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Cool the future with solar PV ?

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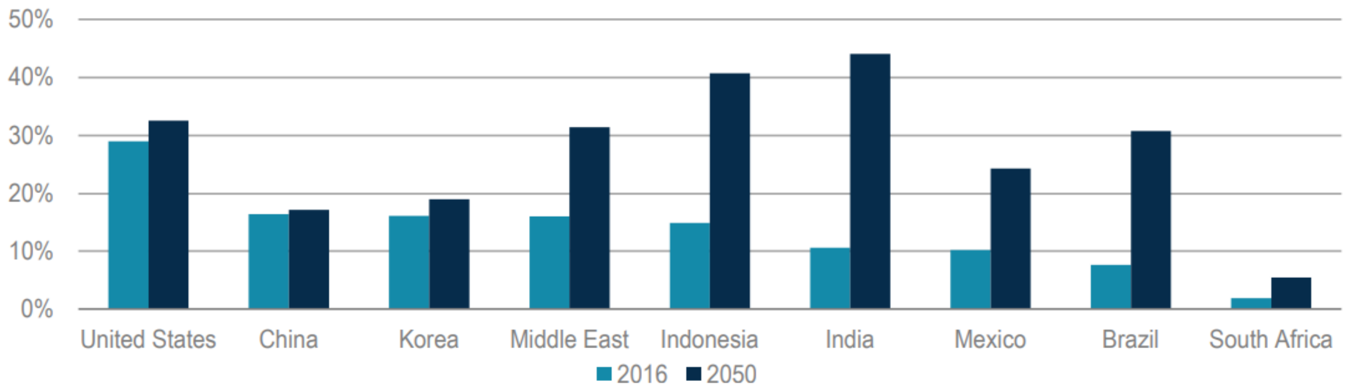
Why cooling ?

2020TWh (2016)	⇨	6200TWh (2050)	Global	
80TWh (2016)	⇨	1300TWh (2050)	India	28% of total demand
40TWh (2016)	⇨	260TWh (2050)	Brazil	22% of total demand
420TWh (2016)	⇨	1000TWh (2050)	China	9% of total demand

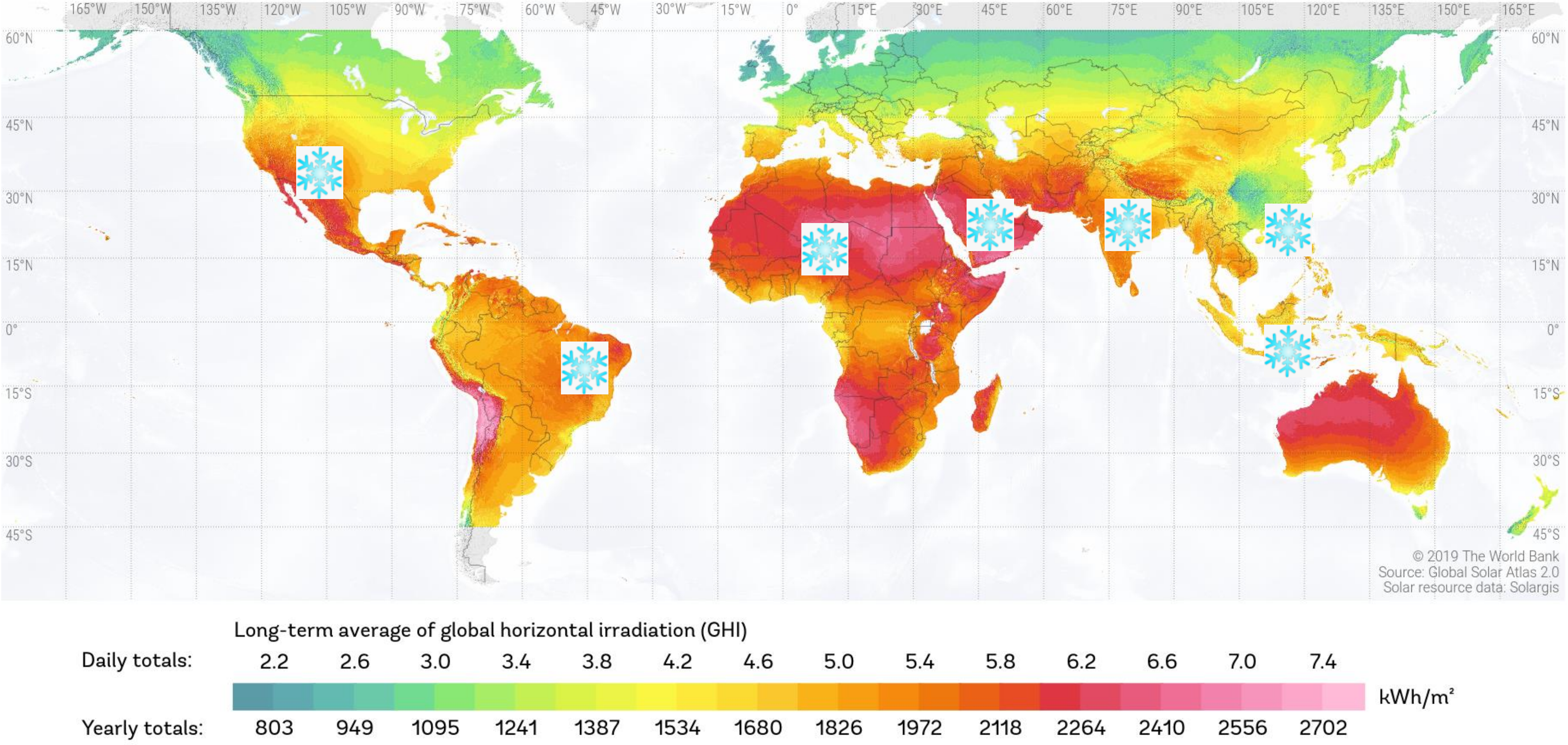
IEA, 2019

Why cooling ?

Share of cooling demand in hourly peak load



IEA, 2019


165°W 150°W 135°W 120°W 105°W 90°W 75°W 60°W 45°W 30°W 15°W 0° 15°E 30°E 45°E 60°E 75°E 90°E 105°E 120°E 135°E 150°E 165°E
60°N 45°N 30°N 15°N 0° 15°S 30°S 45°S
© 2019 The World Bank
Source: Global Solar Atlas 2.0
Solar resource data: Solargis
Long-term average of global horizontal irradiation (GHI)
Daily totals: 2.2 2.6 3.0 3.4 3.8 4.2 4.6 5.0 5.4 5.8 6.2 6.6 7.0 7.4
kWh/m²
Yearly totals: 803 949 1095 1241 1387 1534 1680 1826 1972 2118 2264 2410 2556 2702

Research question:

1) How does electric cooling affect the cost-effective investment in solar PV for the future decarbonized electricity system?

2) How is the effect contingent on the CO_2 emission target?

Method

- Method: *Green field cost minimizing electricity investment and dispatch model*
- Emission: *200-10g* CO_2*/kWh*
- Population and GDP: *SSP2 (shared socioeconomic pathway)*
- Synthetic demand, GIS data for wind, solar and hydro: *GlobalEnergyGIS*
- 7 regions in the tropical and subtropical zones

Model

Energy system optimization model

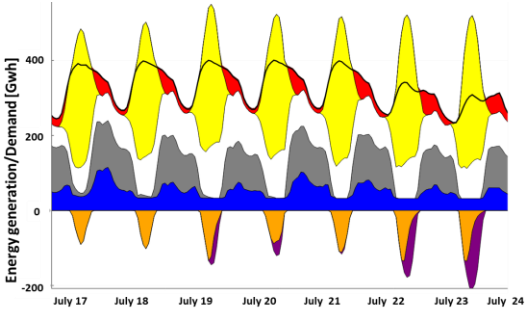
Objective function: Minimize annual electricity system cost

Demand, VRE potentials and Scenarios

- Electricity demand
- Renewable energy potentials: installable capacities, hourly power output, resource limits
- Scenario input
  Cost assumptions

Energy system optimization model REX

- Wind
- Solar
- Hydro
- Coal



Hourly operation of all components

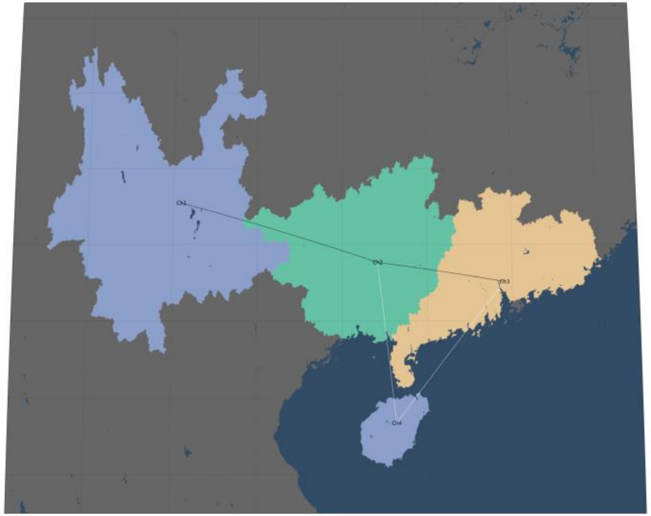
- NG OCGT
- NG CCGT
- Transmission
- Storage

Results: Strategies for Generation, Transmission and Storage

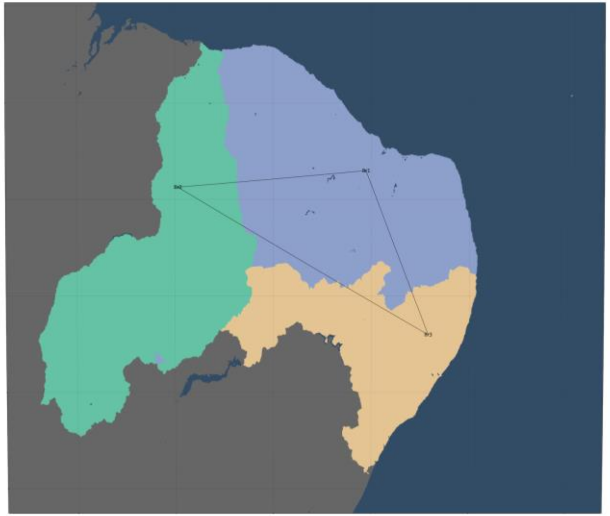
- ❑ Optimal electricity system cost
- ❑ Optimal energy mix
- ❑ Hourly system operation


Spain
West Saudi Arabia
South China
North Nigeria
South India
Malaysia
East Brazil

Country	Size [km^2]	Residential cooling demand /Total electricity demand
Spain	505990	3%
ChinaS	844854	7%
IndiaS	635780	16%
Saudi ArabiaW	451210	3%
NigeriaN	412026	23%
BrazilE	657727	17%
Malaysia	329847	18%



ChinaS



BrazilE

Residential cooling demand

Annual residential cooling demand:

$E = N \times A \times S \times e \times \eta$

N:The number of households within the population;

A: The fraction of households which can afford air-conditioning;

S: Climate maximum saturation, the fraction of households, which would acquire air-conditioning if they could afford it;

e: The average annual electricity used for cooling by each household with air-conditioning;

η: Energy efficiency parameter, energy efficiency of air-conditioners improving over time.

Laine et al., 2019

Residential cooling demand

A: Availability;

$A = 1/(1 + \exp(-0.304/1000 \times GDP/cap + 4.152));$

S: Climate maximum saturation;

If $Td(t) > Tbase$, $CDD(t) = Td(t) - Tbase$ else, $CDD(t) = 0$, (CDD: Cooling Degree Day)

$S = 1 - 0.949 \times \exp(-0.00187 \times CDDa).$

e: The annual energy consumption per household;

$e = CDDa \times (0.865 \times \ln GDP/cap - 5.825).$

Laine et al., 2019

Residential cooling demand

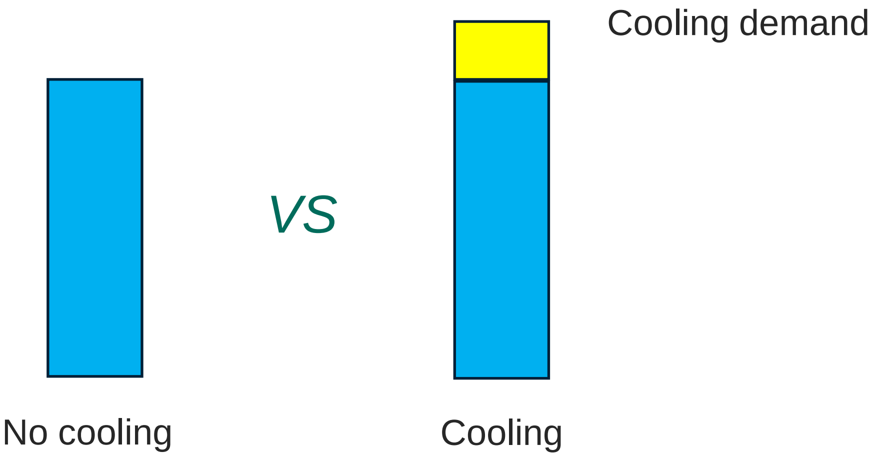
The hourly cooling demand profile is modeled through CDH (Cooling Degree Hour), assuming the demand rises linearly according to ambient temperature above a threshold T_{base}.

If $T(i) > T_{base}$, $CDH(i) = T(i) - T_{base}$, *else* $CDH(i) = 0$

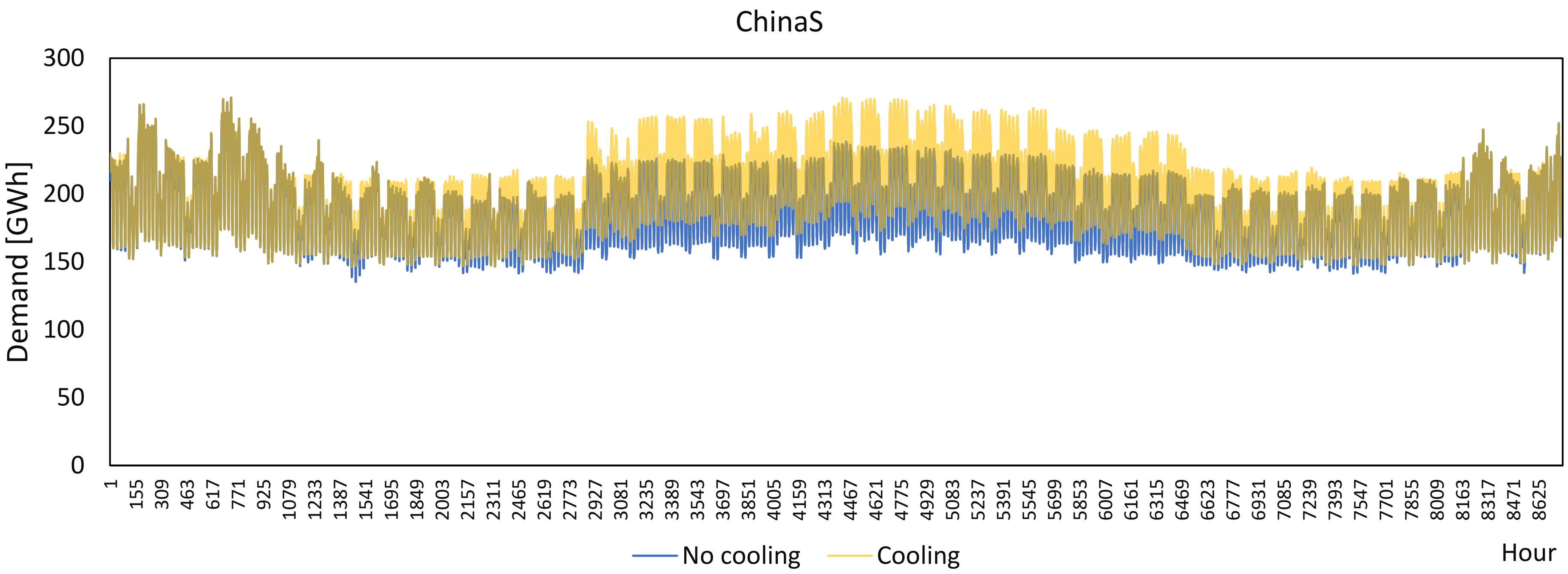
The time series of cooling demand is then scaled according to the annual cooling demand for each region.

Zhu et al., 2020

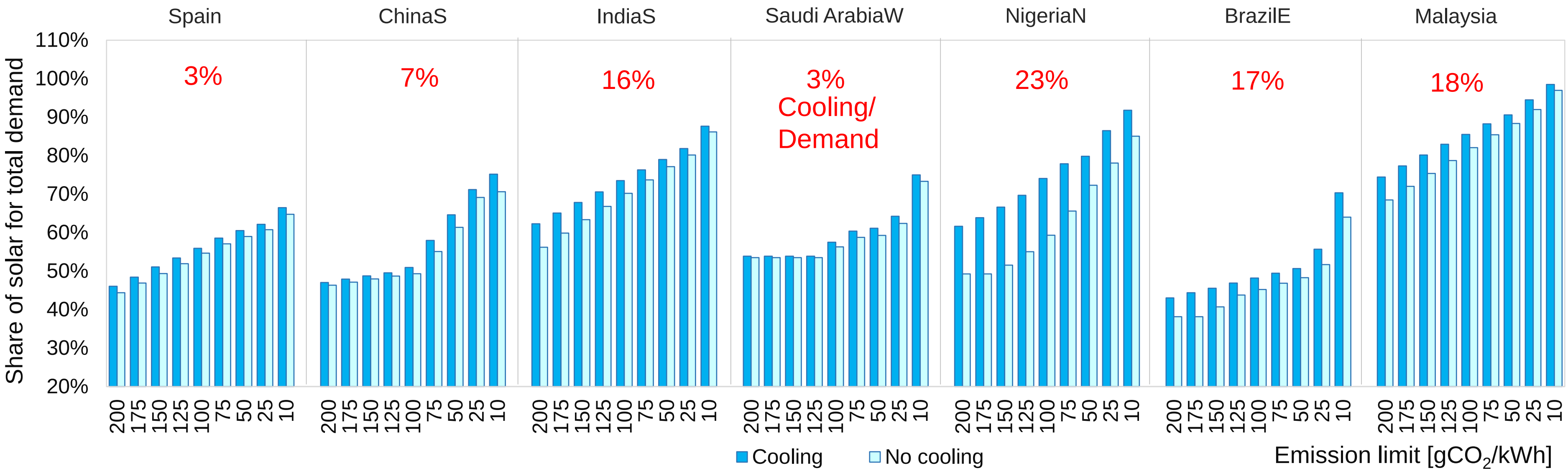
Comparison

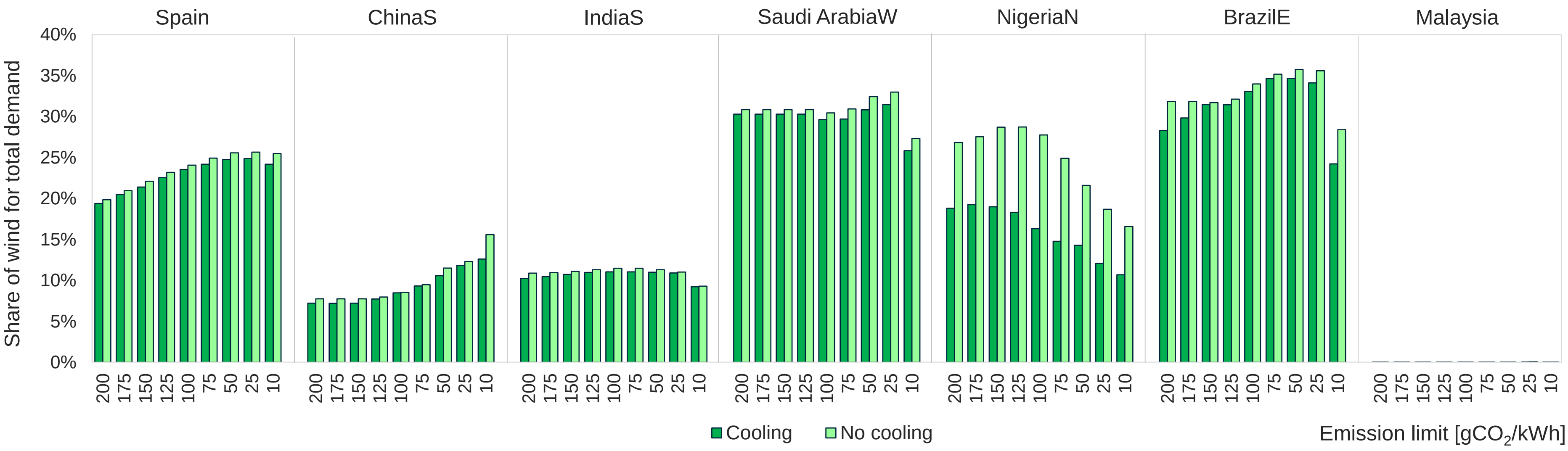


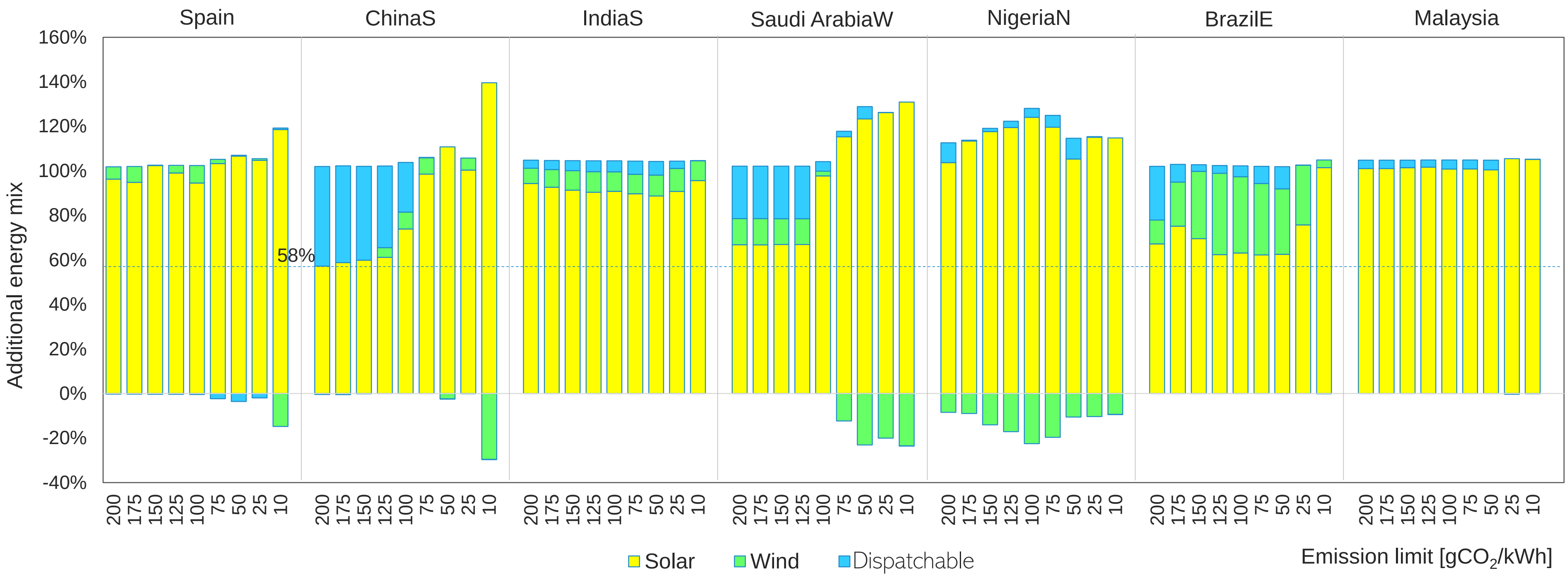
Demand profile



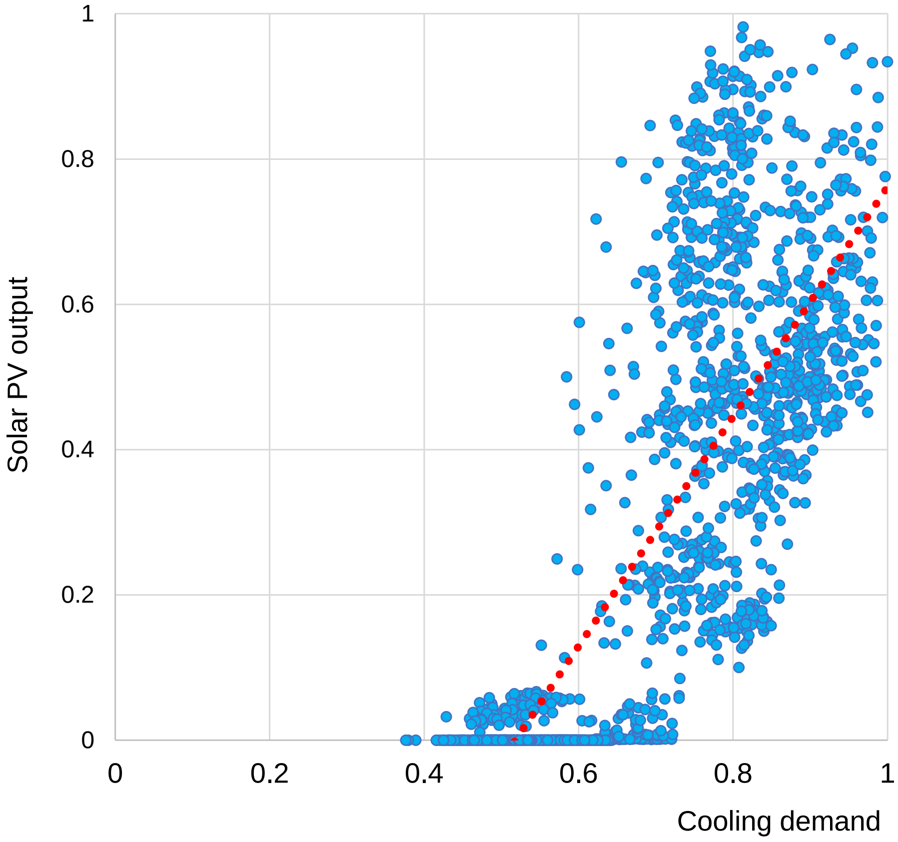
Results

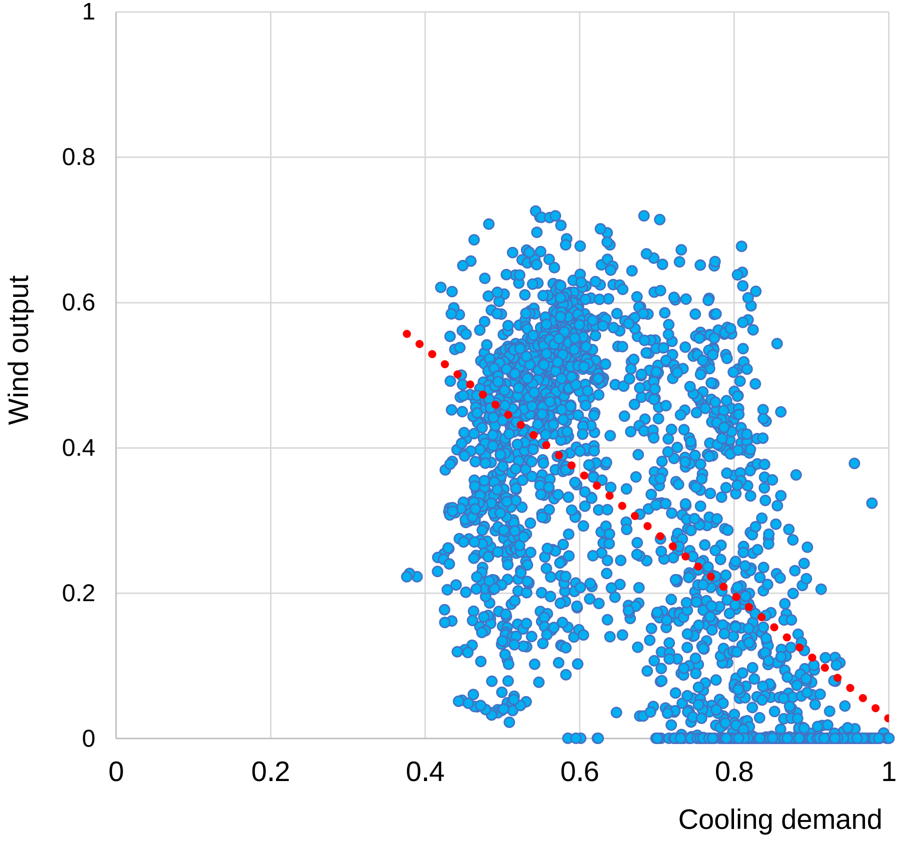

Spain
ChinaS
IndiaS
Saudi ArabiaW
NigeriaN
BrazilE
Malaysia
3%
7%
16%
3% Cooling/ Demand
23%
17%
18%
Share of solar for total demand
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
200 175 150 125 100 75 50 25 10
Cooling
No cooling
Emission limit [gCO_2/kWh]


Spain
ChinaS
IndiaS
Saudi ArabiaW
NigeriaN
BrazilE
Malaysia
Share of wind for total demand
0%
5%
10%
15%
20%
25%
30%
35%
40%
200 175 150 125 100 75 50 25 10
Cooling
No cooling
Emission limit [gCO2/kWh]

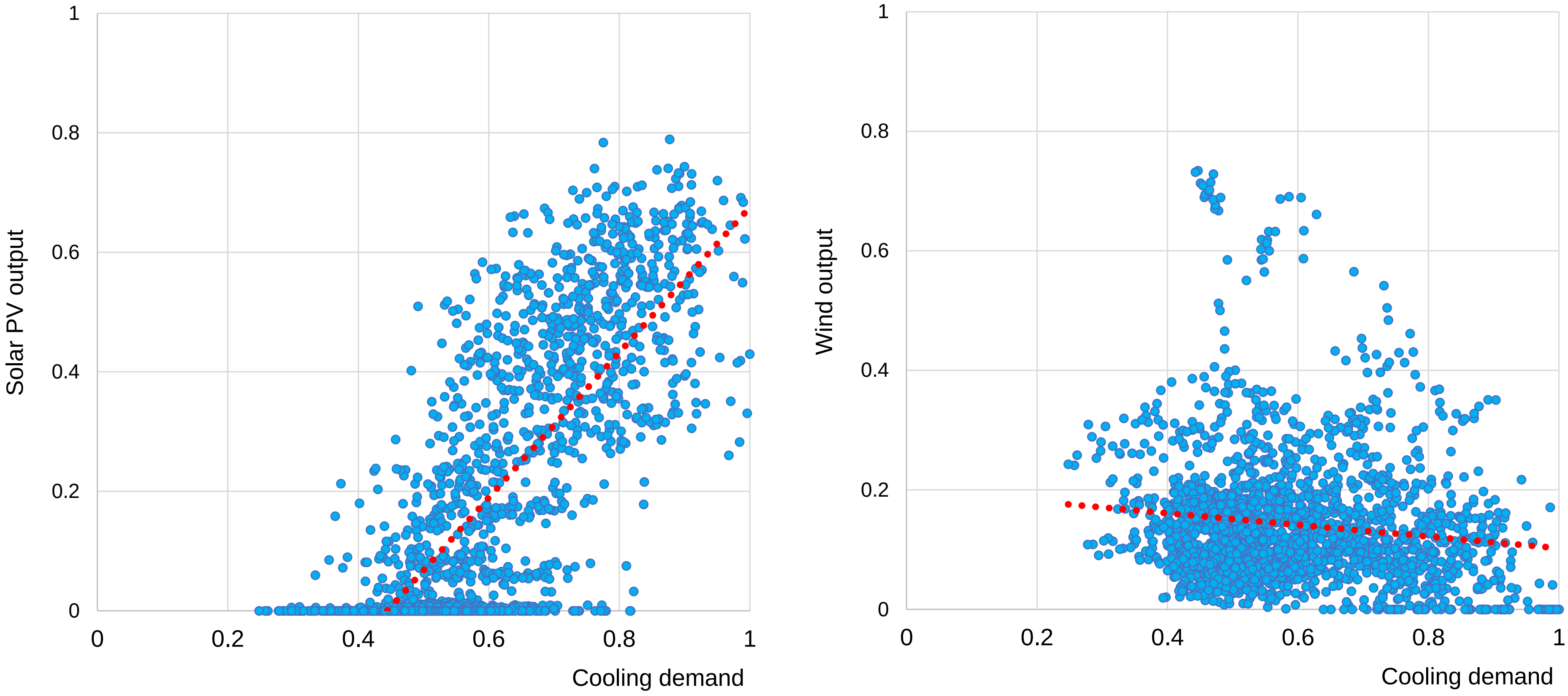

Spain
ChinaS
IndiaS
Saudi ArabiaW
NigeriaN
BrazilE
Malaysia
160%
140%
120%
100%
80%
60%
40%
20%
0%
-20%
-40%
Additional energy mix
58%
200
175
150
125
100
75
50
25
10
Solar
Wind
Dispatchable
Emission limit [gCO2/kWh]

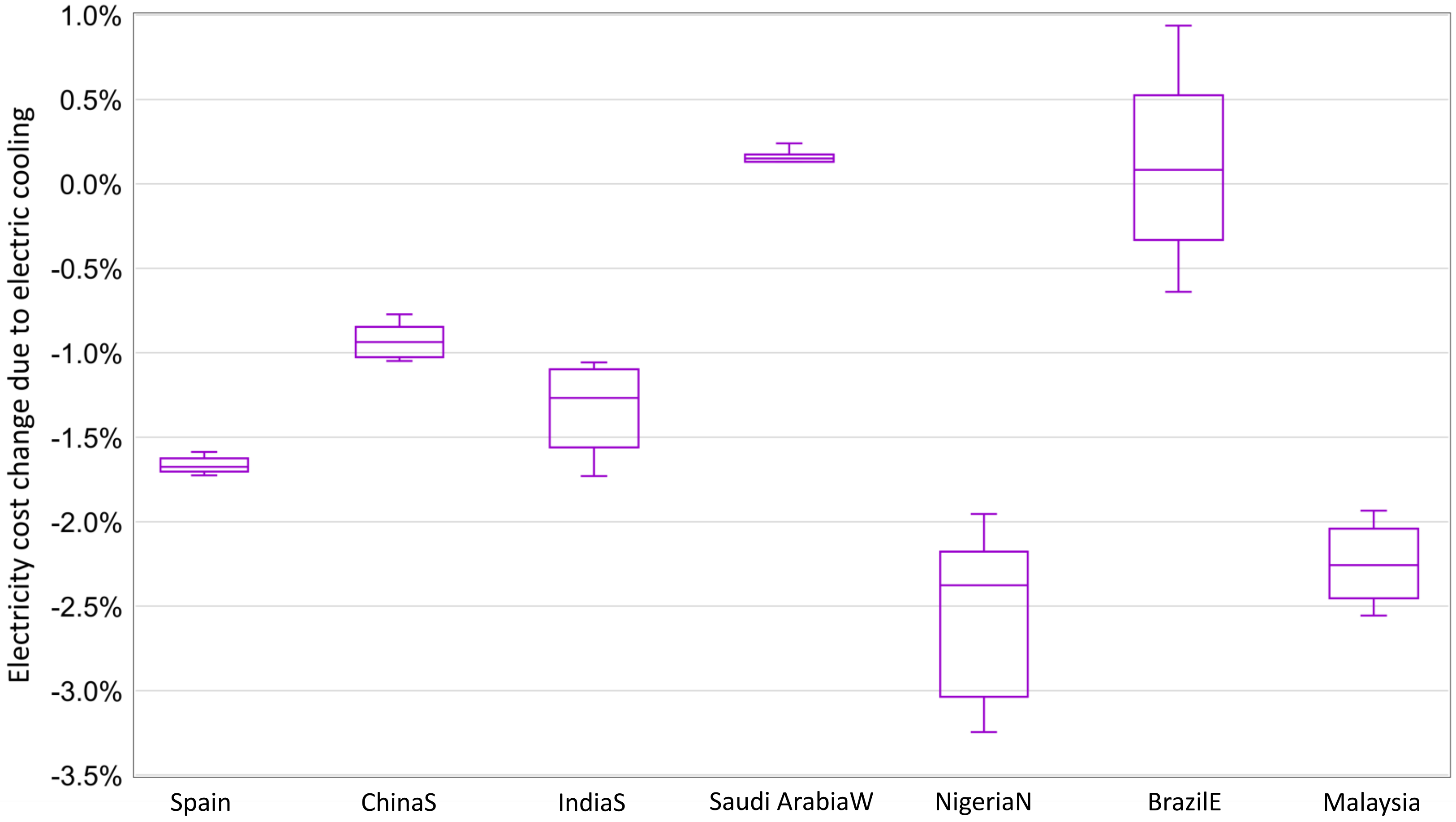
BrazilE


Solar PV output
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Cooling demand


Wind output
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Cooling demand

ChinaS


Solar PV output
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Cooling demand
Wind output
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Cooling demand


Electricity cost change due to electric cooling
1.0%
0.5%
0.0%
-0.5%
-1.0%
-1.5%
-2.0%
-2.5%
-3.0%
-3.5%
Spain
ChinaS
IndiaS
Saudi ArabiaW
NigeriaN
BrazilE
Malaysia

Conclusions

- Utilizing electric cooling benefits the investment in solar PV regardless of the CO_2 emission target;
- Utilizing electric cooling has limited impacts on the average electricity cost;
- Solar PV might be a suitable solution to affordable cooling for developing countries.

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Thank you!

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