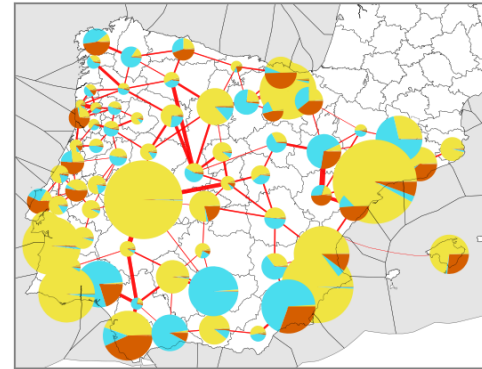
$L = 0.81 \%$,
 $G = 0.79$

Min. diff.
land use



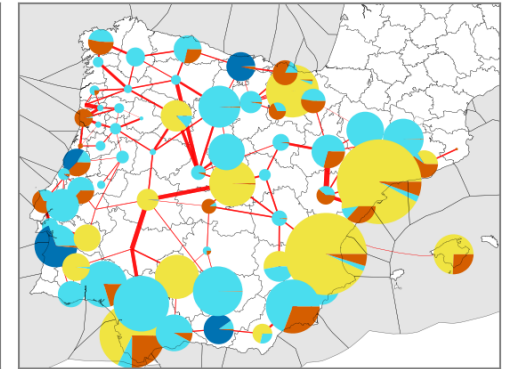
$L = 1.14 \%$,
 $G = 0.59$

Min.
offshore wind



$L = 2.3 \%$,
 $G = 0.75$

Max.
onshore wind

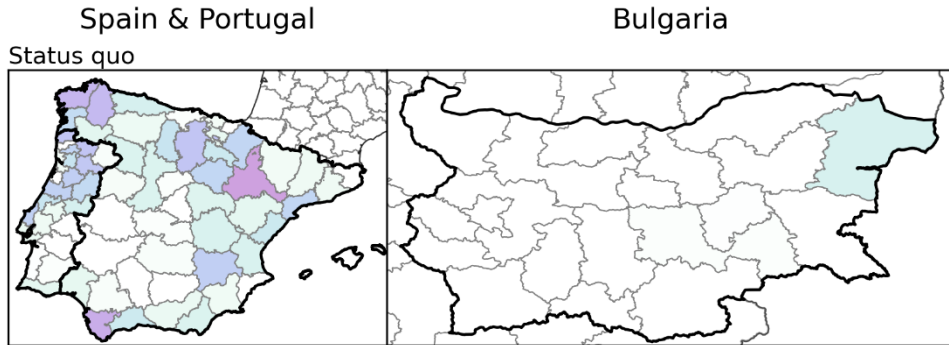


$L = 3.3 \%$,
 $G = 0.81$

- Onshore wind
- Offshore wind
- Rooftop PV
- Open-field PV
- Gas power plant
- Transmission

L: Land use share
G: Gini land use

System design can mitigate land use



For comparison: status quo

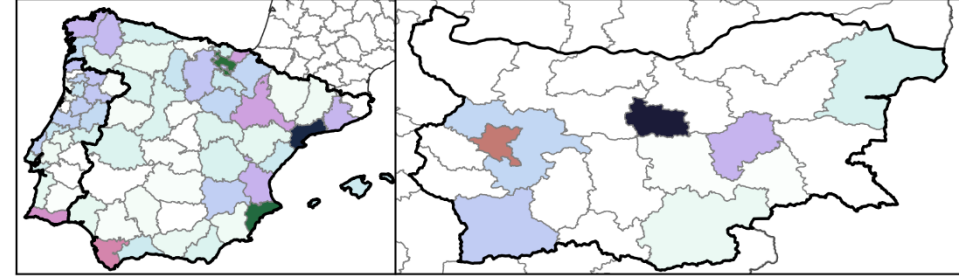
Mitigate land use at moderate cost increase.

Or, by minimising land use inequality, distribute land-use related burdens more evenly.

But: no perfect equality.

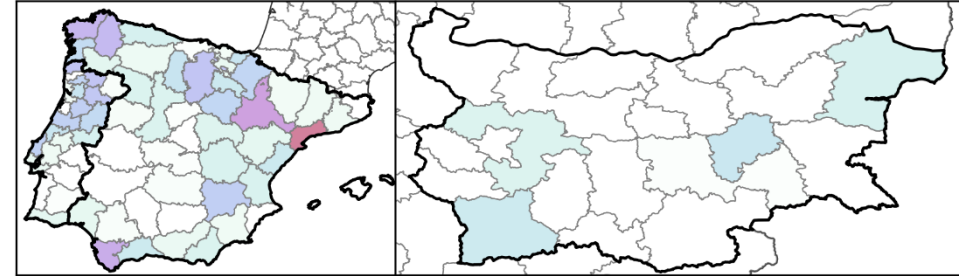
Note: Land use shares are lower than e.g. in the study „Land for Renewables“ (EEB 2024): 2.2% for climate neutrality in 2040.

RE90 Min. cost



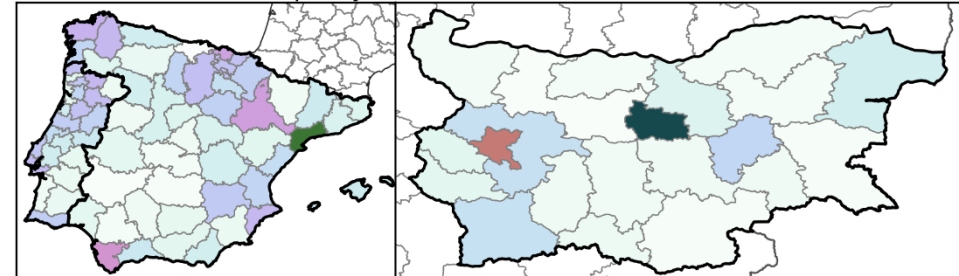
Min. cost

RE90 Min. land use (10% cost tolerance)

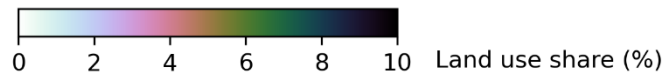


Min. land use

RE90 Min. land use inequality (10% cost tolerance)



Min. land use inequality



Scenario RE 90, 10% cost tolerance

Conclusions

**Can we fairly balance
system cost and land-use
inequality across Europe?**

Conclusions

Can we fairly balance system cost and land-use inequality across Europe?

1. The energy transition can **intensify current land use and land-use inequality** in Europe.
2. Alternative system **designs can mitigate** land use and land use inequality.
3. Our method generates **substantially different options for system design** that help addressing questions of **spatial distributive justice**.
4. With **little added computational cost**, our approach can be directly used in models for **regional policy targets and planning**.



<https://justwind4all.eu/>



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Grant Agreement 101083936

Interested? Get in touch!

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<https://github.com/jnnr>

Supplementary Material

Methods: Model workflow

