Cool the future with solar PV?

Xiaoming Kan [a,1] Fredrik Hedenus[a] Lina Reichenberg[a] Olav Hohmeyer[b] Maruf Nasimul Islam [b] Christian Fleischer [b]

[a]Department of Space, Earth and Environment, Chalmers University of Technology, Gothenburg, Sweden

[b]Department of Energy and Environmental Management, Europa-Universität Flensburg, 24943 Flensburg, Germany

1. Overview

Sustaining a comfortable temperature condition on hot days is essential for health, well-being and economic productivity [1-3]. Air conditioners (ACs) and electric fans are widely used to keep cool. In 2016, the global electricity consumption for space cooling was 2020 TWh, accounting for 10% of total electricity demand [4]. This value is estimated to increase to around 6500 TWh by 2050 due to the growth of income and population, and global warming [4, 5]. In terms of regional distribution, the growth of cooling demand will mainly take place in developing countries located in the hot regions due to increased use of ACs [4, 6, 7]. The chief driving force is the wealth growth in these regions, which enables more people to afford electric cooling. Birol et al. [4] estimated that the cooling demand would increase 15-fold in India and 13-fold in Indonesia by 2050. As a result, cooling demand would reach around 30% of the annual electricity demand and up to 40 % of the peak demand. Thus, electric cooling may have significant impacts on the total electricity demand as well as the inter-temporal demand pattern.

The demand for electric cooling typically correlates with high solar irradiation [4, 6, 7]. In addition, the past decade has witnessed a large cost reduction for solar photovoltaic (PV) and this trend is likely to continue thanks to technology innovation and economy of scale [8, 9]. Given the apparent synergy between cooling demand and solar irradiation, Laine et al. [7] assumed that the entire future cooling demand will be satisfied with solar PV. In stark contrast, the IEA report [4] showed that not only solar PV, but also wind power and a large share of fossil fuel-fired power plants are installed to meet the cooling demand if the electricity system is cost optimized. Yet, fossil fuel is not likely to be the solution to electric cooling, given the requirement of decarbonizing the electricity system to meet the goal of restricting the global temperature rise to well below 2°C above pre-industrial levels [10]. Zhu et al. [11] investigated the electricity system for Europe and found that a higher cooling demand has a minor impact on the cost-effective investment in solar PV for Europe as a whole. Therefore, it remains unknown regarding the impact of electric cooling on the cost-effective investment in solar PV for the future low-carbon electricity system in regions with potential large cooling demand. In addition, we do note that the methods adopted in the above studies [4, 7, 11] are not sufficient to tackle this question. Laine et al. [7] focused on the cooling sector only without optimizing the investment and the dispatch of the technology portfolio. Birol et al. [4] imposed generous CO_2 emission targets and the impacts of electric cooling on the investment for a low-carbon electricity system was not evaluated. Zhu et al. [10] investigated a case with a limited increase in cooling demand (mainly temperate zone) and the impact of income growth was neglected.

To make a comprehensive analysis regarding whether or not utilizing electric cooling makes investments in solar PV more cost-effective, we adopt a techno-economic cost optimization model with hourly temporal resolution, and the representation of solar, wind, hydro, coal, natural gas, storage and transmission. In contrast to the IEA

[1] Corresponding author: kanx@chalmers.se

report [4] and Zhu et al. [11], we explore the future electricity system for 7 regions with potential large demand for electric cooling subject to nine progressively more stringent CO_2 emission targets. Specifically, we address two questions with regard to the cost-effectiveness of investing in solar PV to meet the potential large demand for electric cooling:

1) How does electric cooling affect the cost-effective investment in solar PV for the future decarbonized electricity system?
2) How is the cost-effective investment in solar PV due to cooling contingent on the CO_2 emission target?

2. Methods

In this study, 7 regions located in the tropical and subtropical zones with potential large demand for residential air-conditioning are investigated with the REX model [12]. The electricity system with and without electric cooling for the residential sector is modeled with hourly time resolution given a CO_2 emission limit ranging from 200 to 10 g CO_2 per kWh of electricity demand. We focus on the residential sector as most of the increased cooling demand is estimated to originate from the residential sector [4, 6]. By comparing the energy mix for the system with electric cooling to the one without electric cooling, we are able to understand the impact of electric cooling on the investment in solar PV and other generation technologies. Here, we use the term 'Case-Cooling' to refer to the system that utilizes electric cooling and the term 'Case-No Cooling' to refer to the system without electric cooling. The change in electricity supply mix due to cooling is achieved by calculating the difference in energy mix between Case-Cooing and Case-No cooling. The modeled regions and the overview of the method are presented in Figs. 1 and 2 respectively.

Fig. 1. Map of the modeled regions. All the modeled regions are located in the hot parts of the world and they are highlighted with the orange color.

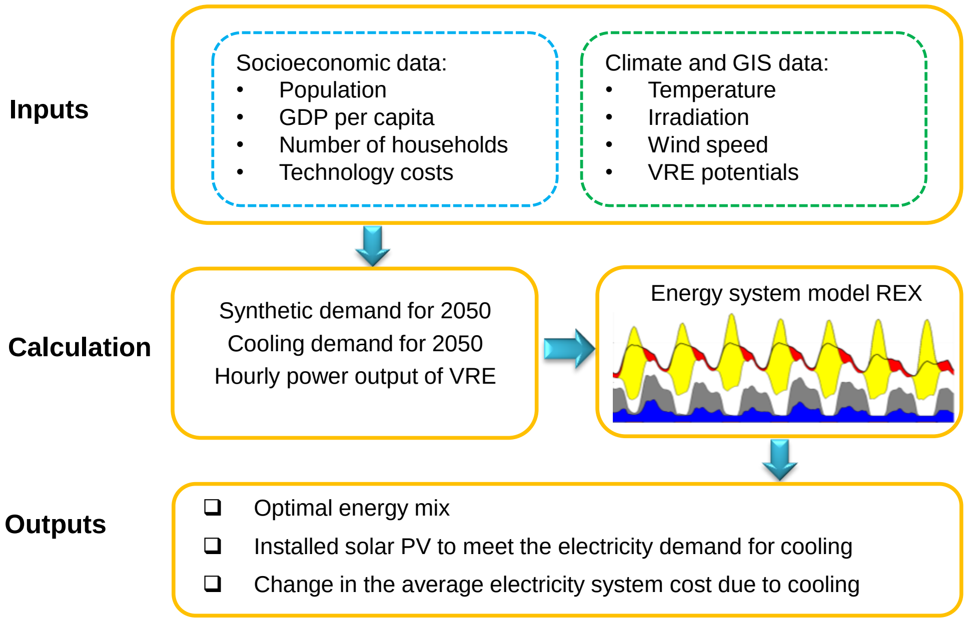

Fig. 2. Overview of the method. The dashed-line text boxes represent the: Socioeconomic data (blue); Climate and GIS data (green).

3. Results

3.1 Impact of electric cooling on solar PV investment

We first evaluate the impact of electric cooling on the investment in solar PV. As is apparent from Fig. 3, across a wide range of geographical locations and CO_2 emission limits, utilizing electric cooling (Case-Cooling) consistently increases the energy share of solar PV in the least-cost portfolio as compared to the case without electric cooling (Case-No cooling). The precise energy share increase for solar PV due to electric cooling varies, depending on the modeled region and the specific emission limit. The largest increase is observed for North Nigeria (NigeriaN) possibly due to the highest share of cooling demand (in the total electricity demand) and the best solar irradiance among all the modeled regions.

As expected, the energy share of solar PV declines as the emission limit grows less stringent. This is mainly because, with a more generous emission limit in force, the system is able to invest in more dispatchable fossil fuel-fired power plants. Thus, less solar PV is installed. Nevertheless, even for a system with a comparably low share of solar PV, it is still more cost-effective to invest in solar PV for a system with electric cooling compared to the one without cooling. Therefore, it is clear that utilizing electric cooling benefits the investment in solar PV.

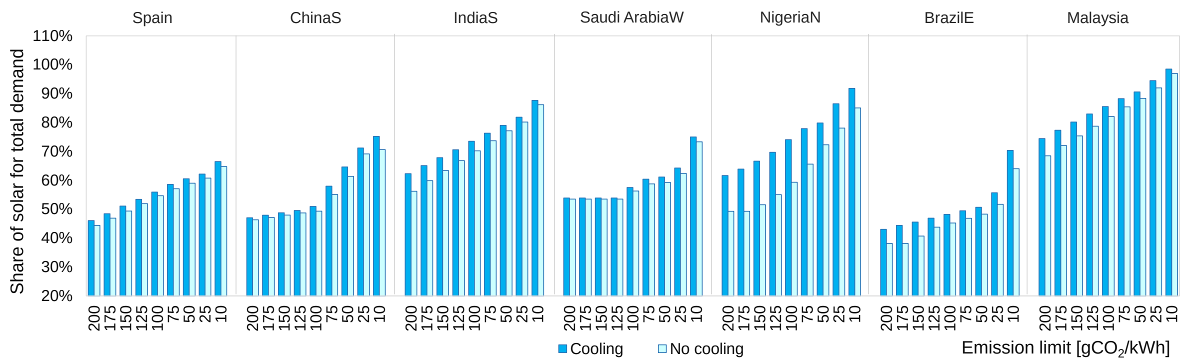

Fig. 3. The energy share of solar PV in the least-cost portfolio for the modeled regions under different carbon emission limits. The energy share is calculated as the electricity produced by solar PV (curtailment excluded) over the total electricity demand of the system.

3.2 Average electricity system cost

The change in the average electricity system cost due to electric cooling is shown in Fig. 4. For most of the modeled regions, the average electricity system cost declines slightly due to the utilization of electric cooling. A minor cost increase is observed for West Saudi Arabia and East Brazil, yet the increase in cost is less than 1% (see Fig. 4). The share of cooling demand in the total demand varies from 3.5% to 30% for the modeled regions. Despite such a large variation in cooling demand, utilizing electric cooling has a limited impact on the average electricity cost. This may seem counterintuitive to our expectation, as the experience of a power system based on thermal power plants may have instilled in us the notion that the increase in peak demand (due to electric cooling) precipitates a need for peaking plants. As these plants have lower utilization times and higher running costs than base-load plants, they entail a higher system cost. Yet, here we show that it no longer holds for utilizing electric cooling for a system with a high penetration level of solar PV. The cooling demand coincides well with the output of solar PV, which leads to a high utilization rate for solar PV. Thanks to the long utilization time and zero running cost for solar PV, the average electricity cost remains stable or even decline when installing solar PV to meet the cooling demand. This result indicates that solar PV might be a suitable solution to sustain comfortable temperature condition for developing countries in the hot regions without escalating electricity cost.

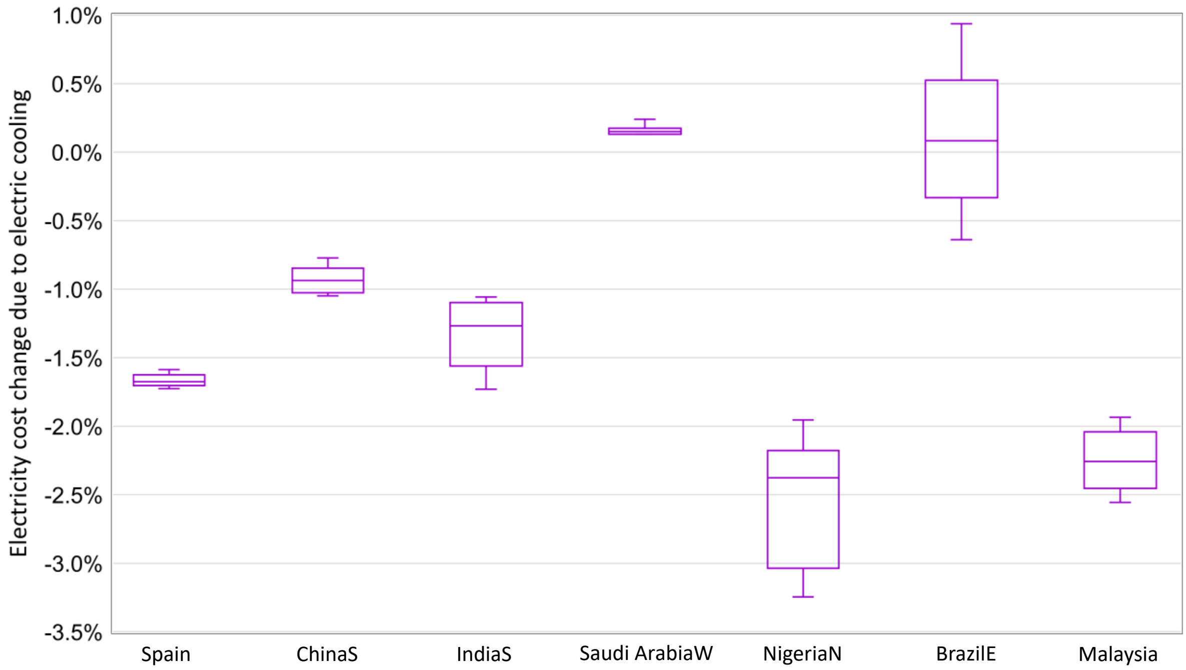

Fig. 4. The change in the average electricity system cost due to electric cooling. The ends of the box are the upper and lower quartiles, so the box spans the interquartile range. The bar in the box represents the median value. The whiskers are the two lines outside the box that extend to the highest and lowest values.

4. Conclusion

In this paper, a greenfield techno-economic cost optimization model is used to investigate the impact of electric cooling on the cost-effective investment in solar PV for seven regions with potential large demand for cooling. By comparing the energy mix for a system with cooling to the one without cooling, we find that:

- Utilizing electric cooling makes the investment in solar PV more cost-effective relative to a system without cooling regardless of the CO_2 emission target;
- Utilizing electric cooling has limited impacts on the average electricity cost.

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