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Solar Industrial Process Heat and Thermal Desalination

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Solar Heat for Commodity Production: Mapping and Comparison With Fossil Fuel and PV

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Abstract. A systematic assessment of concentrated solar thermal (CST) energy and its levelized cost of heat (LCOH) is essential to demonstrate the global potential of CST-energy for decarbonizing industrial heat demand – especially, since time is running out to tackle climate change and a significant part of industrial heat demand can be covered with CST as solar heat for industrial processes (SHIP). For this study, CST-LCOH in dependence of the DNI (direct normal irradiance) are obtained from literature as the annual energy yield changes with DNI and thus, the LCOH changes accordingly. These are mapped for Spain and compared locally with fossil fuel- as well as PV-based heat. A sensitivity analysis is performed for CST-LCOH, varying it by ±10 %, and including an implementation of CO_2-taxes of 0, 50 and 100 €/t CO_2 for the fossil fuels coal and natural gas. In all cases, if a renewable source is cheaper than fossil fuels, it is overwhelmingly CST. The margin for CST-energy, obtained as the difference of fossil fuel price with CST-LCOH, divided by CST-LCOH and which can also be interpreted as the relative margin from CST-LCOH to -price, reaches in the extreme case 139 % for fossil fuel prices in 2022 and a CO_2-tax of 100 €/t CO_2.

Keywords: CST, LCOH, SHIP

1. Introduction

While concentrated solar energy is somewhat present in renewable energy scenarios for power production, its real advantage for being a direct source of heat is often overlooked. This is more remarkable, as the heat demand above 400 °C makes up half of the total industrial heat demand, which is *e.g.* needed for the production of major commodities like metals and construction materials [1]. Concentrated solar thermal (CST) systems can provide the heat and this work assesses a solution space for the levelized cost of heat (LCOH) in Spain in dependence of the DNI (direct normal irradiance) by using several data sources. The production of bricks, zinc, calcination of limestone as well as the recycling of aluminium were selected as exemplary commodities with a high-temperature heat demand.

2. Methodology

The analysis focused on Spain and two cases were considered for the fossil fuels natural gas and coal: a higher fossil fuel price case with data from the second half of 2022 and a lower fossil fuel price case considering the first half of 2023 (both averaged). Prices for natural gas were obtained from Eurostat [2] and for coal, type ARA CIF, from the IEA [3]. The results were obtained by averaging the fuel costs in the considered time spans and no other conversions

or modifications were done: 4.3 c€/kWh and 1.9 c€/kWh for coal, and, 10.5 c€/kWh and 6.5 c€/kWh for natural gas, respectively for the second half of 2022 and first half of 2023.

DNI-dependent LCOH of concentrating solar thermal systems, line- and point-focusing, were obtained from literature [4–10], and updated to 2022 with inflation where necessary and plotted to obtain a correlation. It includes plant sizes from 0.2–50 MW_{th} and storage sizes from 0–12 hours. The data is shown in **Figure 1** and was approximated with a logarithmic trendline. The obtained R^2 is 0.6742 which can be explained due to the different data sources, as using the singular data sets yields R^2 values of 0.78 to 0.99. A sensitivity study is included to cover a wide range of LCOH values by varying the obtained trendline by ±10%. Combining the DNI-LCOH data with a geospatial DNI map [11] allows the visualization via mapping.

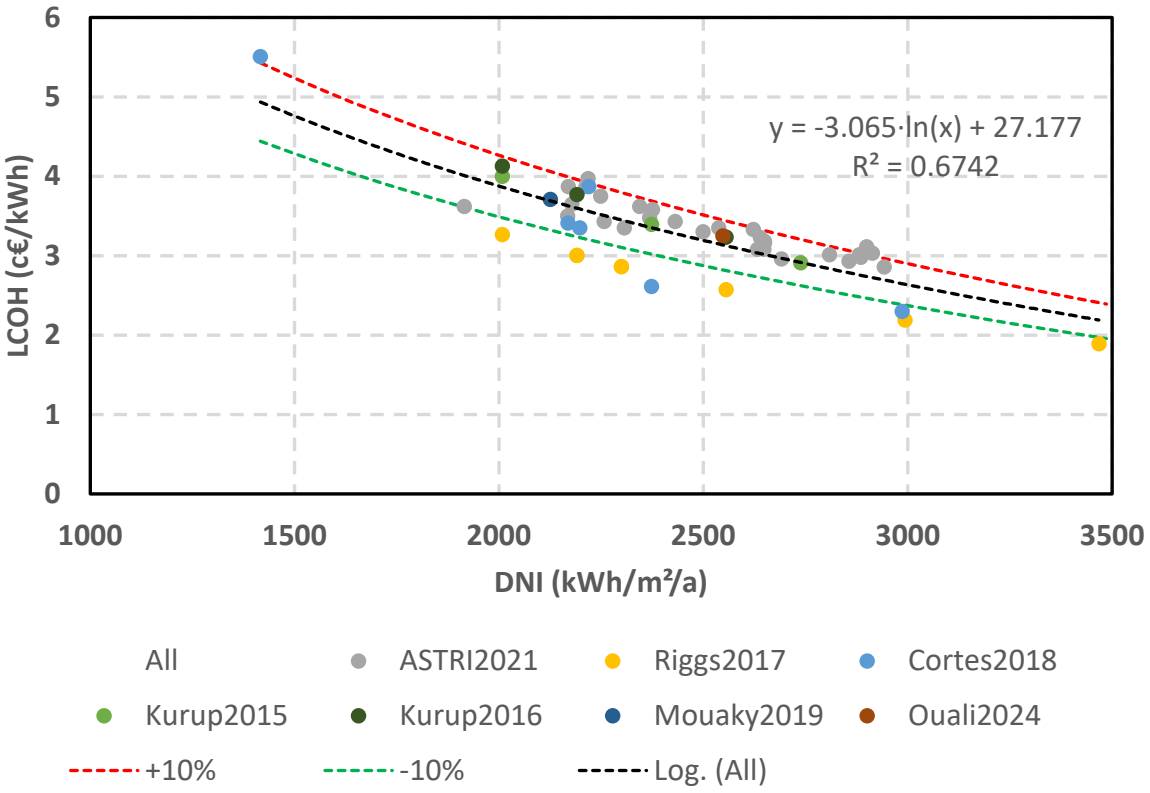


Figure 1. *Literature values for LCOH of CST-systems obtained from 6 sources. The logarithmic trend-line is fitted to all data points and variations with ±10 % are shown. All LCOH data were updated to 2022.*

For a potential PV-based heat LCOH, the following approach was taken: A geospatial PV LCOE map, provided by the World Bank in 2020 [12], was used and updated to 2022 with data for Spain from IRENA [13], matching their mean values by applying a factor of 0.557. No further changes in the data were done, such as considering an electricity-to-heat efficiency, additional heaters or storages. Lastly, currently externalized costs of fossil fuels were added in a sensitivity analysis: CO_2-taxes. These were added according to the CO_2 released by combustion of coal and natural gas. As the solar technologies have very low CO_2 footprints [14], an impact on them was neglected. Where CST is cheaper, the results are given as the margin for CST-LCOH calculated as:

$$Margin\ for\ \text{CST-LCOH} = \frac{Price\ of\ fossil\ fuel - LCOH_{CST}}{LCOH_{CST}} \cdot 100\ \% \qquad (1)$$

3. Results

Figure 2 shows the economic potential for different heat sources in Spain, considering fossil fuel prices in the second half of 2022, no CO_2-taxes and the base line for the CST-LCOH. In all the assessments, the lower priced fossil fuel was taken as the reference for comparison, which is the same for each location as these prices are assumed to be constant for the whole country. The mean value in the shown case for CST is 4.13 c€$_{2022}$/kWh while it is 4.6 c€$_{2022}$/kWh for PV. For the most part of Spain, CST represents the cheapest heat source. While this is only a binary assessment, Figure 3 shows the margin of the CST-LCOH versus the fossil fuel as a ratio of the CST-LCOH. Thus, the gap is as high as 23 % in southern Spain while the median is 10 % for the identified regions.

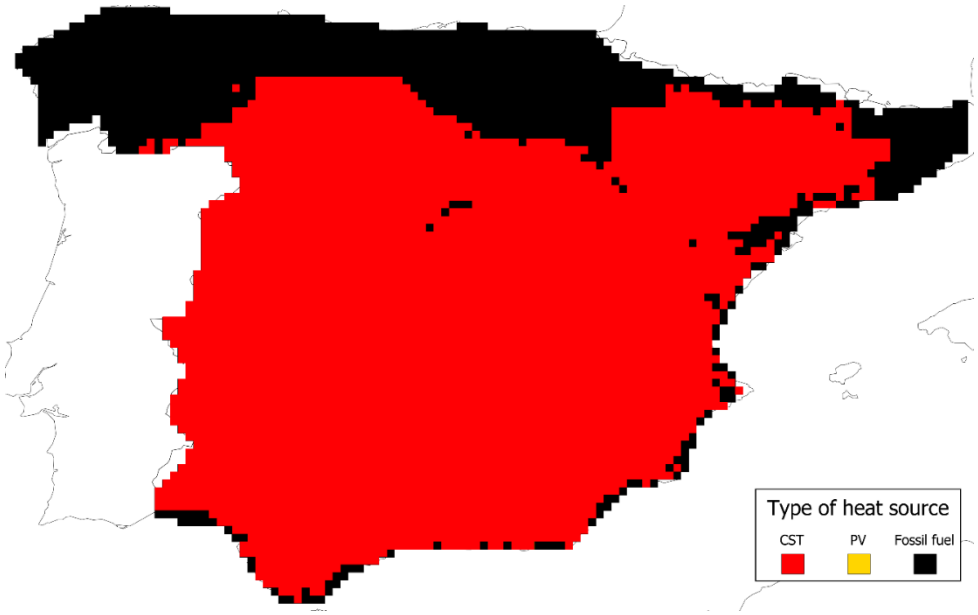


Figure 2. *Comparison of most economic heat sources for the second half of 2022 with no CO_2-taxes and base line CST-cost.*

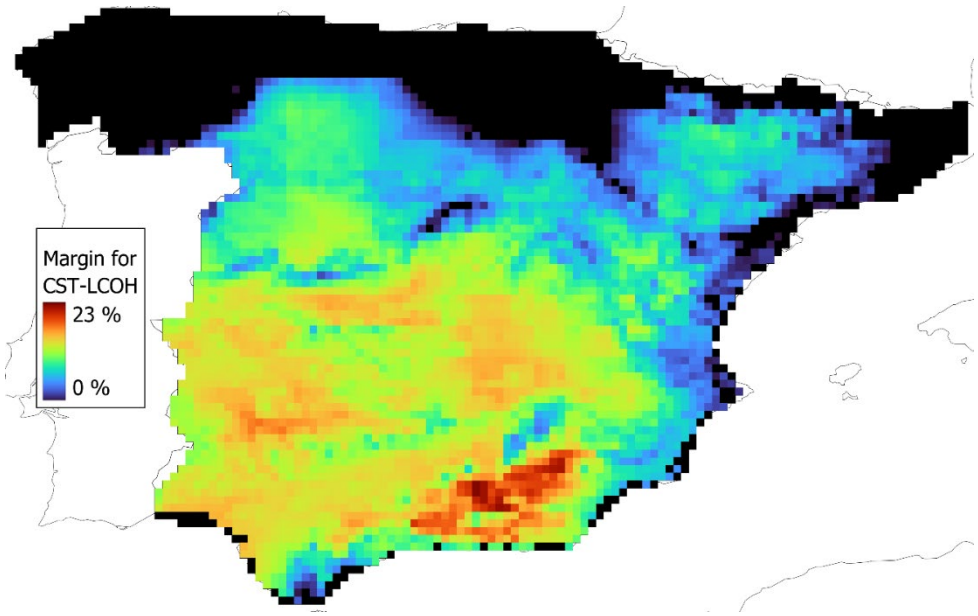


Figure 3. *Map showing the margin for CST as a ratio of its LCOH compared to fossil fuels for the second half of 2022 with no CO_2-taxes and base line CST-LCOH.*

Table 1 and **Table 2** show the results for all the analysed scenarios, with CO_2-taxes of 0, 50 and 100 €/t CO_2 and all three CST-LCOH trendlines from **Figure 1**. In all cases, if a renewable source is cheaper than fossil fuels, it is overwhelmingly CST. The margin for CST-energy, which can be interpreted as the margin from LCOH to the price of CST heat, reaches in the extreme case 139 % for fossil fuel prices in 2022 and a CO_2-tax of 100 €/t CO_2 (**Table 1**). Even for the base line, a median of 94 % is found.

Table 1. *Sensitivity analysis of heat sources for second half of 2022 with different CO_2-taxes and different trendlines of CST-LCOH. The colour scales are relative to the maximum in each row, given in the first column.*

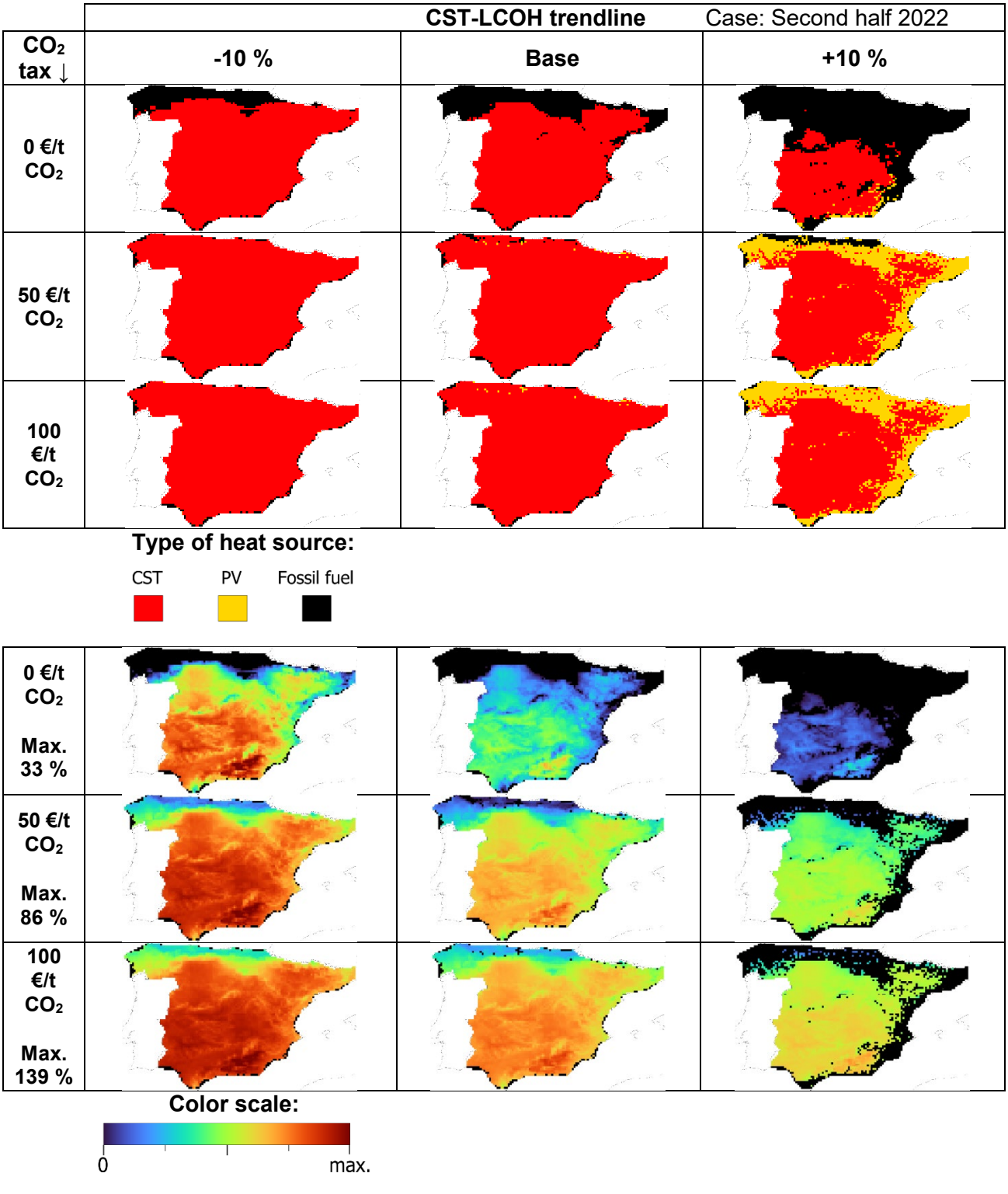
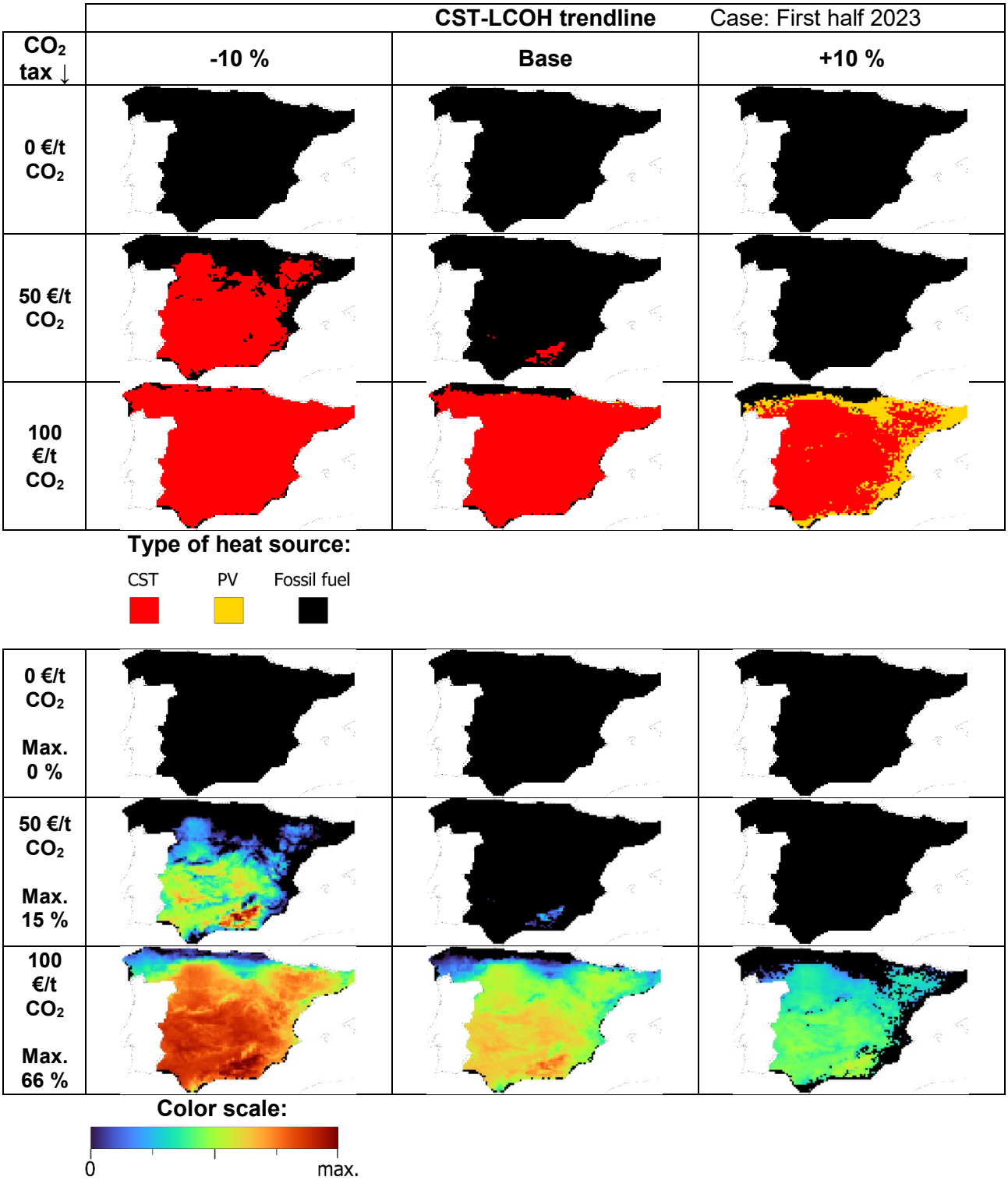


Table 2 shows that with lower fossil fuel prices, *i.e.* considering the first half of 2023, a minor advantage is only to be expected with a CO_2-tax of at least 50 €/t CO_2. This gives for the –10 % trendline cost a max. margin of 15 %. However, once the tax reaches 100 €/t CO_2 even with the base line a median for the margin of 34 % is found. In all the identified cases, coal is the cheaper fossil fuel source.

Table 2. *Sensitivity analysis of heat sources for first half of 2023 with different CO_2-taxes and different trendlines of CST-LCOH. The colour scales are relative to the maximum in each row, given in the first column.*



4. Discussion

The analyses show, that CST has a significant potential to be a major source for renewable heat in Spain. Self-explaining, all the identified margins for CST-LCOH are significantly higher if the choice of the fossil fuel cannot be coal but has to be natural gas. In that case, the margins increase by a factor of 1.4–2.5 (for 2022) and 1.4–3.3 (for 2023), where the higher numbers refer to lower CO_2-taxes. The subsequent **Figure 4** shows relevant industries, requiring temperatures up to 1100 °C (considering the roasting step for zinc and only the calcination step for cement plants), which could all be potential users of CST-energy.

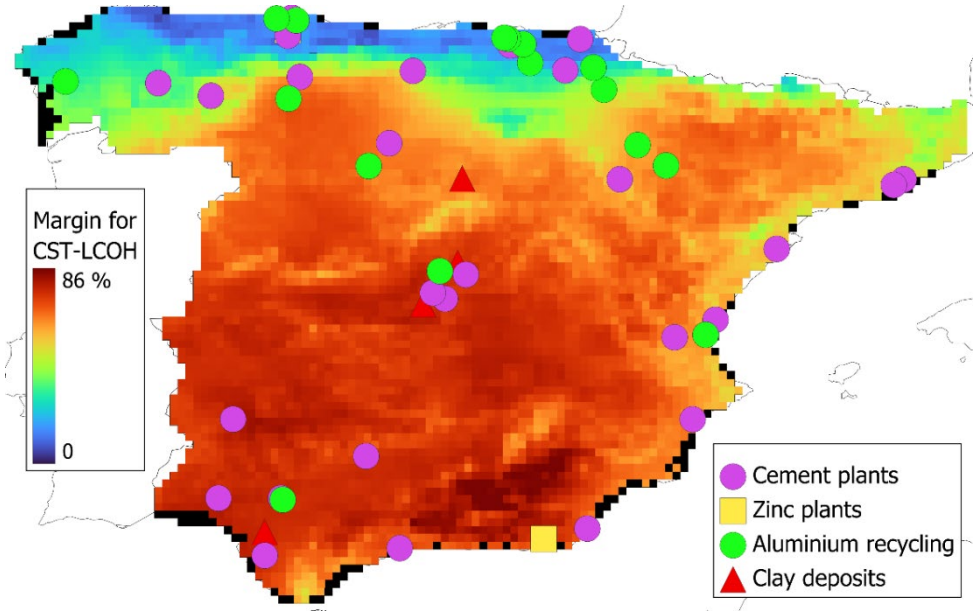


Figure 4. *Map showing relevant industry sites and mines in Spain together with the margin for CST as a ratio of its LCOH compared to fossil fuels for the second half of 2022 with 50 €/t CO_2-taxes and – 10%-line CST-LCOH. Industry sites and mines data is obtained from [15–18].*

5. Outlook

We provided in this study a first estimation of CST potential as heat source by using assumptions which are in favour of PV as the aspect of storages were neglected and no electricity-to-heat losses were considered. As a matter of fact, the CST data points from ASTRI consider a 12 h storage. Likewise, new receiver concepts predict CST-LCOH as low as 2.3 c€$_{2022}$/kWh with 12 h storage [19], having an outlet temperature of 900 °C at a DNI of ca. 2440 kWh/m²/a, *i.e.*, –30 % below our optimistic –10 % trendline in **Figure 1**. Another affirming aspect is that CO_2-taxations are inevitable, which will turn the current “scenarios” very soon into realities. At that point CST should be ready to fill the need for an easily storable, renewable heat source.

In future work, the aspect of full load hours or demand coverage, linked to the storage capacity, should be assessed, as well as additional costs to the LCOH which will occur to link the solar system to an industrial process. Also, the demand profiles of the relevant industries and the use of complementary technologies such as backup heaters should be incorporated as these can strongly affect the LCOH.

Data availability statement

All of the underlying data is publicly available and has been cited where used.

Author contributions

Gkiokchan Moumin: Conceptualization, Methodology, Investigation, Visualization, Writing – original draft, Writing – review & editing, Supervision. **Riccardo Cuneo:** Formal analysis, Investigation, Visualization. **Nicole Carina Neumann:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision.

Competing interests

The authors declare that they have no competing interests.

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