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Commentary and critical discussion on 'Decarbonizing the Chilean Electric Power System: A Prospective Analysis of Alternative Carbon Emissions Policies'

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ABSTRACT

This paper is a commentary on 'Decarbonizing the Chilean Electric Power System: A Prospective Analysis of Alternative Carbon Emissions Policies' –an article published by Babonneau et al. in the Energies Journal. On the one hand, our aim is to point out and discuss some issues detected in the article regarding the literature review, modelling methods and cost assumptions, and, on the other hand, to provide suggestions about the use of state-of-the-art methods in the field, transparent and updated cost assumptions, key technologies to consider, and the importance of designing 100% renewable multi-energy systems. Furthermore, we end by highlighting suggestions that are key to modelling 100% renewable energy systems in the scientific context to contribute to expanding the knowledge in the field.

Keywords

100% renewable energy,
Energy system modelling,
Chile, Sector coupling,
Literature review,
Energy transition,
Energy planning

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1. Introduction

We would like to thank the authors Babonneau et al. [1] of "Decarbonizing the Chilean Electric Power System: A Prospective Analysis of Alternative Carbon Emissions Policies" for their efforts into understanding alternatives to decarbonize and reach a 100% renewable-based electricity system in Chile, which is essential for mitigating climate change. In summary, Babonneau et al. [1] simulate the evolution of the power system using a long-term planning model that identifies investments and operation strategies to meet demand and CO_2 emissions reductions at minimum cost. The used model considers representative days to simulate operations and analyse scenarios with different renewable energy (RE) and emission reduction targets by 2050, including carbon capture and storage (CCS) technologies. The authors conclude that it is preferable to invest in CCS technologies rather than to aim for a 100% RE scenario.

However, we would like to point out some issues detected, in order to avoid misinforming the readers, which we assume had been unintended. Concretely, we think their literature review and modelling methods deserve attention (see sections 2 and 3 below). We would also like to take the opportunity to give suggestions about the use of state-of-the-art methods in the field, transparent and updated cost assumptions, key technologies to consider, and the importance of designing 100% renewable multi-energy systems (see sections 3, 4, 5, and 6).

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2. Literature review and discussion

In general, a comprehensive and critical literature review of available methods and case studies in the field is fundamental not only for providing an appropriate background to the readers but also to have a solid foundation on which to discuss and build new knowledge. Babonneau et al. [1] did include several articles on 100% RE system models applied to different parts of the world, namely Europe [2], France [3], Germany [4], Canary Islands [5], Japan [6], and Columbia [7]. However, they failed to identify all previously published articles on 100% RE analyses for Chile, which we count to be at least seven. Refer for example, to the planning exercises on Chile's electricity system [8–12] and the work that also addressed the power, heat, transport, and desalination sectors [13, 14], while an even more comprehensive study investigating different scenario options and utilising sector coupling features [15] has been published in the same month that Babonneau et al. [1].

Comparing the findings of Babonneau et al. [1] to this existing body of literature would have been essential to show whether the obtained results were in line to the published ones, or if they shed light on new findings that might have not been previously reported.

3. Use of state-of-the-art methods

Using state-of-the-art methods is key in science, especially in modelling 100% RE scenarios, which has seen several hundreds of studies in the last years (for example each of these reviews [16–22] have dealt with dozens of studies). One of the drawbacks of the study in question, is its low temporal resolution: eight typical days corresponding to weekday and weekend of the four seasons. This introduces errors, as two out of the three big challenges of integrating renewables (variability, location-specificity, and uncertainty) are structurally not captured by the model.

These errors have been analysed in the literature, for example by Prina et al. [23]. In this sense, Kotzur et al. [24, 25] have found resolution deviations in seasonal variations of time-slices that are used in 100% RE modelling, and Pursiheimo et al. [26] point out that a full hourly modelling of 100% RE would be better suited. This is mainly because an overly simplistic time-resolution, like an annual energy balance or time-slices, is incapable of quantifying the real need for flexibility; neither is such a resolution able to model the competition and complementarity of the diverse flexibility options (such as grids, flexible generation, storage, sector coupling, demand response). Another issue is that time-slices do not allow for the use of consistent weather data (e.g. wind flows and weather patterns of days and weeks, but also representative days impact the real complementarity between solar and wind resources and flow and dynamic of real weather development), thus hurting the meaningfulness of the results. This becomes significantly more important since weather data has an impact on the economically optimal design of RE systems [27].

In short, using typical days is outdated, compared to the now-standard fully-resolved, hourly and sequential year for analysing RE systems. This is due to various related issues such as: (i) being incapable of describing the variability of renewable generation and the resulting requirements for short- and long-term flexibility that could trigger investments in storage infrastructure [24, 25]; (ii) the increasing difficulty of defining "typical" days: what sets or conditions of load, solar, and wind are actually representative and how are critical operating conditions being considered [18]; (iii) the impossibility of representing climate-space-time correlations needed to capture persistent weather conditions (like multi-week droughts which show to be critical condition for highly renewable systems [28]); and (iv) being incapable of capturing the advantages of hydroelectricity, especially in regards to buffering energy unbalances beyond the daily horizon in a region that is rich in hydro dams.

According to Brown et al. [29], Hansen et al. [20], Prina et al. [23], and Breyer et al. [22], state-of-the-art in 100% RE modelling use full hourly-time resolution, especially with the objective of capturing the various forms of flexibility, in order to achieve optimized energy system solutions, which is complemented by a broad portfolio of energy technologies.

4. Usage of transparent and up-to-date cost projections

Technology cost projections are key parameters for expansion planning exercises, as these are *techno-economic* models. Babonneau et al. [1] mention two refences regarding cost assumptions, but do not list those cost projections used by technology in the paper. Given their critical relevance for the tractability and reproducibility of the study, we suggest that in future works, technology cost assumptions to be expressly shown. A good way to assess the quality and transparency in modelling energy scenarios is to use the checklist suggested by the German Aerospace Center [30]. This is also important because of rapidly falling technology costs and how energy modelers tend to underestimate them. In this sense, Xiao et al. [31] and Victoria et al. [32] found how outdated assumptions about cost lead to stark distortions in the results of energy scenarios.

Concretely, as can be observed from Table 1, Babonneau et al. [1] reported 10% of concentrated solar power (CSP), 22% of solar photovoltaic (PV) and 45% of wind energy of the total installed capacity by 2050. The levelized cost of electricity (LCOE) of the system

Table 1. Installed capacity for key technologies and LCOE in the 100% RE scenarios applied to Chile (results for 2050).

	Sectors	Technology	Installed Capacity (GW)	LCOE of the system (€/MWh)
Babonneau et al. [1]	Power	CSP	6.17	Not given
		Solar PV	14.1	
		Wind onshore	28.9	
		Total (system)	63.4	
Gaete-Morales et al. [10]	Power	CSP	2.1–5.5	67.8–72.4
		Solar PV	15.1–25.8	
		Wind onshore	12.4–13.1	
		Total (system)	53.4–62.1	
Haas et al. [8]	Power	CSP	Not included	35.8–44.0
		Solar PV	38.0–62.0	
		Wind onshore	38.0–20.0	
		Total (system)	82.0–88.0	
Haas et al. [9]	Power	CSP	Not included	34.6–38.5
		Solar PV	49.5–57.2	
		Wind onshore	26.6–30.4	
		Total (system)	82.3–93.8	
Osorio-Aravena et al. [14]	Power, heat, transport and desalination	CSP	0.44	36.0
		Solar PV	43.6	
		Wind onshore	24.8	
		Total (system)	87.2	
Osorio-Aravena et al. [15]	Power, heat, transport and desalination	CSP	0.00	25.7–26.0
		Solar PV	216–233	
		Wind onshore	3.1–3.8	
		Total (system)	238–254	

was not informed. These results seem to be in line with Gaete-Morales et al. [10] (that used 2010–2014 learning curves for estimating future capital costs based on 2015 costs), who reported a 4–9% of CSP, 28–42% of solar PV and 21–23% of wind onshore of the total installed capacity by 2050, and 67.8–72.4 €/MWh as the LCOE of the system. However, these results differ significantly from current articles on 100% RE applied to Chile. In these studies, for instance, CSP is not considered or resulted in negligible amounts due to its higher costs. And solar PV and wind onshore play a much more important role, ranging from 46–92% and 1–46% of the total installed capacity by 2050, respectively. The found LCOE of the system is significantly lower in these studies with a range of 25.7–44.0 €/MWh [8, 9, 14, 15], where the lower end comes from the most recent study with the most up-to-date cost assumptions [15].

Perhaps most importantly, solar PV is today seen as predominant technology in most state-to-the-art studies and by industry deployment, even more so in sunny regions, such as Chile, as documented in Breyer et al. [21]. However, Babonneau et al. [1] found 2.7 to 16 times less solar PV installed capacity by 2050 as other 100% RE studies applied to this country. This issue underlines the criticality of using not only transparent but also up-to-date cost assumptions, to avoid distorted results. For instance, the use of simplified methods and outdated cost assumptions that involve CCS technology with fossil fuel-based electricity generation can mislead the readers into thinking that perhaps this technology is a choice for the energy transition, which favours the fossil fuel industries. According to the recently published World Energy Outlook report [33], fossil CCS has higher levelized cost of electricity than all relevant renewable power technologies. This is also mirrored by the other studies applied to Chile [8, 9, 14, 15]. They have shown that a 100% RE system could be substantially lower in cost than a base-generation fossil CCS. In fact, green renewable hydrogen was expected to become competitive during the 2020s based on 2021 natural gas prices, but based on 2022 natural gas prices reached that target by now in becoming significantly cheaper than blue hydrogen –from natural gas with CCS– in major markets [34] and in Chile will be cheaper than any other option before 2030 [35]. In addition to fossil CCS being a costly technology, it only captures 90% of the CO_2, thus not adequate for zero CO_2 emissions without further net-negative options.

5. Key missing technologies

The market today offers a manifold of flexible technologies that can buffer the variability from renewable generation. It is important to include these flexible technologies in the model, going far beyond a single-generic storage option [18]. Chile in particular, offers a breath of options going from existing hydropower dams (their turbines could be upgraded), a great geothermal potential for electricity and heat purposes [36], a vast potential for pumped hydro energy storage (PHES) [37], existing and future battery projects, the currently discussed hydrogen strategy (which would likely have national storage) with indirect power sector balancing from electrolysers [15].

As previously mentioned, the results of Babonneau et al. [1] differ significantly from other 100% RE articles applied to Chile [8, 9, 14, 15]. These studies at least have included PHES and H_2 storage in the analysis. Therefore, for more credibility in the results based, in addition to considering the existing hydropower dams and batteries, we strongly recommend involving PHES and H_2 storage in the energy system modelling. In fact, the inclusion of different storage technologies is key for modelling and planning flexible multi-energy systems with a high share of variable renewable sources [38, 39].

6. Broaden the analysis from the power sector to the entire energy system

Most of the research articles on 100% RE have focused on the power sector, with the extension towards cross-sectoral analysis becoming state-of-the-art in the literature [20]. This trend of multi-sector planning started in the 2010s [18] and has been gaining ground ever since [20]. In fact, out of the 30 peer-reviewed articles on 100% RE systems that have reported a share of solar PV greater than 50% by 2050, 14 of them have been carried out including all sectors in the analysis [21]. Power sector analyses are starting to become increasingly limited in meaning, because massively integrating low-cost electricity from solar PV and wind is rather direct. Instead the open questions relate to how to transmit this cheap electricity to all energy sectors, either by electrification of demand or by green e-fuels [22, 40]. Acknowledging these other sectors in turn impacts the electricity sector design, not only in terms of generation but also in terms of flexibility technologies [41].

7. Concluding remarks

In this paper, we have pointed out some issues detected in Babonneau et al. [1] regarding the literature review, modelling methods and cost assumptions. We have also taken the opportunity to provide suggestions in the research field on 100% RE systems.

Firstly, we have detected that the study in question neglected all previous works on the modelling of the 100% RE system applied to Chile. Secondly, we have shown differences in technology recommendations between the commented paper with most of the previous work. For instance, the study in question found a share of solar PV (which is the predominant technology already today) by 2050 that is 2.7 to 16 times less than other existing studies for the region. We argue that the differences can be attributed to not using state-of-the-art methods, using outdated cost assumptions, limited modelling of flexibility technologies, and addressing only the power sector. We also described the main problems arising from these issues.

Finally, to contribute to expanding the knowledge in the field, we would like to highlight some suggestions that are key to modelling 100% RE systems in the scientific context:

1. Apply state-of-the-art methods with special attention to the time resolution, i.e. use an hourly time resolution for a fully-resolved sequential year to capture the variability of renewables across the different time-scales.
2. Utilize transparent and up-to-date cost assumptions. A helpful guide on transparency in modelling energy scenarios is provided in reference [30].
3. Include multiple flexibility technologies with a focus on the diverse storage solutions that already exist today, including at least diurnal (like batteries and pumped hydro) and seasonal storage (like hydrogen and hydropower dams).
4. Address the energy system (electricity, heat, transport, water) as a whole, as the open challenges mainly refer to the sectors beyond electricity, but planning for these sectors also impacts the electricity sector.

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