Estimating storage needs for renewables in Europe: The correlation between renewable energy sources and heating and cooling demand

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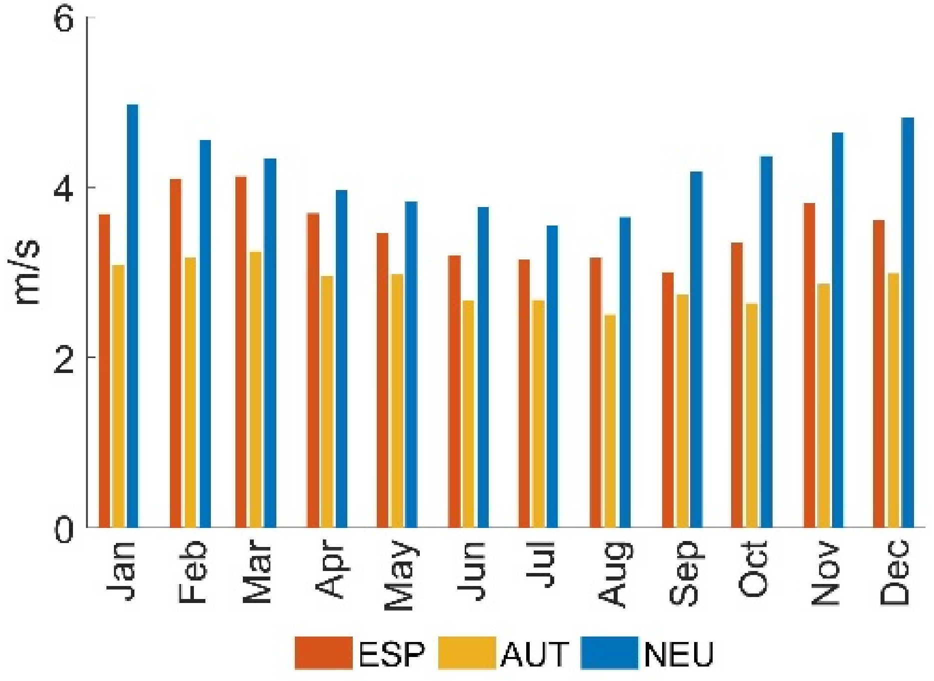
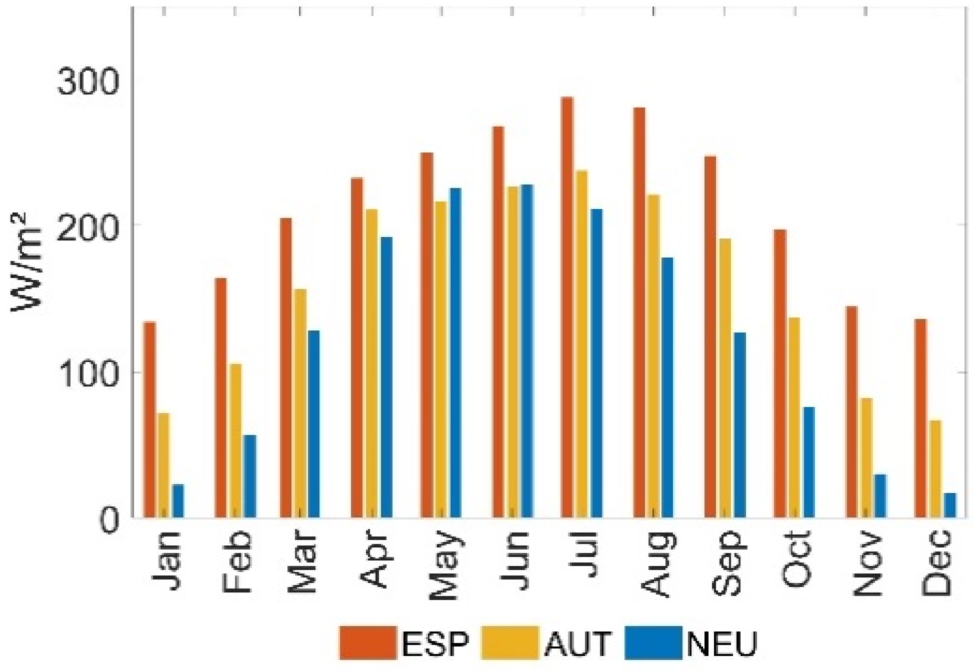
Renewable energy sources are characterised by a strong seasonal cycle

Monthly average wind speed



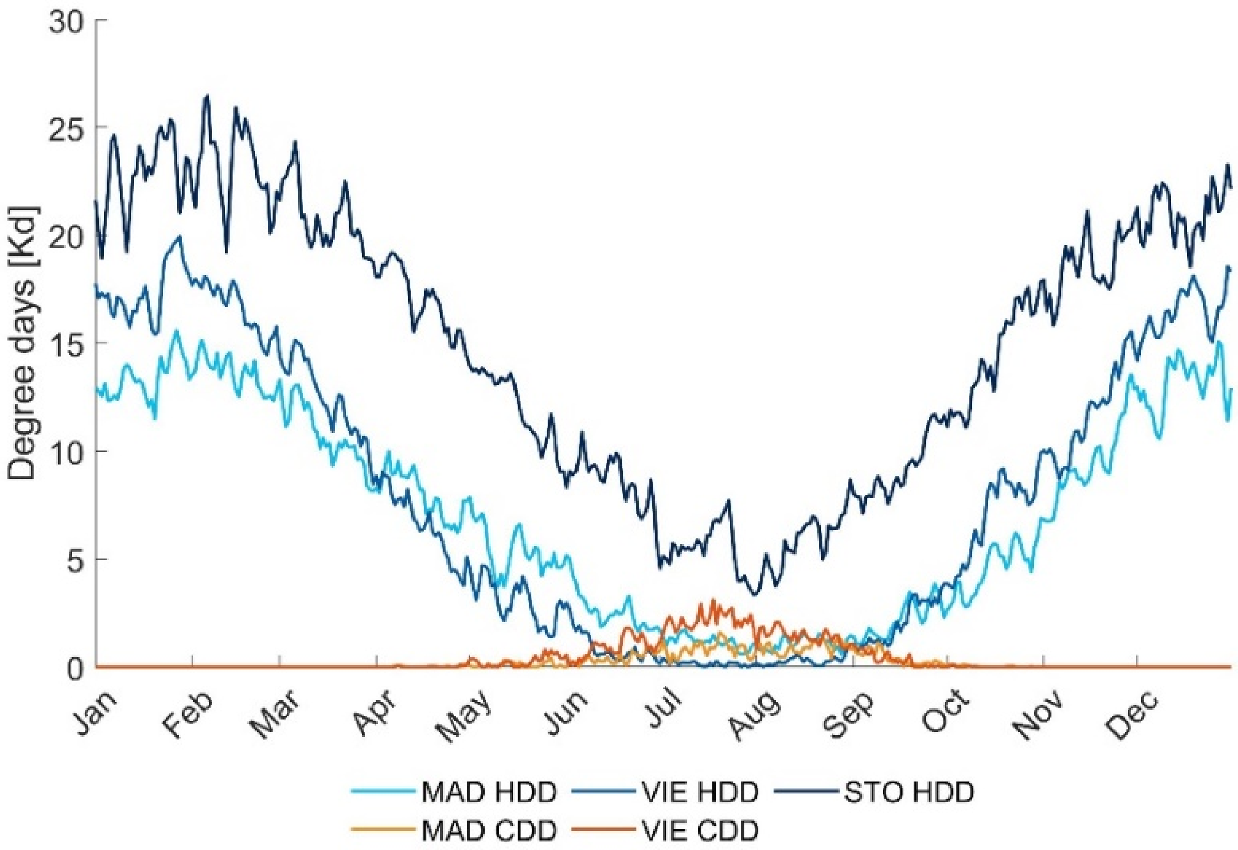
Monthly average solar irradiance



ESP … Spain
AUT … Austria
NEU … northern Europe

So do temperatures and heating & cooling: Similarity between wind speed patterns with HDD and solar irradiance with CDD

Historical average HDD and CDD in Madrid, Vienna and Stockholm



MAD … Madrid
VIE … Vienna
STO … Stockholm

How can this be used as an advantage in renewable energy systems?

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*How well does the **seasonal/monthly/daily pattern** of **wind speed** and **solar irradiance** correlate with **temperature** changes and consequently with **heating & cooling** needs?*

- **Hypothesis:** There is a significant correlation that specifically suggests the use of energy from solar irradiance for cooling and from wind speed for heating needs.
  - How big is the time discrepancy between supply and demand?
  - What type of storage time period is needed?
  - Do the results differ among different climate regions and locations?
  - What is the effect of climate change on HDD and CDD as well as solar irradiance and wind speed?
  - What are resulting policy recommendations?

* HDD… Heating degree days
CDD… Cooling degree days

Approach

Estimating storage needs for renewables in Europe

Relevant data and definition of heating and cooling needs

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- The analysis carried out for Spain, Austria and northern Europe uses the following climate data:
  - Solar irradiance [W/m²]
  - Wind speed [m/s]
  - Temperature [T_i] [°C]
- Historic analysis based on hourly data[1)] 2005 – 2016 for 6 locations per climate region
- Consideration of climate change with daily climate projection data by CMIP5[2)] for 1 location per climate region (MAD, VIE, STO)
- Heating/cooling needs are derived from temperatures via HDD/H and CDD/H[3)]

$$T_i \begin{cases} \leq T^h : HDH = (T^h_{room} - T_i) \\ > T^h : HDH = 0 \end{cases} \quad (1)$$

$$T_i \begin{cases} \geq T^c : CDH = (T_i - T^h_{room}) \\ < T^c : CDH = 0 \end{cases} \quad (2)$$

Heating demand T^h= 15°C

Desired Room T^h_{room}= 18°C

Cooling demand T^c= 24°C

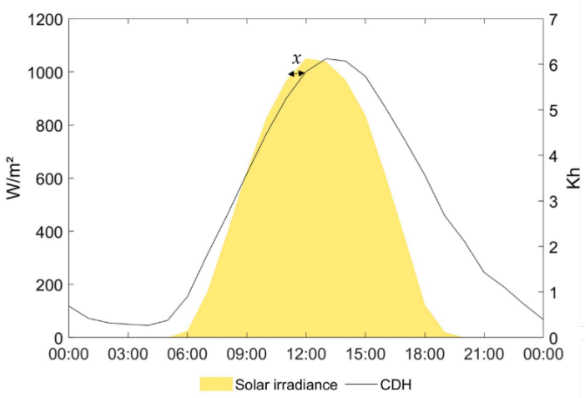
Desired Room T^c_{room}= 21°C

1) https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#TMY
2) https://cds.climate.copernicus.eu
3) eurostat (2020)

HDD/H… Heating degree days/hours
CDD/H… Cooling degree days/hours

Correlation analysis: The data is adjusted by the time lag *x* between VRE availability and temperature changes

- The variable x describes the amount of hours that the derived variable, for example CDH, lags behind the primitive variable (solar irradiance) in any point in time.



1. Solar irradiance - CDH *x=2* *[h]*
2. Wind speed - HDH *x=16* *[h]*
3. Solar irradiance - HDH *x=14* *[h]*

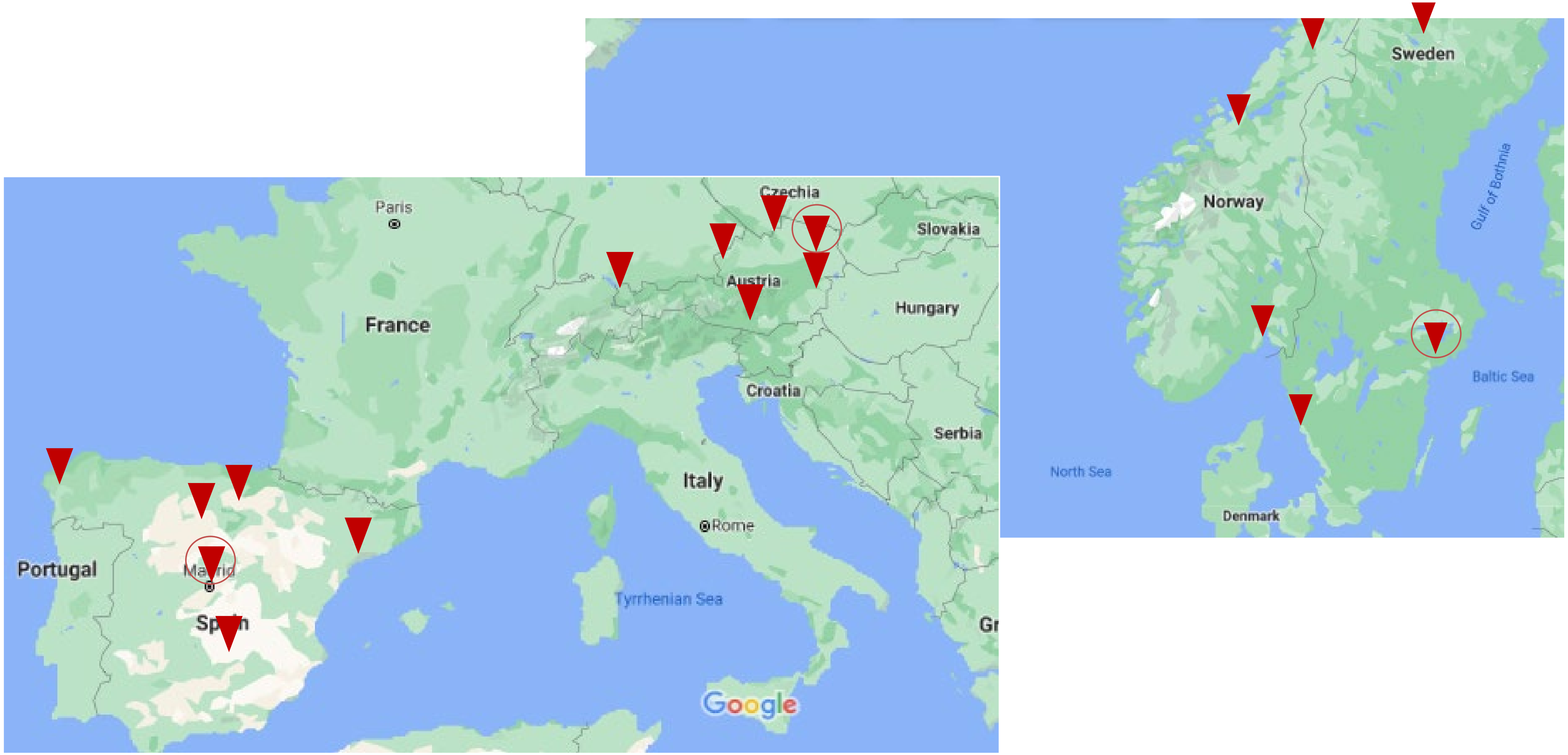
Defined as an average for all locations

- We analyse the correlation coefficient ρ after Pearson on different time scales between HDD & wind speed, CDD & solar irradiance and HDD & solar irradiance
- ρ is interpreted as the following:

ρ	INTERPRETATION
< 0.19	Very weak
0. 20-0.39	Weak
0. 40-0.59	Moderate
0. 60-0.79	Strong
0. 80-1.00	Very strong

Choice of locations in three climate regions

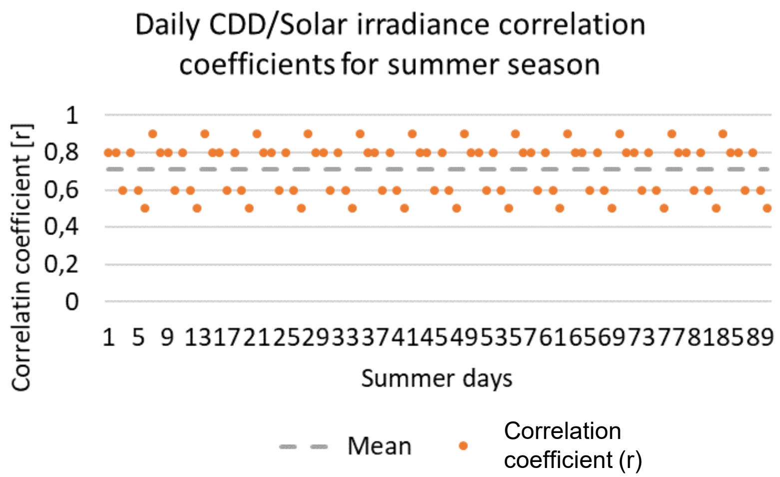
…to cover a broad set of historic average solar irradiance and wind speed



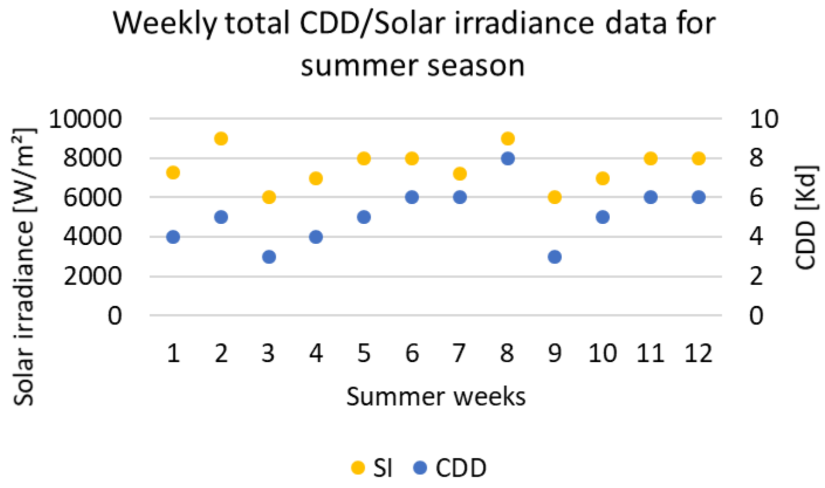
https://globalsolaratlas.info/
https://globalwindatlas.info/

Two approaches for the historic analysis using hourly data

Approach 1 (A1) determines the hourly correlation adjusted by *x* for hourly, daily and weekly time-periods in a season (90 days in summer)



Approach 2 (A2) investigates the value of storage based on daily or weekly aggregated weather data in a specific season or the monthly aggregated data across the whole year. (12 weeks in summer)



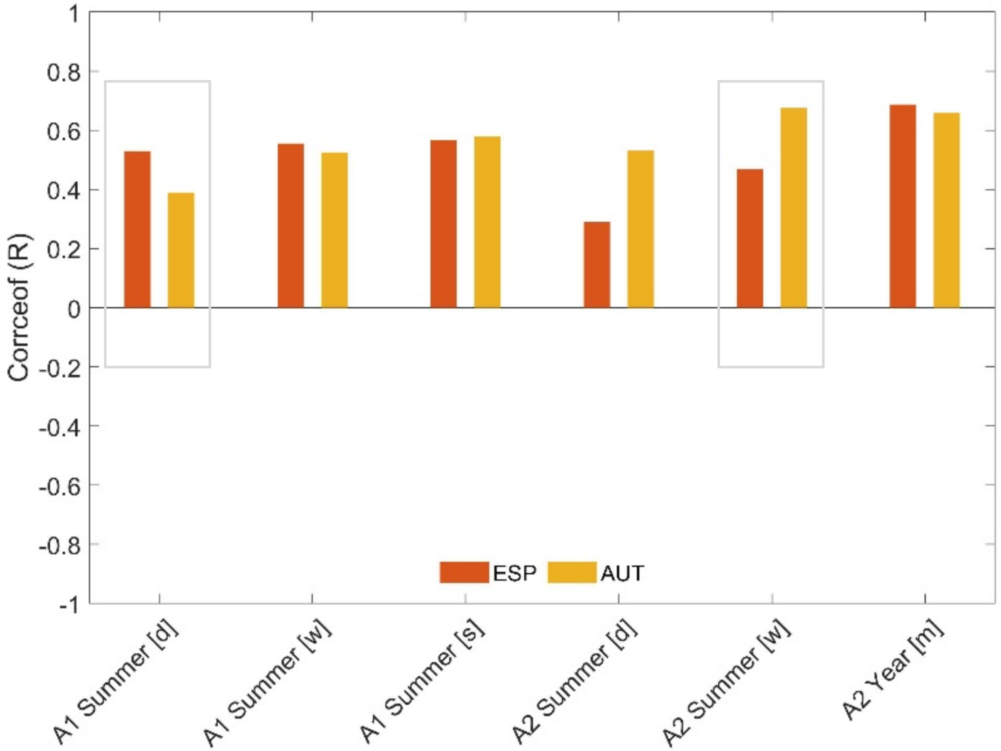
Results

Estimating storage needs for renewables in Europe

Solar irradiance and CDH correlate moderately on average and strongly in many locations

A1: Hourly patterns in Spain match better on daily basis while Austria improves stronger towards seasonal time periods.

A2: Weekly aggregated CDH correlates strongest with solar irradiance in Austria, while monthly storage leads to stronger results in Spain.



Solar irradiance and CDH correlation coefficient (ρ) in summer

Per climate region for different time-periods applying approach 1 (A1) and approach 2 (A2)

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The correlation between HDH and wind speed is insignificant

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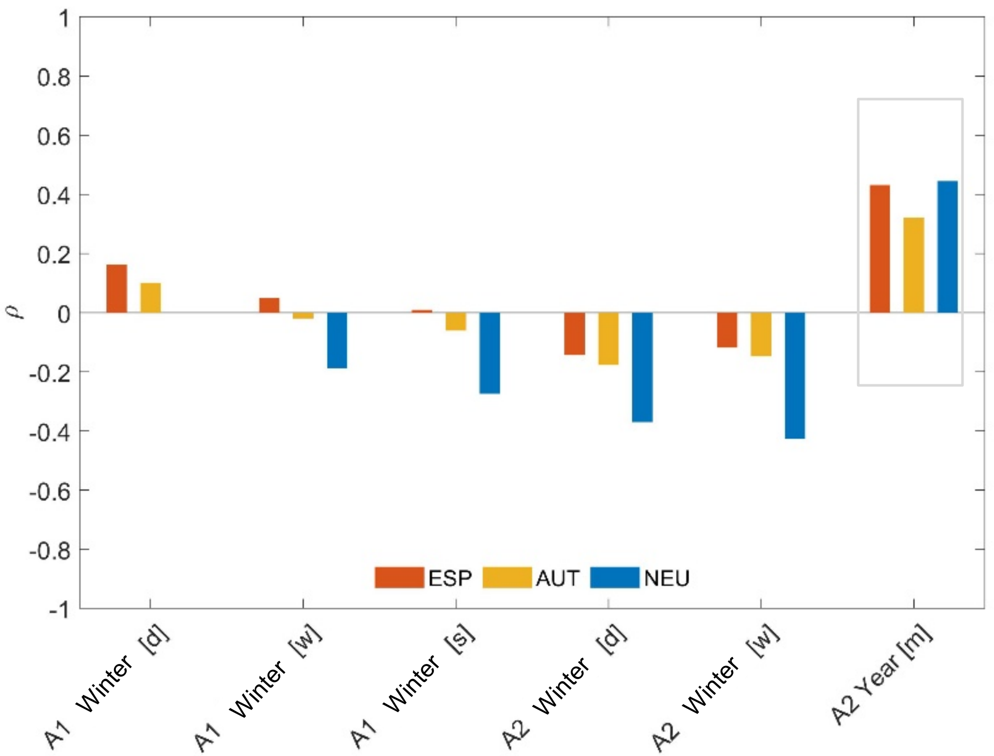
All in all **HDH and wind speed do not show a significant positive correlation**.

This means that wind speed increases do not necessarily lead to temperature decreases within the time lag x.

Only monthly aggregation of the wind speed data correlates moderately with heating needs specifically in Spain and northern Europe.



Hourly wind speed and HDH correlation coefficient (ρ) in winter

Per climate region for different time-periods applying approach 1 (A1) and approach 2 (A2)

A1 – hourly correlation [d/w/s]
A2 – aggregated data [d/w/m]
day [d], week [w], season [s], month [m])

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Solar irradiance could be a promising energy source for heating

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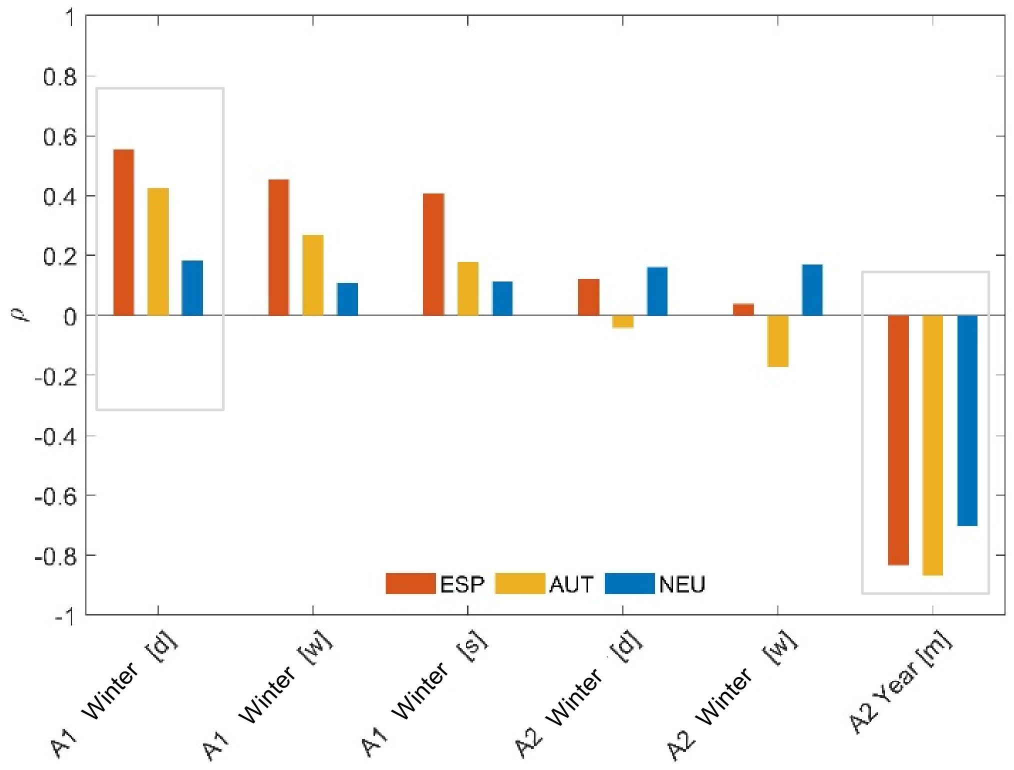
A1: In an average across all locations, Spain achieves almost strong correlation between daily HDH and solar irradiance patterns.

Limited solar irradiance in northern European winters

A2: Monthly solar irradiance correlates on a very strong negative basis with heating needs.



Hourly solar irradiance and HDH correlation coefficient (ρ) in winter

Per climate region for different time-periods applying approach 1 (A1) and approach 2 (A2)

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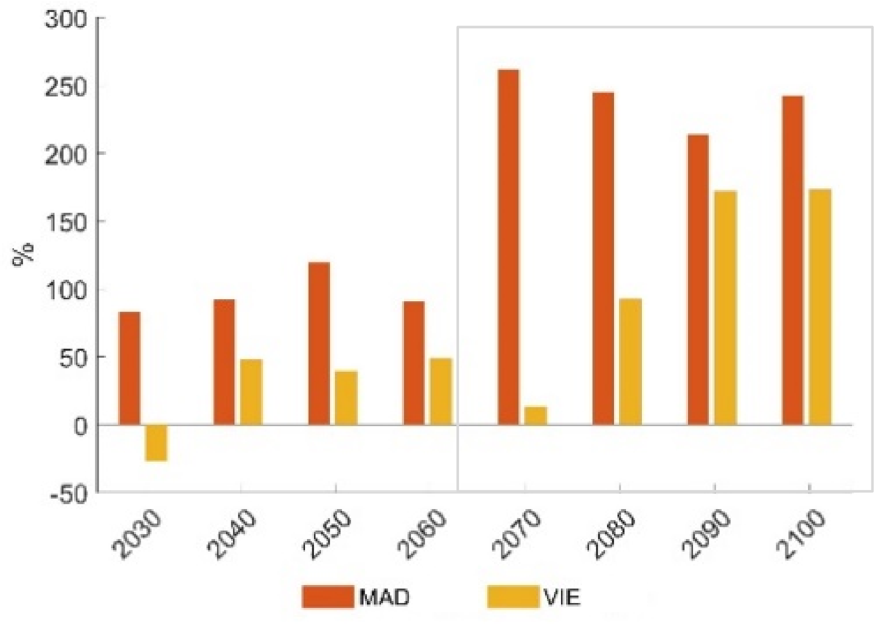
CDD are expected to decrease strongly with climate warming

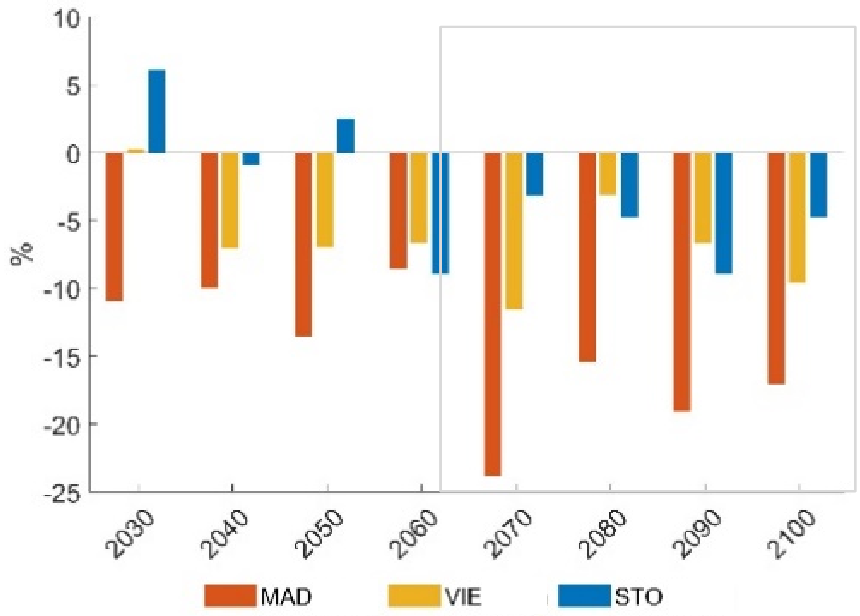
Climate change leads to a decrease in HDD and an increase in CDD.

- The latter is critical in Madrid/ESP.
- Building standards/insulation/shading are critical to avoid direct impact on energy demand.
- Solar power could cover increasing cooling needs.

Relative CDD change compared to 2020



Relative HDD change compared to 2020



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Conclusions

- Regional differences in weather variables need to be considered
- Solar irradiance correlates significantly with CDH and, from this perspective, could efficiently provide renewable energy for this purpose
- The relationship between wind speed and temperature derived heating needs in winter — the strongest heating period — is complex in all locations and would require up to monthly balancing.
- Solar irradiance and heating needs correlate almost strongly after consideration of the 14h time lag mostly in Austria and Spain.

- Climate warming causes a substantial increase in CDD (2-fold in Spain in between 2020 - 2070)
  - Insulation and shading are essential to avoid direct impact on energy demand.
  - High temperatures could also limit PV efficiency.
  - The reduction of HDD through climate change is less severe (-20% between 2020 - 2070)

References

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