Efficient and fair allocation of renewable energy production sites across Germany

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EnergyEFFAIR

- The project was part of the research initiative „**Climate change and economics**“ by the Federal Ministry for Education and Research
- Overall objective of EnergyEFFAIR: identify an „**optimal**“ spatial allocation of renewable energy production sites (REPS)
- “Optimal” with respect to both **costs and fairness**

Workpackages EnergyEFFAIR

1. Potential of on-shore renewable energy production sites (REPS): **wind** and **solar** only
2. Extension of transmission grid
3. Landscape externalities (of **biomass** as well) and production costs
4. Acceptance and fairness
5. Efficient & just **energy landscape**

Energiewende in Germany

- One target is to produce **50%** of the gross electricity consumption (GEC) in 2030 from renewables increasing to at least **80%** in 2050
- In 2015, renewables produced **32.6%** or **195.9** TWh of the GEC; wind onshore was **79.3** TWh (offshore 8.2 TWh), solar **38.4** and biomass **49.4** TWh
- To achieve policy targets, **more REPS are needed** – to what extent is an open questions (e.g. repowering)
- The Federal Environment Agency (UBA), e.g., assumes that onshore wind energy **can contribute around 1000 TWh/a in the long term** (Umweltbundesamt 2014)

Number of REPS in Germany

REPS	Year				
	2005	2010	2015	2030	2050
Solar	198.283	901.606	1.515.063	?↑?	?↑?
Wind	15.486	20.083	26.206	?↑?	?↑?
Hydro	5.358	6.743	7.513	?↑?	?↑?
Biomass	3.409	10.628	15.499	?↑?	?↑?
Other	669	807	873	?↑?	?↑?
Note: Solar includes roof panels					

Source: www.EnergyMap.info - state: August 2015

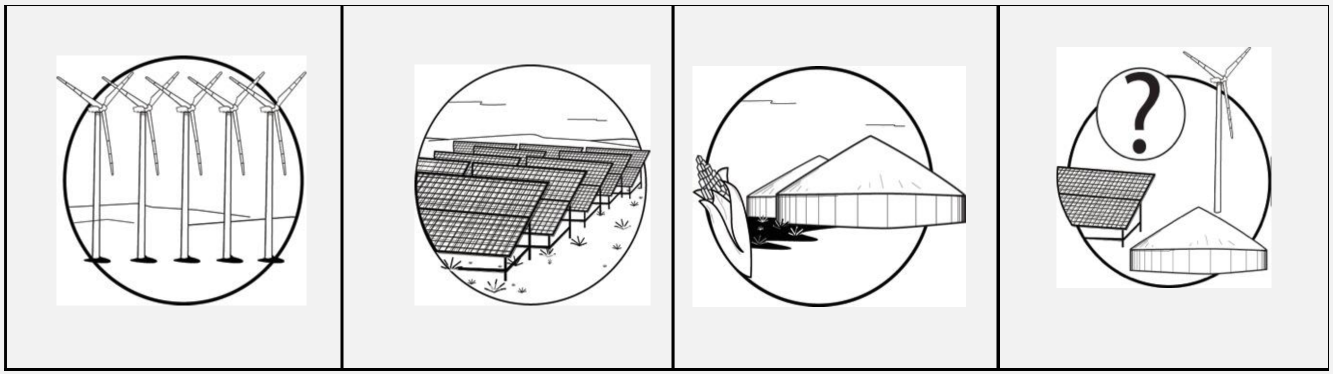
LANDSCAPE EXTERNALITIES OF RENEWABLES

Nationwide survey

- Aim is to capture **landscape externalities** of REPS (on-shore - only open land) as well as attitudes toward and acceptance of REPS
- Externalities were measured by a **labelled** discrete choice experiment
- Place of residence was **geo-coded** via Google-Maps interface
- **Online survey** with 3400 respondents across Germany

The choice experiment

- **Labelled** choice experiment: labels are wind, solar and biomass, plus “don’t care”



- Respondents were asked to choose their preferred option for the development in the **10km surroundings** of their place of residence

Attributes and levels

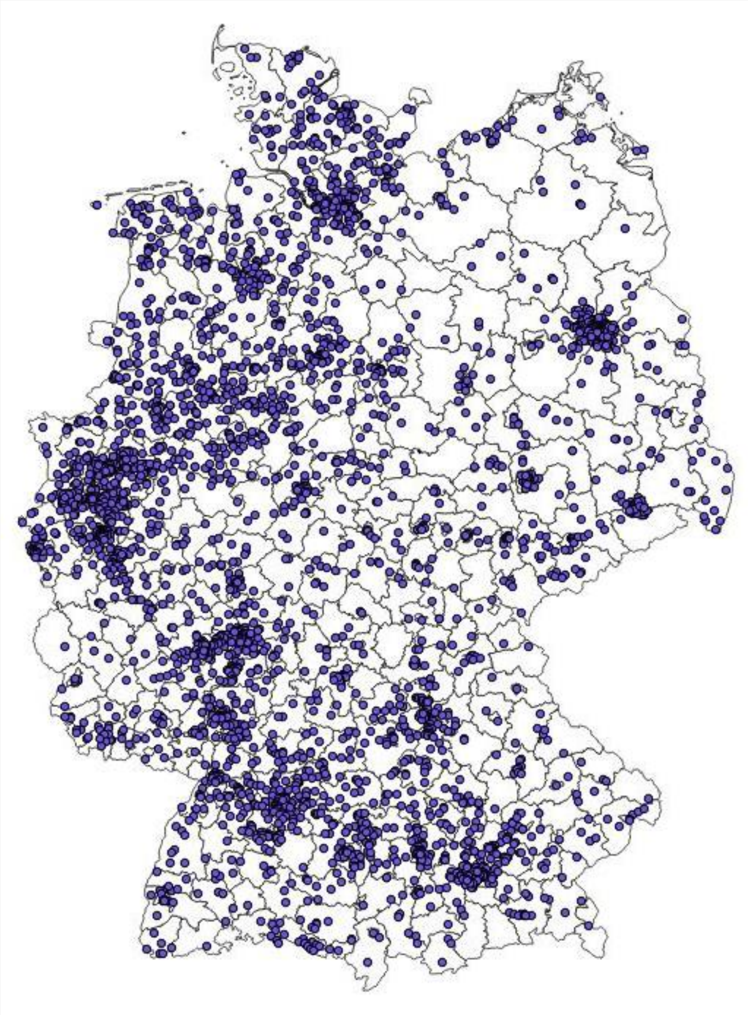
Attribute	Levels	Unit	Zero-price value
Distance	300 ; 600 ; 1600; 2500	metres	900
Area	small; medium; large	0/1/2	medium
Sites (farms)	1; 2; 3; 4; 5	number	3
Landscape	10; 20; 30; 40; 50	percentage	30
Grid	overhead, underground	0/1	overhead
Cost	-10; -5; 0; 2; 7; 14; 23	Euro/month	zero

Please choose the option you would prefer for the extension of renewables in the surrounding of 10 kilometres around your place of residence. In case you are living in a large city, please think of the landscape around.

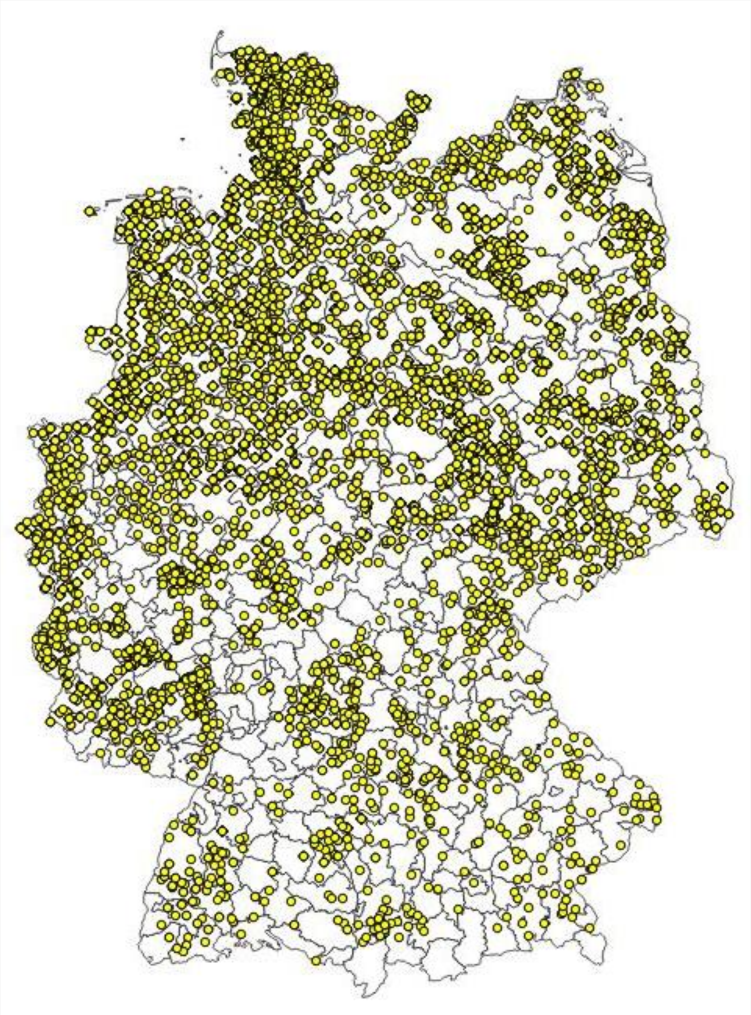
	Wind	Biomass	Solar	Don‘t care
Minimum distance	600 metres	2500 Meter	300 Meter	900 Meter
Size of REPS	large (35-50 turbines)	large (15-25 tanks)	small (1-10 football fields)	medium
Number of REPS	4	5	5	3
Landscape protection	20%	50%	10%	30%
Grid	underground	underground	overhead	overhead
Change in energy bill per month (year)	+14 € (+168 €)	-5 € (-60 €)	+ 14 € (+ 168 €)	0 €
I choose…				
… best alternative	○	○	○	○

⇒ six choice tasks, order of appearance randomized, also order of alternatives

Locations: interviews and turbines



3,388 useable interviews



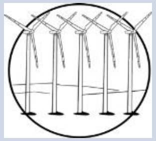
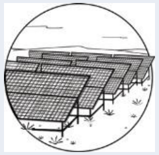
23,012 turbines (2013, year of survey)

Renewable electricity production sites: Presence (column %) and disturbance (row %)

	in 10 km	%	Do you feel disturbed by …			
			Very much	Rather yes	Rather no	Not at all
Wind	Yes	66.7	4.1	12.7	32.4	50.9
	No	26.5	8.2	19.6	32.5	39.6
	D-know	6.8	5.6	14.3	36.7	43.7
Solar	Yes	52.6	1.4	4.2	24.4	70.1
	No	29.1	0.9	6.3	29.6	63.2
	D-know	18.3	1.0	2.7	29.0	67.3
Biomass	Yes	46.1	6.1	16.6	32.6	44.7
	No	14.5	8.6	23.3	30.4	37.8
	D-know	39.5	2.8	16.8	35.6	44.8

Note: presence in 10 km surroundings; Unit: row %

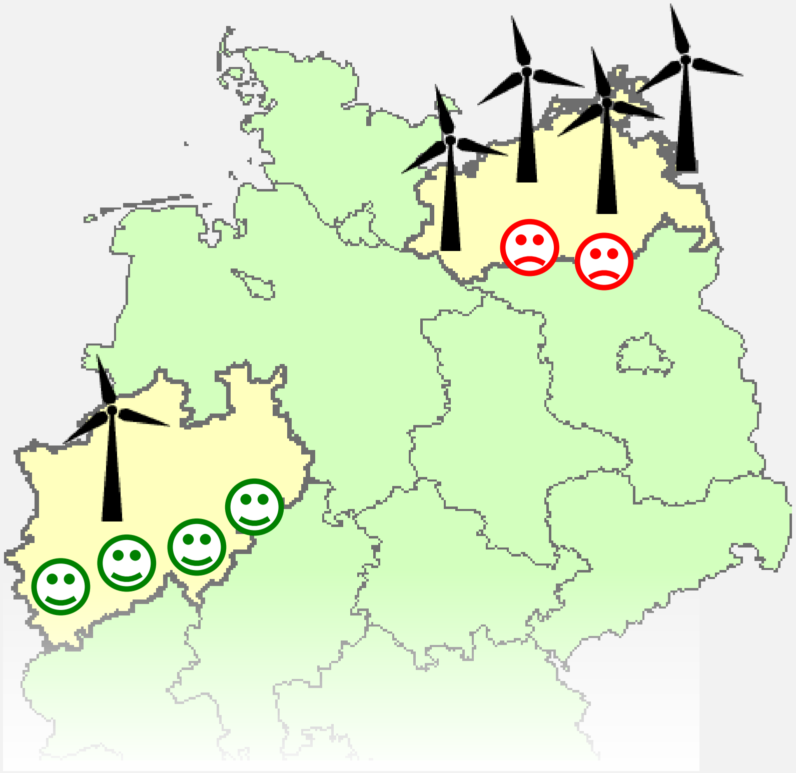
Chosen alternatives
(10 km surroundings)

Alternative	Label	Percentage
Wind		**27.3**
Solar		**39.8**
Biomass		**22.2**
Don’t care		**10.8**
20.328 choices		

WTP estimates (monthly)

attribute	WTP	|z-value|	st. de.	|z-value|
Distance_wind (per km)	**6.92**	16.63	4.14	5.58
Distance_solar (per km)	**2.87**	7.76	2.96	3.45
Distance_biom (per km)	**4.50**	10.45	4.74	5.95
Small_sites	**5.06**	9.81	16.49	27.43
Large_sites	**-4.76**	9.76	6.51	6.96
Number of sites	**-0.49**	3.40	1.04	2.33
Landscape protection (%)	**0.16**	11.75	0.35	16.91
Grid (underground)	**7.57**	18.20	9.77	17.91
ASC_wind	0.81	0.98	23.26	31.33
ASC_solar	14.50	18.10	22.09	32.87
ASC_biomass	-3.35	3.76	20.39	25.85
"Don't care" (reference)				

WTP-Space model, attributes normally, cost lognormal distributed



OPTIMAL & FAIR ALLOCATION

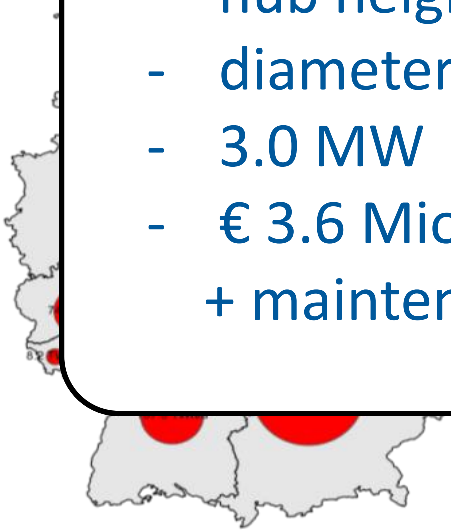
Optimisation

Physical landscape → Land use, legislation → Potential areas → Optimal packing → Potential sites

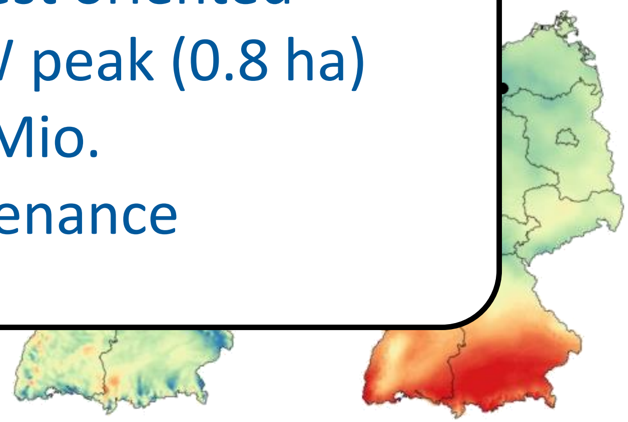
Sites,

E

El



technology

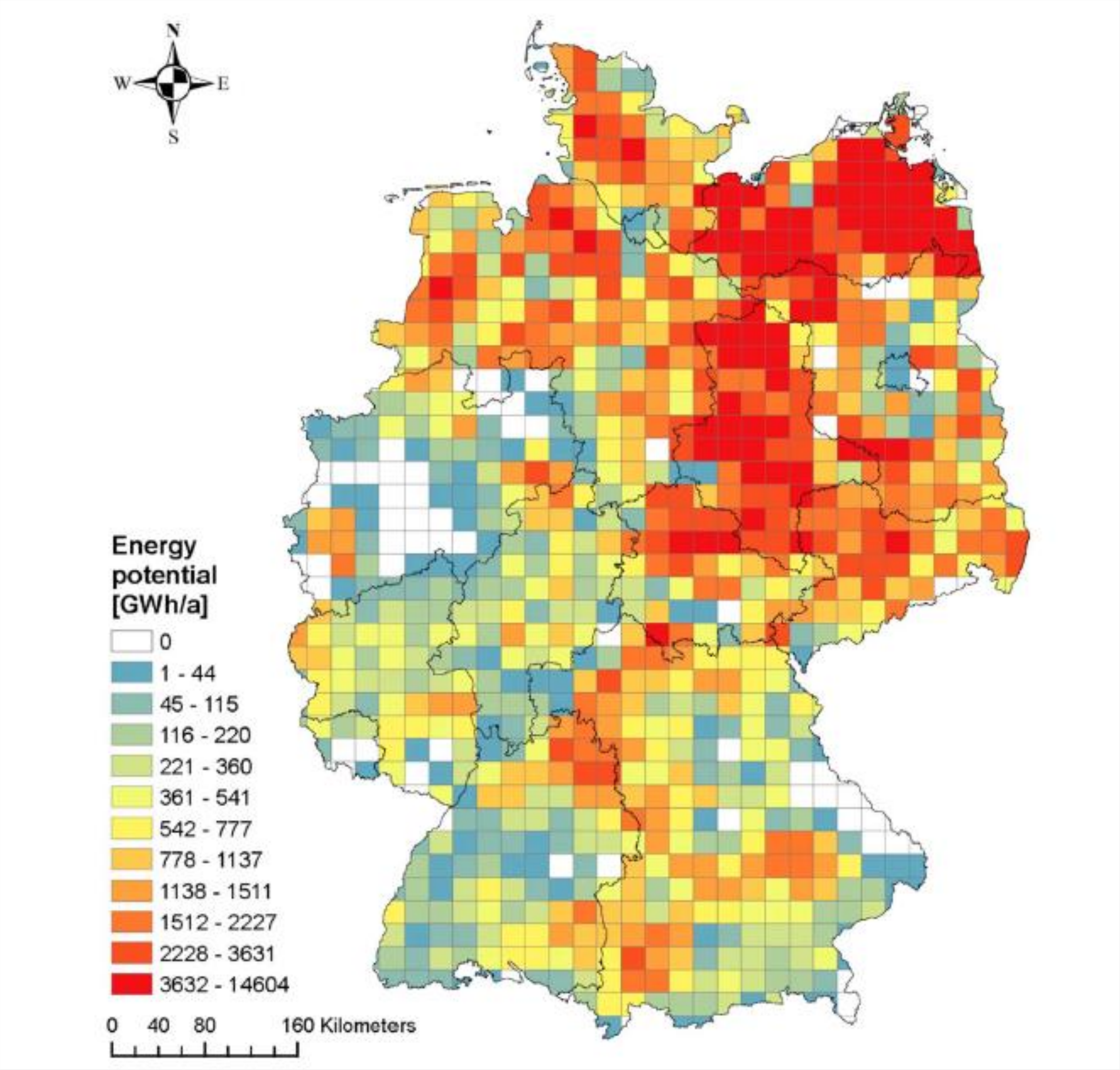


Reference technology

Wind energy plant
- hub height 150 m
- diameter 100 m
- 3.0 MW
- € 3.6 Mio.
  + maintenance

Solar energy plant
- monocrystalline
- East-West oriented
- 1.0 MW peak (0.8 ha)
- € 1.05 Mio.
  + maintenance

Energy potential wind



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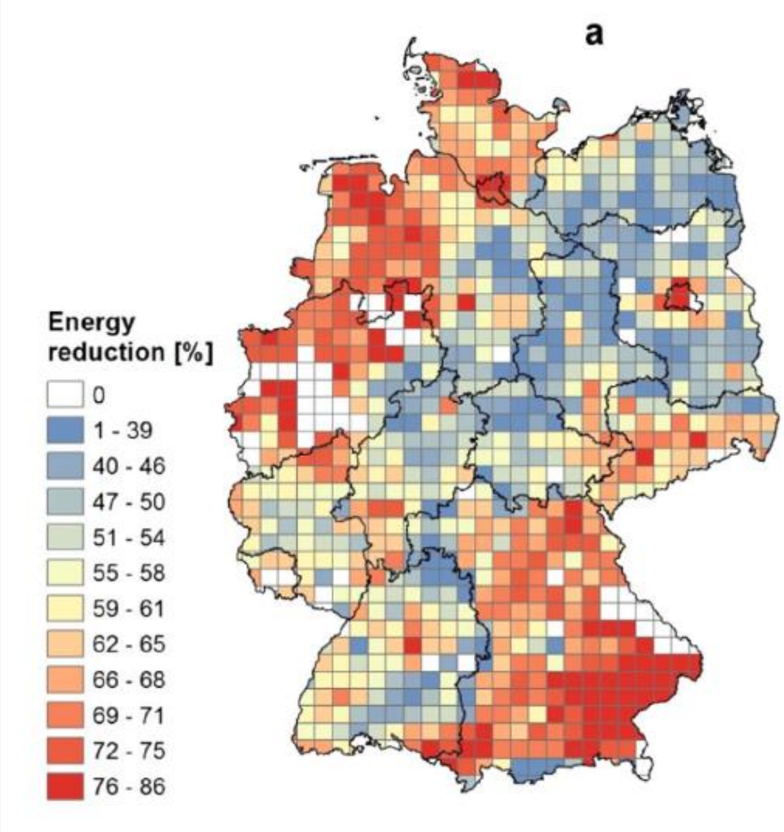
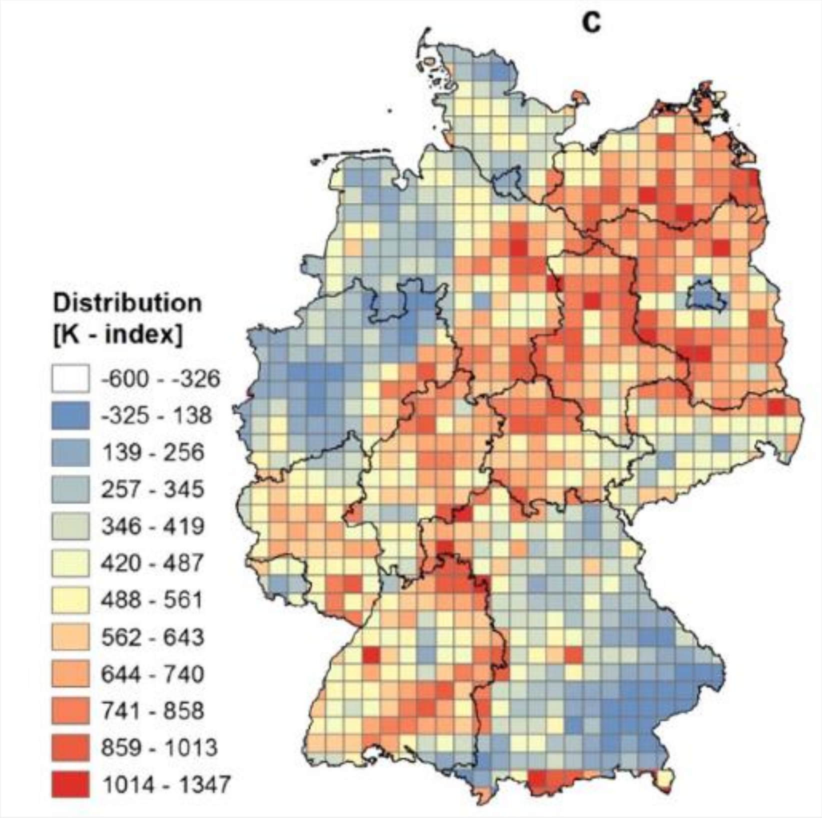
Loss of potential due to distances

Reduction potential for 100 m increase



Settlements clustered or scattered



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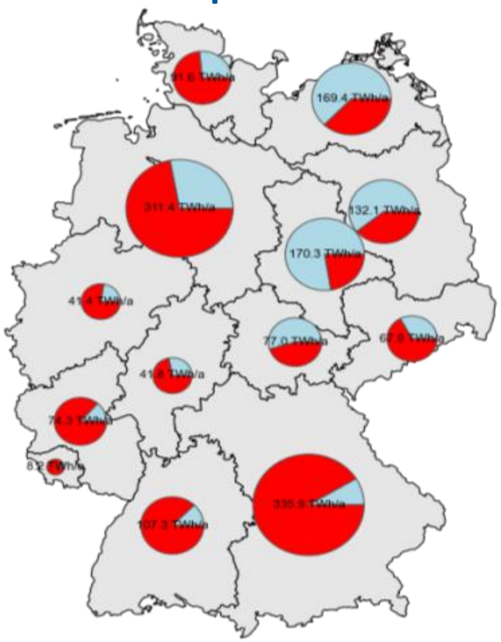
Workflow optimisation

locations,
potential at location,
costs per kWh



Survey

WTP for distance

Fairness

Optimisation

Objective: 150 TWh/a

Incorporating externalities

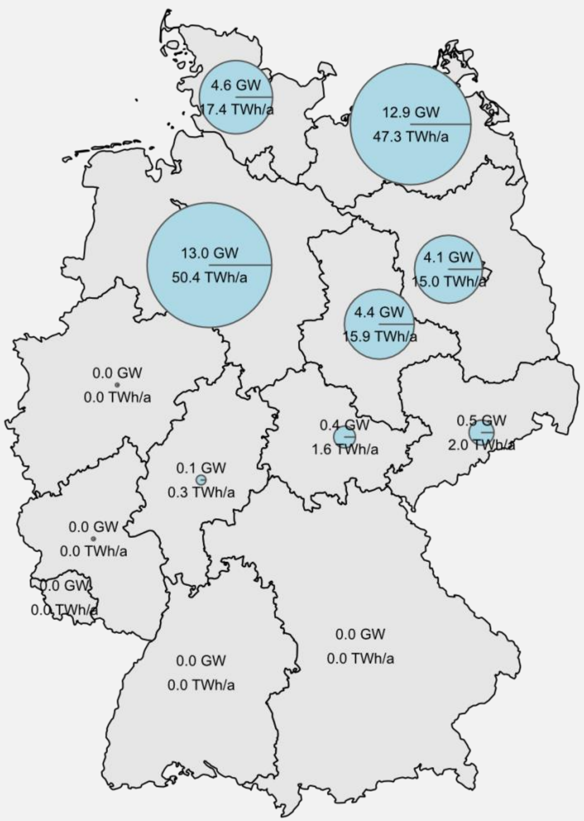
1. Minimum distances to settlements were fixed at 800 m for turbines and 0 m for solar
2. Optimal locations for REPS given minimum distances and private costs were determined
3. WTP for 100 m distance increase for wind and solar was calculated for the populations of each district, the step was repeated until 3000 m distance were reached

=> In the end distance never affected the optimisation result as the externalities were too low to outweight the benefits from locations preferable due to private costs

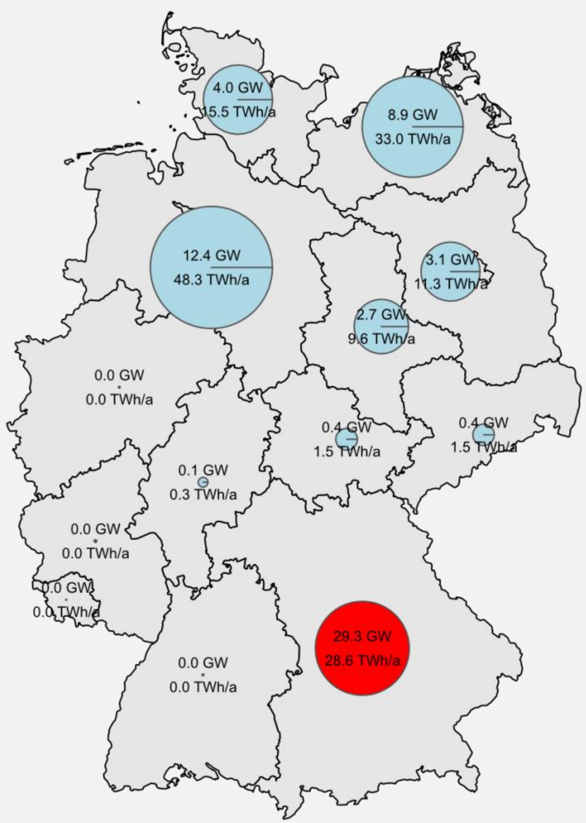
Cost-optimal allocation

Solar investment costs compared to 2014 prices

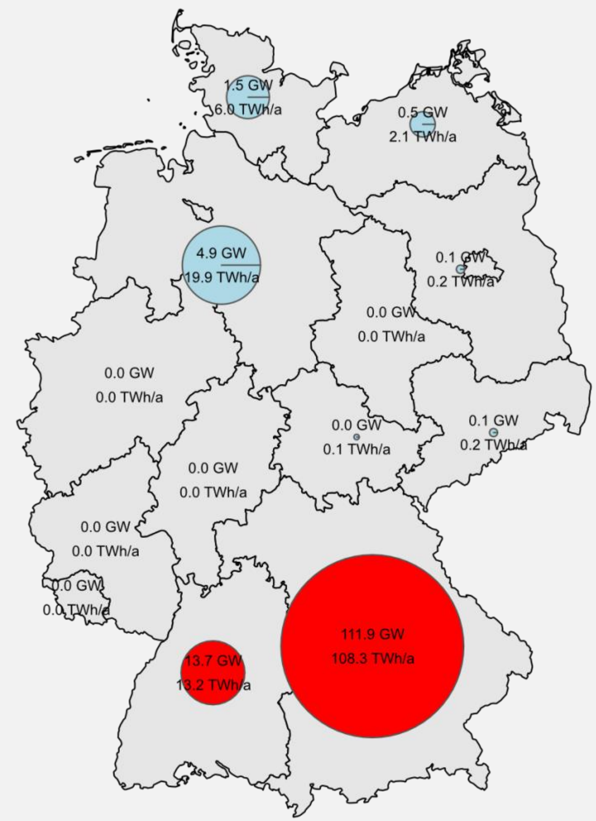
40 %



36 %



33 %



Fairness across federal states

Respondents were presented items aiming at fairness of the distribution of production sites

Which of the following four statements to construct new facilities is due to your opinion the most just?

Only one response possible.

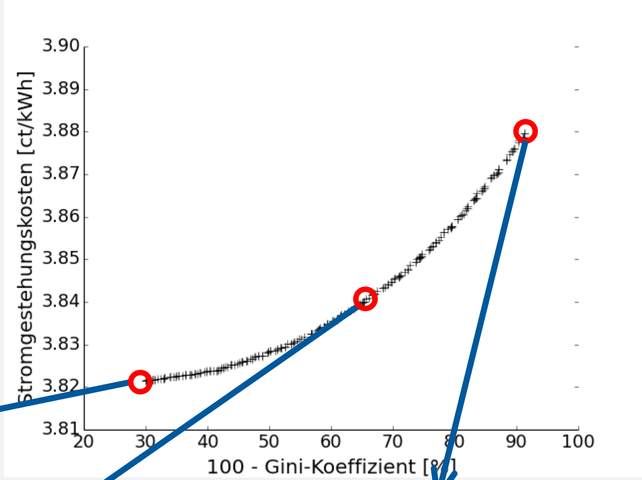
Based on the size (area) of the individual states (Bundesländer) I find most just ...	
… when the same number of new plants will be built in each state.	15%
…when in those states that have today most plants in future the least will be build.	19%
…when new plants are build that way that in total the least number of plants is necessary across all states.	50%
…when all states would have the same number of plants.	16%

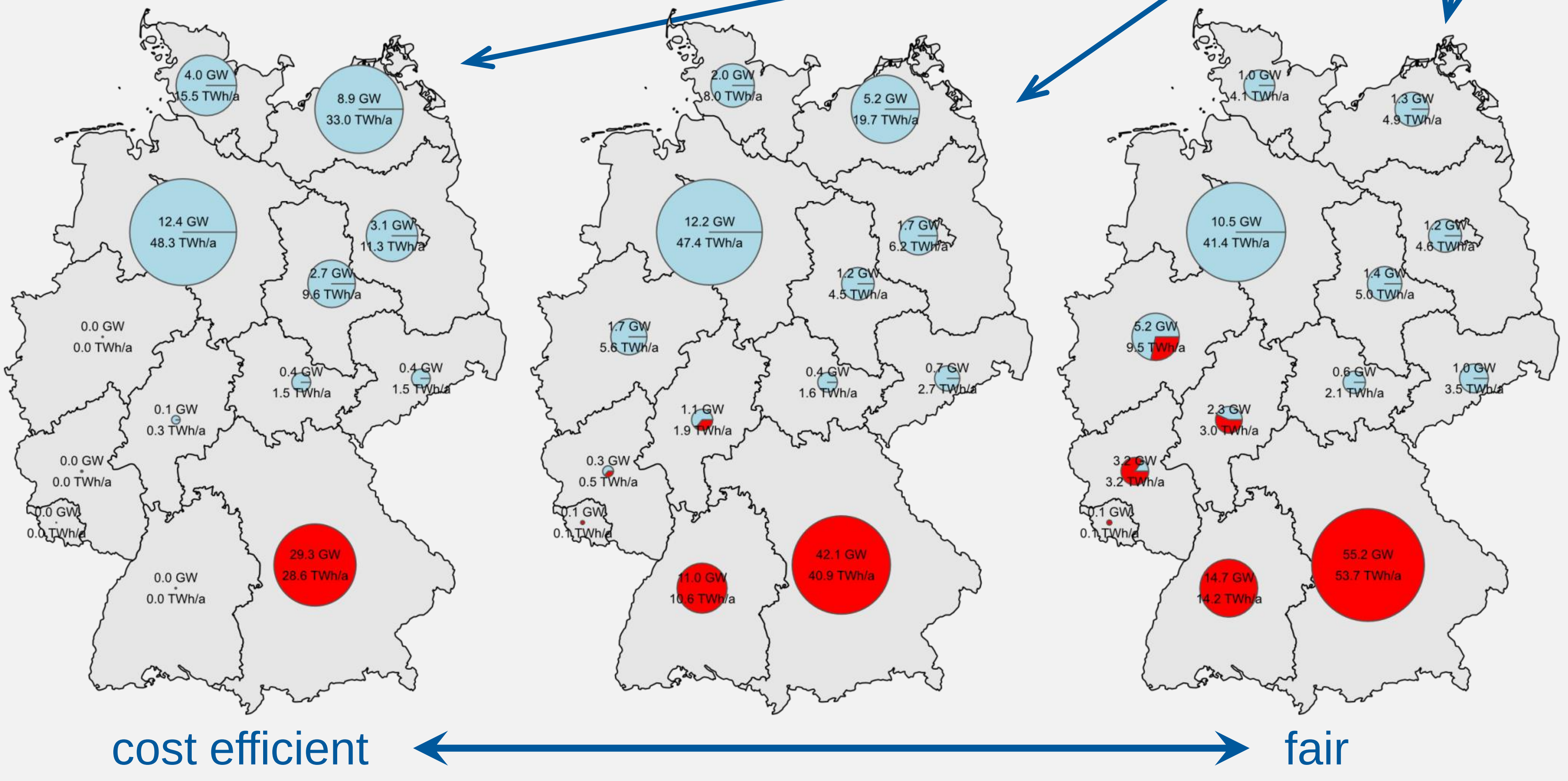
Equity defined for optimization

- Majority says that new productions sites should be build were conditions are best => **cost efficient**
- Second highest agreement was to the rule that current allocation should be recognized => **equal burden**
- Measure of this burden was the **ratio of the energy production and the energy potential** weighted by population
- An equal burden at the state level should imply that at the individual level all endure the same across the country
- The **Gini coefficient** was used to describe the equity ranging from 0 (high inequity) to 100 (perfect equity)

Electricity generation by federal states

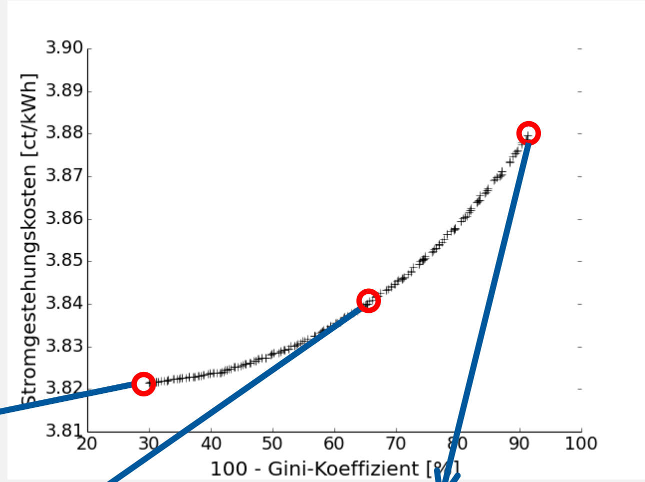
Solar investment costs 36%

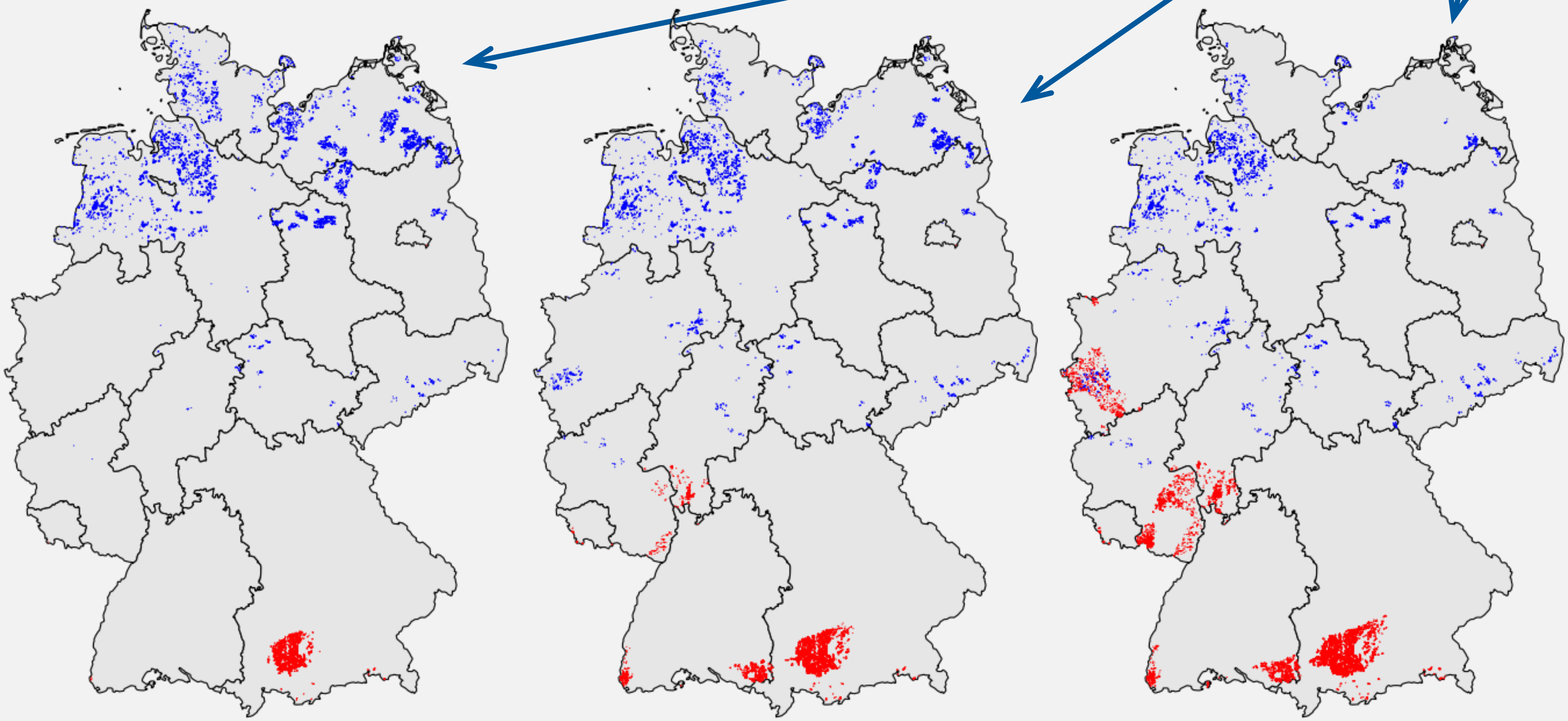




Production sites by federal states

Solar investment costs 36%





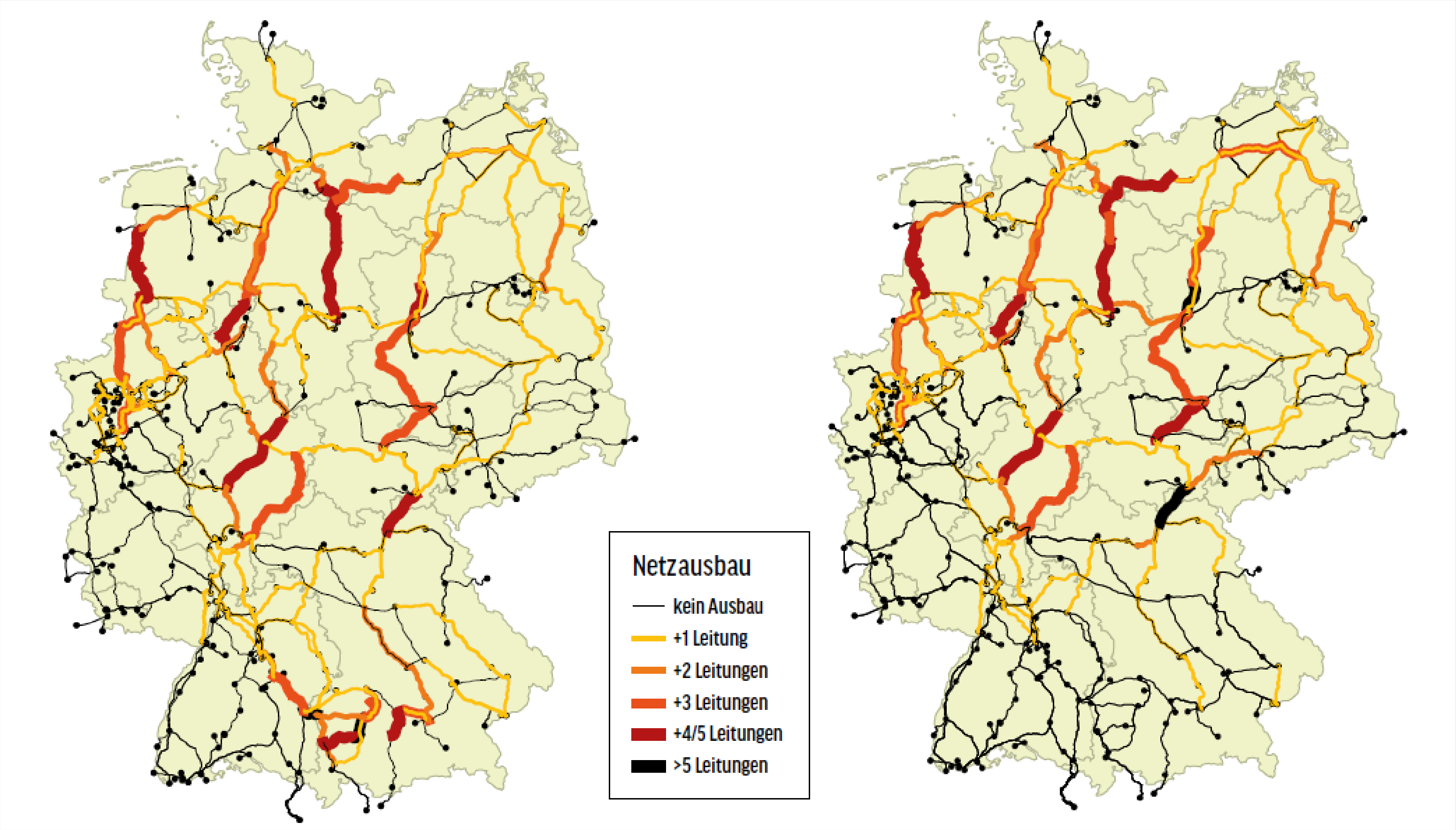
cost efficient ⟷ fair

The role of grid expansion costs

- Costs for expanding high-voltage transmission grid were integrated in the optimization
- An **iterative process** was used starting with an efficient allocation of REPS with zero grid costs
- Next, grid expansion costs were determined and distributed among generators at the respective network nodes
- These cost were used for a new run of the spatial allocation model
- This cycle was continued until the allocations of REPS converged

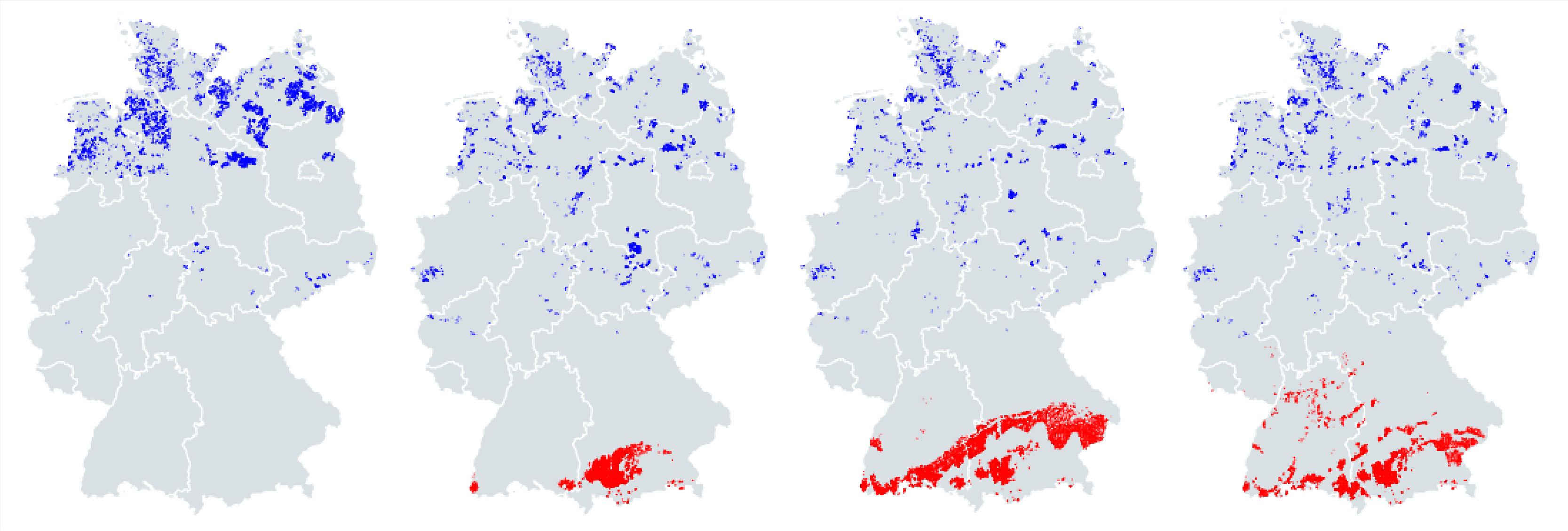
Grid expansion for 150 TWh/a

150 TWh/a only by wind **120 TWh/a wind, 30 solar**



Optimisation considering grid costs

No grid costs, 40% solar investment | **1. Step** | **2. Step** | **8. Step**



blue: wind turbines; red: solar panels

CONCLUSIONS

… regarding preferences

- Only a **minority** of the respondents feels disturbed by REPS in their 10 km surroundings (but how does it vary in the 10 km range?)
- REPS **cause** negative landscape externalities, i.e., people want to push them away and prefer smaller and less sites (e.g., wind farms)
- WTP for increasing distance, for example, is highest for **wind** turbines, lowest for **solar** panels

… regarding spatial allocation

- Cost optimal allocation (with externalities due to distance) results in **only wind** in the north (2014 prices)
- When investments costs for solar significantly **decrease** (36% or less of 2014 prices) it emerges in the south (Bavaria first)
- Considering **fairness/equity of burden** spatial distribution becomes more equal (wind moves south, solar north), however, equity costs are small with 0.07 Euro cent/kWh
- **Grid expansion costs** also have an equalising effect on the distribution

… regarding shortcomings

- **Biomass was excluded** from optimisation because externalities are not only caused by the plant but also by biomass production (corn, e.g.)
- Present REPS are not considered as we assume an **empty landscape** when starting optimization, but: How far are we away today from optimal allocation?
- Externalities are **only represented by distance**, e.g., not including biodiversity
- Optimisation (fairness, grid) is not done jointly due to computational problems
- 150 TWh is probably to low but calculations can “easily” be done for more

… regarding policy relevance

- **Decision makers** started to discuss spatial allocation of sites across Germany as they are concerned that promoting renewables only based on efficiency would decrease acceptance among the population
- However, factorial survey from Poland and Germany (2015) shows that people **do not care that much** about whether their region has more or less turbines than an average region (Liebe, Bartczak, Meyerhoff, in prep.)
- Finally, currently we are preparing a new proposal using these data analysing the **effectiveness of instruments influencing the spatial allocation**

THE END ☺

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