AIMS Energy

AIMS Energy, 12(4): 809–821.
DOI: 10.3934/energy.2024038
Received: 21 May 2024
Revised: 28 June 2024
Accepted: 08 July 2024
Published: 16 July 2024

http://www.aimspress.com/journal/energy

Research article

Scenarios for combating global warming: China's critical role as a leader in the energy transition

David Schwartzman[1,*] and Peter Schwartzman[2]

[1] Professor Emeritus, Department of Biology, Howard University, Washington, DC, United States
[2] Department of Environmental Studies, Knox College, Galesburg, Illinois, United States

* **Correspondence**: Email: dschwartzman@gmail.com; Tel: +2028299063.

Abstract: China is now the world leader with green capital actually creating renewable energy technologies. We address the possibility of whether China can emerge a new ecological civilization, as well as become the global leader to reach climate security. In particular, China has the potential to implement a solar energy infrastructure in the deserts of the Middle East as part of the Belt and Road Initiative, mainly in the form of concentrated solar power. The creation of this renewable energy capacity could supply electricity to much of the world, as well as power the direct air capture (DAC) of carbon dioxide with a permanent burial in the crust, in particular, using the ultramafic deposits in Oman. This realization would increase the chances of not breaching the International Panel on Climate Change (IPCC) warming target of 1.5 °C, of course only if coupled with the termination of utilizing fossil fuels as early as possible and their replacement with renewable energy supplies globally. In this context, our pioneering model establishes that coupling a DAC-driven drawdown of atmospheric carbon dioxide with a rapid increase in the renewable energy capacity is more than capable of producing enough clean energy to eliminate energy insecurity globally (to all 8–10 billion humans) and to provide energy for the drawdown for the rest of the 21st century, thereby reducing atmospheric carbon dioxide to safe levels. This contingency will likely only be realized with a shift to demilitarization of the global economy. Likewise, this potential emergence of China as the global leader for climate security would likely inspire the push for a global Green New Deal to make this goal possible.

Keywords: China; concentrated solar power; deserts; climate security; drawdown of atmospheric carbon dioxide; sequestration; direct air capture

Abbreviations: CSP: Concentrated solar power; COP: Conference of Parties; DAC: direct air capture; BRI: Belt and Road Initiative; GND: Green new deal; EROI: Energy return on energy invested; IPCC: Intergovernmental panel on climate change; NET: Negative emission technology; RE: Renewable energy
Units: EJ: exajoule (10^{18} joule); GJ: gigajoule (10^9 joule); GT, Gt: gigatonne (10^9 tonne); GW: gigawatt (10^9 watt); MW: megawatt (10^6 watt); TW: terawatt (10^{12} watt)

1. Introduction

Climate catastrophes with a greater magnitude than are currently witnessed are real possibilities this century. As the most recent Intergovernmental Panel on Climate Change (IPCC) report tells us, there is still a chance to keep warming at no more than the 1.5 °C target, though tipping points to much worse climate catastrophes than we are currently witnessing will likely kick in if this target is breached. A very recent assessment concluded that the remaining carbon budget for a 50 percent chance of keeping warming to 1.5 °C is around 250 GtCO_2 as of January 2023, which is equal to around six years of the current CO_2 emissions [1].

It is now clear that ongoing wars, in particular the Ukraine war and the Israel/Palestinian conflict, create huge obstacles to the global cooperation necessary for any chance of meeting the 1.5 °C warming target. Please take note of the Science editorial from March 31, 2022, “To solve climate, first achieve peace,” which recognized this obstacle and called for the imperative cooperation of the United States and China to reach the goal of climate security [2,3]. Since conventional oil has the lowest greenhouse gas footprint of all the fossil fuels (with coal and natural gas having the highest footprint, which should be phased out first), we should recognize the potential of oil-producing countries such as Saudi Arabia, Iran, and Venezuela to extract, the minimum amount of conventional oil necessary as an energy source to rapidly build renewable energy technologies especially in the Global South, while phasing out global fossil fuels as quickly as possible; at the same time, there is a potential to earn revenues from such a production to improve the quality of life of their own people [4].

Recognition of the huge potential for tapping the incoming solar flux to global deserts has led to the founding of the Trans-Mediterranean Renewable Energy Cooperation in 2003, which evolved to the non-profit Desertec Foundation in 2009 [5,6]. It was estimated that less than 10% of the area of the Sahara Desert would be sufficient to meet the world’s electricity demand with a Concentrated Solar Power (CSP) siting [5]. However, this project has only been implemented at a scale far less than originally imagined, with a variety of identified obstacles, including internal conflicts of its multiple participants, the impact of the 2009 global financial crisis, and critiques of its Eurocentrically focused organization [7,8]. Nevertheless, a Moroccan concentrated solar plant (CSP) that started with a 160 MW capacity, is currently expanding to include a supplementary photovoltaic installation [9]; with the proper channeling of investment capital from the world’s nations, this initial plant is just one of tens of thousands that could be quickly erected.

In what follows, China’s capacity is analyzed, specifically how China can take the lead for climate security by promoting investments in concentrated solar power in the deserts of the Middle East, alongside a sufficient capacity to drive the permanent storage of sequestered atmospheric carbon dioxide in the ultramafic deposits of Oman on the eastern side of the Arabian desert. We provide model calculations to demonstrate that this potential project can meet the 1.5 °C warming target if commenced soon in a 20-year transition to a global renewable energy supply, which would replace all fossil fuels.

2. China can take the lead for climate security with their Belt and Road Initiative (BRI)

China can take an historic lead in promoting a renewable energy transition within the Middle East and confront the increasing climate threat. China is the world leader in green capital, actually creating renewable energy supplies; however, this green capital is still coupled in the Chinese economy with powerful sectors dedicated to the continued implementation and importation of fossil fuels, as well as an ambitious plan to build hundreds of new nuclear fission reactors [10,11]. China can potentially become the global leader in not breaching the 1.5 °C IPCC warming target [12–14], effectively becoming the global leader for climate security. We suggest that China should consider ending its plan to build hundreds of nuclear reactors [15–17], proceed with the rapid phaseout of utilizing coal, and accelerate the creation of renewable energy supplies. A significant expansion of nuclear fission power will add incremental heat to the Earth's surface, which could contribute to exceeding the 1.5 °C warming target, since every 0.1, or even 0.01 °C, increase above this target constitutes a potential threat to bring on tipping points that can lead to much worse climatic impacts. In a new project of the Belt and Road initiative (BRI), our undermentioned modeling reveals that China could build solar power in the Arabian and Sahara Deserts to supply electricity to the whole region and Africa, while powering the direct air capture (DAC) of carbon dioxide and the permanent burial of carbon as carbonates in the crust of Oman. DAC with a permanent burial as carbonates in the crust ais a carbon removal technology that will be imperative, along with restoring natural ecosystems and replacing industrial agriculture with agroecologies, given that the atmospheric carbon dioxide level must be brought down to below 350 parts per million and is kept there as the ocean re-equilibrates with the atmosphere. As imperative as a shift to agroecologies and the restoration of natural ecosystems are, solely relying on the soil carbon pool will likely be insufficient to do this job because of the saturation of this pool and the limits imposed by additional warming, even if it is kept below 1.5 °C [18]. We take note of the recent assessment by Richard Betts (Head of Climate Impacts at the UK Met Office and University of Exeter) that 1.5 °C of global warming is a marker as to where we should become increasingly concerned, and tipping points to much worse global impacts will kick in if this warming target is breached over time; he recognized that there is uncertainty regarding how long will it take for overshoot will trigger, and pointed to the IPCC estimate of a 20-to-30- year average to breach 1.5 °C. Furthermore, Betts concluded that carbon removal technologies (i.e., Negative Emission Technology (NET)) will be needed to effectively address overshooting the temperature and atmospheric carbon dioxide levels [19].

We model a form of NET, namely, the DAC of carbon dioxide, which entails the permanent burial (of carbon) in the crust powered by renewable energy. While other mafic and ultramafic deposits around the world are potential sites for this drawdown, we point to the very large Oman ultramafic site, where Kelemen and his team estimated that it could absorb and permanently bury up to 100,000 metric tons of CO_2 every year by speeding up the natural reactions by drilling several kilometers down to higher temperatures and pumping in seawater saturated with CO_2 drawn from the air [20]. Many other potential sites are globally available for ultramafic/mafic rock carbon sequestration [21, Figure 5]. Kelemen's project emphasized that while the natural carbonation of the peridotite from the Oman deposit is rapid, it can be significantly accelerated with a potential of greater than 1 billion tons of CO_2/year, thereby facilitating a low-cost, safe, and permanent method to capture and store atmospheric CO_2 [22]. Progress to implement this approach has already been made with the agreement of the Oman's Ministry of Energy and Minerals (MEM) to a concession for the world's first commercial-scale peridotite mineralization project, starting in the Hajar mountains in 2014. This will be the largest peridotite mineralization project in the world. The project will transfer atmospheric CO_2, dissolve it in water, and then inject it into peridotite formations deep underground, where it will mineralize (i.e., turn it into rock) for the permanent storage of sequestered CO_2 [22]. Minerals within the peridotite, namely olivine and pyroxene, react with the carbon dioxide extracted by the DAC technology and water (derived from seawater) to form serpentine and calcite, which results in permanent storage in the crust of atmospheric carbon dioxide as carbonates [18,22].

The China Solar Thermal Alliance is an ongoing initiative to build CSP in deserts [23]. They computed a total of 23,398 terawatt-hours generated by CSP, which corresponded to a land area of about 1.6 percent of the Sahara Desert. This power generation is equal to 2.7 terawatt-years, which is approximately the present annual global electricity consumption level, while the present global primary energy consumption level is 20 terawatt-years. This Saharan land area devoted to CSP could be reduced by siting the CSP on other deserts including the Arabian Desert. Global energy needs will very likely require even more than 20 terawatts for climate adaptation and mitigation, which would mainly be generated by CSP, oceanic wind farms, and photovoltaics on roofs and floating platforms [18].

Therefore, since we could not find any previous modeling-based consideration of CSP development in Middle Eastern deserts sufficient enough to power the DAC of carbon dioxide with its permanent burial by means of chemical reaction in the ultramafic complex of Oman, and thereby contribute to the global goal of not breaching the 1.5 deg C warming target, we present the following modeling results.

3. Actual model calculations and results

Our modeling of the total renewable energy capacity and gross CO_2 emissions over time (based on our 2021 paper with minor changes) is coupled with simultaneous DAC drawdown and the implementation of two different scenarios of the fossil fuels drawdown [18]. The equations and definitions of the model parameters are shown in Table 1.

Table 1. Equations and definitions of model parameters (from Table 2, reference [18]).

Equations:
1a. $d(P_{RE})/dt = [(M/L)(f)(P_{RE})] + [(M/L)(F_{ff})(P_{2018})]$
Solution: $P_{RE} = (f)^{-1}(F_{ff})(P_{2018})[e^{[(f)(M/L)(t)]} - 1]$
1b. $R^* = P_{FF} + P_{RE}$
2. Total CO_2-equivalent emissions $= Sum\,[(Ex) \cdot (Fx)]$
Definitions:
R^* is global primary energy consumption relative to the consumption in 2018 corresponding to 19 TW in power units
P_{FF} is the global primary energy consumption of non-RE at time t
P_{RE} is the global primary energy consumption of RE at time t
P_{2018} is the 2018 global primary energy consumption
f is the fraction of RE (wind, photovoltaics, concentrated solar power (CSP)) invested to make more of itself, where CSP is applied mainly in deserts
F_{ff} is the fraction of the non-RE supply equal to present primary energy consumption level (P_{2018}) invested to make RE Technology (constant amount invested over the 20-year transition to 100% renewable supply)
M is the Energy Return/Energy Invested Ratio (EROI) for the RE Technology
L is the Lifetime of the RE Technology
E_x is the energy consumed annually by each energy source
F_x is the emission factor for each energy source

The model shown in Table 1 provides two basic scenarios for the development of the energy transition. These are presented in Table 2.

Table 2. Model Results (Scenario I (20-year ramp down of Coal & NG), Scenario II (10-year ramp down of Coal & NG)).

Scenario I				
Year		0[1]	11	20[2]
Total energy	[EJ]	602	666	1075
Total FF[3]	[EJ]	520	287	0
Total RE[4]	[EJ]	12	346	1075
CO_2 emissions/yr	[GT]	50.7	27	0
Cumulative CO_2 emissions	[GT]	50.7	471.4	583.6
DAC energy draw (Lo/Hi)	[EJ]		7/21.4	70/214
DAC CO_2 drawdown	[GT]		2	20
DAC cumulative drawdown	[GT]		2	110
Scenario II				
Year		0[1]	11	20[2]
Total Energy	[EJ]	602	533	1075
Total FF[3]	[EJ]	520	154	0
Total RE[4]	[EJ]	12	346	1075
CO_2 Emissions/yr	[GT]	50.7	12.6	0
Cumulative CO_2 emissions	[GT]	50.7	368.9	424.4
DAC energy draw (Lo/Hi)	[EJ]		7/21.4	70/214
DAC CO_2 drawdown	[GT]		2	20
DAC cumulative drawdown	[GT]		2	110

*Note: [1] Year 0 is 2018; [2] Year 20 is 2038; [3] F_{ff} = 0.03; [4] RE is wind & solar only.

In the two scenarios, energy generation (renewables, "RE") and the phase out (fossil fuels etc.) were modeled over the next twenty years (beginning with 2018). For Scenario I all coal, natural gas, and other non-solar and non-wind energies were reduced in a linear fashion (5% a year) for the 20 years, and reached zero use in the final year. At first, petroleum was reduced less rapidly, but still decreased to zero in the final year. Scenario II is similar to Scenario I, except coal and natural gas were reduced linearly over the first 10 years to zero (10% a year). These scenarios are equivalent to our 2021 paper, except in this modeling, where we include the fact that wind and solar energy production starts at 12 EJ in year 0. In both scenarios, DAC began in year 11 with 2 GT of CO_2 drawdown and ramped up linearly until they reached a 20 GT drawdown in the final year. We computed global renewable energy creation similar to our 2021 paper [16], with a significant fraction being generated in Middle Eastern deserts by CSP development (see reference [23] for this potential). The inputs and results are shown in Table 2 and Figures 1–3. This table and the three figures show that the net energy (total energy generated for society minus drawdown energy) in the form of 100% renewables at the culmination of the 20 year transition ranges from 1005 EJ (31.9 TW in power capacity) to 861 EJ (27.3 TW in power capacity), with drawdown power capacities of 2.2 to 6.8 TW, respectively, which correspond to the low (3.4 GJ/ton CO_2) and high (10.7 GJ/ton) estimates of energy required for this mode of drawdown for on-land peridotite [18]. These drawdown energy capacities were computed assuming the creation of a 20 GT CO_2/year drawdown at the end of the 20 years RE transition. We incorporated this level of drawdown as pointed to in Fox (2021) and referenced in [20], with the goal of limiting global warming to no more than 1.5 ℃ by creating the capacity of removing between 100 billion and one trillion tons of CO_2 from the atmosphere by the end of this century. With a start in 2050, this would be equivalent to sequestering two billion to 20 billion tons of CO_2 every year.

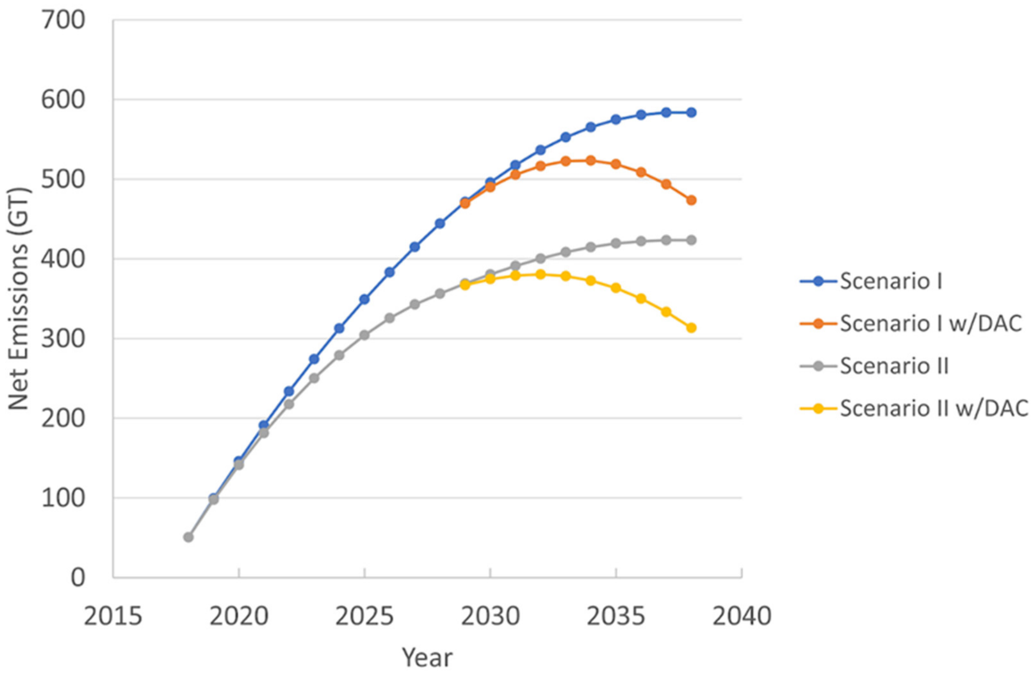

Figure 1. Net CO_2 emissions (cumulative).

Comparing scenarios I and II (20- and 10-year ramp down of coal/natural gas, respectively), we note that the cumulative CO_2 emissions are lower for scenario II, with the net cumulative CO_2 emissions being the lowest for scenario II, with a drawdown corresponding to 300 GT (noting that reference [1] cites 250 GT starting January 2023 for a 50% chance of not exceeding the 1.5 ℃ warming target). A more aggressive drawdown than assumed in our modeling could further reduce the net cumulative emissions of CO_2, thereby increasing the chances of meeting this 1.5 ℃ warming target.

Figure 3 shows that assuming a higher investment of energy to create the RE capacity will result in an even higher cumulative net energy corresponding to the form of 100% renewables at the culmination of the 20-year transition ranges from 1670 EJ (53 TW in power capacity) to 1530 EJ (48 TW in power capacity), which further corresponds to the low and high estimates of energy required for this mode of drawdown as previously cited.

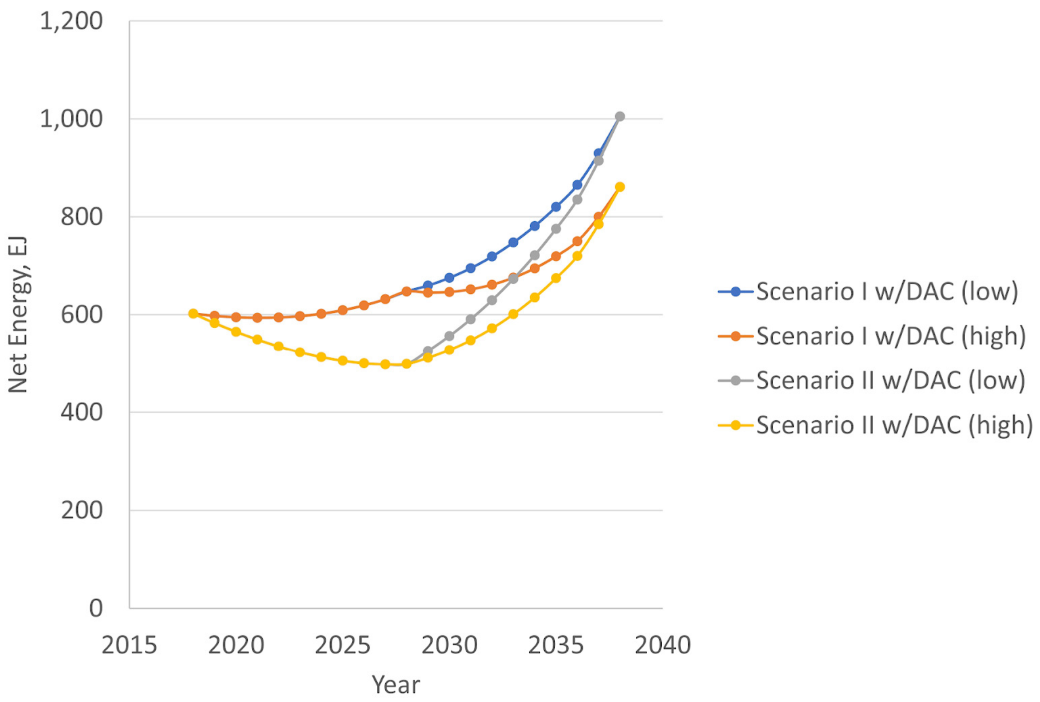

Figure 2. Net energy available (with $F_{ff} = 0.03$). Net energy = Total energy production – energy diverted for DAC.

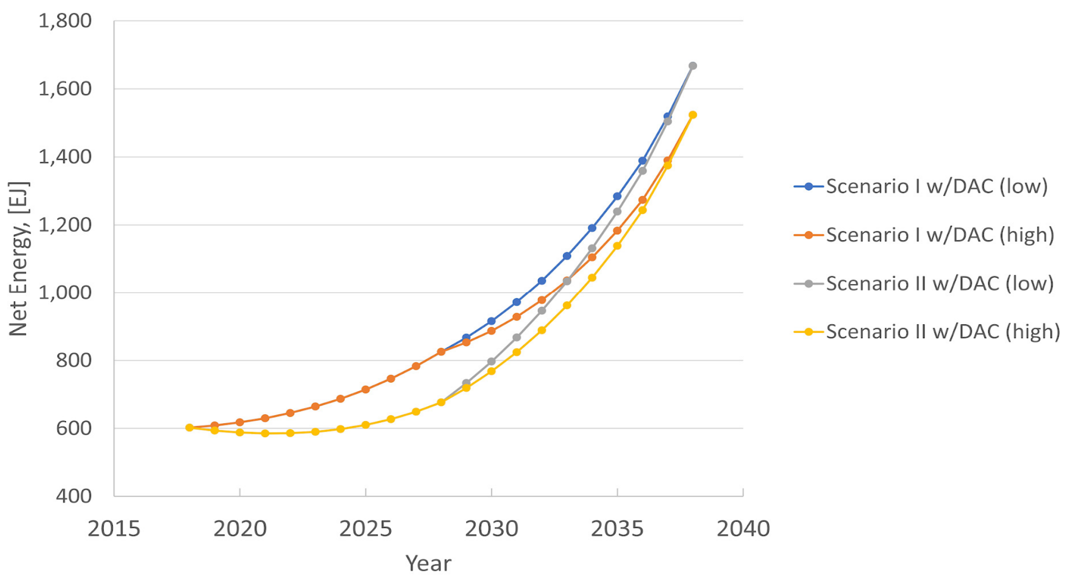

Figure 3. Net energy available (with $F_{ff} = 0.05$). Net energy = Total energy production – energy diverted for DAC.

Whie not assessed here, the financial feasibility should be considered in the context of not addressing the imperative drawdown of atmospheric carbon dioxide and its long-term impacts on global civilization and biodiversity. For example, consider the cost of a fast renewable transition/phaseout of fossil fuels versus breaching the warming targets. Way et al. [24] made this very clear: "Transitioning to a decarbonized energy system by around 2050 is expected to save the world at least $12 trillion, compared to continuing our current levels of fossil fuel use." In addition, Wu et al.'s [25] model of the possibilities for a global system to provide 100% renewable energy concluded that a globally interconnected system would reduce storage costs by 50% and reduce the total costs of a RE transition by 20% compared to systems that are not globally interconnected.

Regarding the ecological impact of our modeled project, we emphasize that only 1.6% of the Sahara Desert is required for a 2.7 TW CSP power capacity [23]. Hence, ~5% of this land area will generate a CSP power capacity of 8.4 TW, which is sufficient to supply the average energy for a drawdown corresponding to a power capacity of 4.5 TW in the Oman ultramafic deposit, alongside an additional 3.9 TW to provide energy for most of Africa in 2050 (whose population is expected to be 1.7 to 2.5 billion, with the lower projection assuming a decrease in the birth rate as a result of a higher quality of life and climate security). If this drawdown energy were to be generated only in the Arabian desert, then ~10% of its land area would be required. Drawdowns in other mafic/ultramafic deposits around the world would reduce these land area estimates.

4. A global green new deal

Of course, unless global fossil fuel consumption is ended soon, at the same time as there is a significant buildup of renewable energy supplies, the 1.5 °C warming target will be exceeded. Therefore, the enemy of humanity, namely militarized fossil capital and its political instruments, must be defeated by a transnational movement driven by a very broad coalition [26,27]. In the future, the best economic and social system for people would be a global solar-powered civilization [28,29].

Recent proposals for a Green New Deal (GND) have focused on the U.S. and Europe [30,31]. Promoting a global GND a viable strategy to defeat militarized fossil capital, and in its initial stages should capture truly green capital as an ally [26,27,30–35]. However, green capital is a problematic ally, since it is also a driver of extractivism with its negative impacts on nature, communities, and its workforce. In this regard, the recognition of critical issues should inform the development of renewable energy supplies in this region, including the need for a democratic input and management, the challenge of "green" colonialism, especially in the context of the COP process, and the goal of true transition away from fossil fuel dependence [36,37]. Therefore, a transnational movement must also confront green capital with the goal of minimizing these impacts, with full respect for the rights of the peoples impacted, notably the Indigenous communities around the world and peoples in the Global South. There are already solutions available that can sharply reduce the negative impacts of extractive mining, particularly as renewable energy infrastructure replaces fossil fuels. In particular, renewable energy allows for the efficient recycling of metals without the negative impacts of relying on fossil fuel energy, i.e., "Forward look: A solar powered recycling revolution" [38], see also [32]. Furthermore, as the fossil fuel and the military industrial complex material infrastructures are dismantled in a progressively demilitarized world coupled with a transition to renewable energy, huge supplies of metals will be available for recycling, which significantly contributes to the phaseout of mining. We have already witnessed a shift from technologies that need rarer elements, for example, lithium for batteries, to more common elements such as sodium [39,40]. China has invested $100 billion in metals and mining in their BRI as of August 2023, which is its third biggest investment, with a primary energy ranking at $400 billion [41,42]. As a leading scholar of transnational capital, William Robinson has pointed to the negative impacts of this extractive mining sector of the BRI [43]; however, at the same time, he recognized the full significance of the investment in renewable energy by the world's leader of green capital. Robinson expanded on his critique of the BRI and China's impact [44].

The Global China Unit has provided a comprehensive assessment of China's extractivist impact in the BRI [45]. For a more positive assessment of the BRI, see [46].

It is encouraging to see that China has recently emphasized that it "is working together with partner countries and international organizations to build a cooperation mechanism for green and low-carbon development under the BRI framework, promote green development, and address climate change" [47]. The leading science journal Nature promoted this cooperation [48].

The defeat of fossil capital will very likely require the emergence of a global subject with sufficient power to prevail [49]. Likewise, the emergence of China as the global leader of the struggle for climate security can inspire a transnational movement for a global GND to make this goal possible. Moreover, China should be joined by all nations as soon as possible, starting with the United States, to achieve climate security in a global regime of cooperation, which is currently advocated by China [12–14].

We should recognize China's enormous achievement of lifting hundreds of millions out of poverty in just a few decades, bringing the Chinese people's life expectancy to a global rank in 2023 of 47, with the United States ranking 59 [50]. Hence, there is a strong basis to hope that China can contribute to this path forward for humanity in the next few decades, which is critical for any chance at meeting the 1.5 °C warming target.

5. Conclusions

Our two scenarios showed the variation in the required energy needed for the drawdown of atmospheric carbon dioxide ("high, low"). The model results provided a net energy after a 20-year transition to 100% renewable energy supplies, which ranged from a 31.9 TW power capacity for the low drawdown energy to a 27.3 TW for the high drawdown energy (i.e., with 14% less net energy generated). The corresponding drawdown energy capacities were 2.2 and 6.8 TW, respectively. This range of net energy was consistent with the estimated levels required to end global energy poverty and has the capacity to address climate adaptation along with the provision of the drawdown energy for mitigation [18].

Therefore, with our novel model calculations, we showed that this proposed project led by China in the context of the BRI on technical grounds has the potential to provide global climate security by not breaching the 1.5 °C warming target, thereby minimizing the growing threats to human civilization and biodiversity as we know it. This finding, which firmly establishes what is technologically possible, should motivate urgent action across all political institutions. However, success in this regard is obviously contingent on a near future dramatic change from the present tensions between the United States and China going forward to a new global regime of cooperation and peace. All peace-loving people around the world should consider their responsibility to help create this future for the youth and generations to come in this century. This requires the appropriate formation of human contact zones at all levels: Global, international, national, and local [51]. The alternative is a world of climate hell, with climate catastrophes occurring on a much bigger scale than now witnessed, all which can still be averted.

Use of AI tools declaration

The authors declare that they have not used Artificial Intelligence (AI) tools in the creation of this article.

Author contributions

Conceptualization, D.S. and P.S.; methodology, D.S. and P.S.; software, D.S. and P.S.; validation, D.S. and P.S.; formal analysis, D.S. and P.S.; investigation, D.S. and P.S.; resources D.S. and P.S.; data curation, D.S. and P.S.; writing—original draft preparation, D.S. and P.S.; writing—review and editing, D.S. and P.S.; visualization, D.S. and P.S.; supervision, D.S. and P.S.; project administration, D.S. and P.S.; funding acquisition, D.S. and P.S. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

References

1. Lamboll RD, Nicholls ZRJ, Smith CJ, et al. (2023) Assessing the size and uncertainty of remaining carbon budgets. *Nat Clim Change* 13: 1360–1367 Available from: https://www.nature.com/articles/s41558-023-01848-5.
2. Thorp HH (2022) To solve climate, first achieve peace. *Sci* 376: 7. https://www.science.org/doi/10.1126/science.abq2761
3. Klare M (2022) Green diplomacy: What if the United States and China cooperated on climate change? *TomDispatch*, November 22. Available from: https://tomdispatch.com/what-if-the-u-s-and-china-really-cooperated-on-climate-change.
4. Jacobson MZ, von Krauland AK, Coughlin SJ, et al. (2022) Low-cost solutions to global warming, air pollution, and energy insecurity for 145 countries. *Energy Environ Sci* 15: 3343–3359. Available from: https://pubs.rsc.org/en/content/articlelanding/2022/ee/d2ee00722c.
5. Duren M (2020) Understanding the bigger energy picture: DESERTEC and beyond. Saint Philip Street Press. Available from: https://link.springer.com/book/10.1007/978-3-319-57966-5.
6. Trieb F (2021) DESERTEC: Europe—Middle East—North Africa cooperation for sustainable energy. In: *Middle East and North Africa Clima, Culture, and Conflicts*. Ehlers E, Amirpur K (eds.). Brill: Boston, MA, USA, Chapter 9, 233–257. https://doi.org/10.1163/9789004444973_011
7. Hamouchene H (2015) Desertec: The renewable energy grab? *New Internationalist* March 1. Available from: http://www.ejolt.org/wordpress/wp-content/uploads/2015/09/EJOLT-6.85-91.pdf.
8. Schmitt TM (2018) (Why) did Desertec fail? An interim analysis of a large-scale renewable energy infrastructure project from a social studies of technology perspective. *Local Environ* 23: 747–776. Available from: https://www.tandfonline.com/doi/full/10.1080/13549839.2018.1469119.
9. Laaroussi A, Laaroussi O, Bouayad A (2023) Environmental impact study of the NOOR 1 solar project on the southern region of Morocco. *Renew Energy Environ Sustain* 8: 9. https://doi.org/10.1051/rees/2023007

10. Carbon Brief Staff (2022) China Briefing, 17 March 2022: Beijing ‘doubling down on fossil fuels’; China’s CO_2 emissions increase; coal production growth. *Carbon Brief*. Available from: https://www.carbonbrief.org/china-briefing-17-march-2022-beijing-doubling-down-on-fossil-fuels-chinas-co2-emissions-increase-coal-production-growth/.
11. Ferris N (2021) Weekly data: China’s nuclear pipeline as big as the rest of the world’s combined. *Ener Mon* December 20. Available from: https://www.energymonitor.ai/power/weekly-data-chinas-nuclear-pipeline-as-big-as-the-rest-of-the-worlds-combined/.
12. Harris J (2019) Can China’s green socialism transform global capitalism? *Civitas Rev Ciênc Soc* 19: 354–373. Available from: https://www.scielo.br/j/civitas/a/4DPdQN5KVrgbrbPxVdHxdVy/?lang=en#.
13. Schwartzman D (2019) China and the prospects for a global ecological civilization. *Clim Capital* September 17. Available from: https://climateandcapitalism.com/2019/09/17/china-and-the-prospects-for-a-global-ecological-civilization/.
14. The State Council Information Office of the People’s Republic of China (2023) A global community of shared future: China’s proposals and actions. September 26. Available from: https://www.mfa.gov.cn/eng/zxxx_662805/202309/t20230926_11150122.html.
15. Nature Editorial (2021) Nuclear technology’s role in the world’s energy supply is shrinking. *Nature* 591: 177–178. https://doi.org/10.1038/d41586-021-00615-w
16. Jacobson MZ (2020) Evaluation of nuclear power as a proposed solution to global warming, air pollution, and energy security. In: 100% clean, renewable energy and storage for everything. Cambridge University Press, New York. https://doi.org/10.1017/9781108786713
17. Jacobson MZ (2023) Why not nuclear power. In: *No miracles needed: how today’s technology can save our climate and clean our air*. Cambridge University Press, 156–173.
18. Schwartzman P, Schwartzman D (2021) Can the 1.5 °C warming target be met in a global transition to 100% renewable energy? *AIMS Energy 9*: 1170–1191. https://www.aimspress.com/article/doi/10.3934/energy.2021054
19. Retallack S (2023) The 1.5 °C challenge: How close are we to overshooting, triggering critical climate tipping points, and needing to go beyond net zero? *Carbon Trust* November 9. Available from: https://www.carbontrust.com/news-and-insights/insights/the-15c-challenge-how-close-are-we-to-overshooting-triggering-critical-climate-tipping-points-and-needing-to-go-beyond-net-zero.
20. Fox D (2021) Rare mantle rocks in Oman could sequester massive amounts of CO_2. *Sci Amer* July 1. Available from: https://www.scientificamerican.com/article/rare-mantle-rocks-in-oman-could-sequester-massive-amounts-of-co2/.
21. Kelemen P, Benson SM, Pilorgé H, et al. (2019) An overview of the status and challenges of CO_2 storage in minerals and geological formations. *Front Clim* 1. Available from: https://www.frontiersin.org/articles/10.3389/fclim.2019.00009/full.
22. Kelemen PB, Matter J (2008) In situ carbonation of peridotite for CO_2 storage. *Proc Natl Acad Sci USA* 105: 17295–17300. https://www.pnas.org/doi/10.1073/pnas.0805794105
23. China Solar Thermal Alliance (2022) Surface area in the Sahara desert required to power the world with solar energy only—world of engineering. December 8. Available from: http://en.cnste.org/html/news/2022/1208/1364.html.

24. Anonymous (2022) Decarbonising the energy system by 2050 could save trillions. *University of Oxford* Sept 14. Available from: https://www.ox.ac.uk/news/2022-09-14-decarbonising-energy-system-2050-could-save-trillions-oxford-study.
25. Wu C, Zhang X, Sterling MJH (2021) Global electricity interconnection with 100% renewable energy generation. *IEEE Access* 9: 113169–113186. https://doi.org/10.1109/ACCESS.2021.3104167
26. Harris J (2021) Green capitalism and the battle for hegemony. *Sci Soc* 85: 332–359. Available from: https://globaljusticecenter.org/papers/global-capitalism-and-battle hegemony.
27. Schwartzman D (2021) The global solar commons, the future that is still possible: A guide for 21st century activists. Solartopia.org press: Galesburg, Illinois, USA. Available from: https://www.theearthisnotforsale.org/solarcommons.pdf.
28. Jakimowicz A (2022) The future of the energy sector and the global economy: Prosumer capitalism and what comes next. *Energies* 15: 9120. https://doi.org/10.3390/en15239120
29. Jakimowicz A (2022) The energy transition as a super wicked problem: The energy sector in the era of prosumer capitalism. *Energies* 15: 9109. https://doi.org/10.3390/en15239109
30. Aronoff K, Battistoni A, Cohen DA, et al. (2019) A planet to win: Why we need a green new deal. Verso: London. Available from: https://www.versobooks.com/products/2546-a-planet-to-win.
31. Klein N (2019) On fire: the (burning) case for a green new deal. Simon & Schuster: New York, NY, USA. Available from: https://www.simonandschuster.com/books/On-Fire/Naomi-Klein/9781982129927.
32. Schwartzman P, Schwartzman D (2019) The earth is not for sale: A path out of fossil capitalism to the other world that is still possible. World Scientific Publishing Co. Pte. Ltd.: Singapore. Available from: https://www.worldscientific.com/worldscibooks/10.1142/10827#t=aboutBook.
33. Barbier EB (2009) Rethinking the economic recovery: A global green new deal. Report prepared for the economics and trade branch. Division of technology, industry and economics. United Nations Environment Programme: Geneva. Available from: https://www.cbd.int/development/doc/UNEP-global-green-new-deal.pdf.
34. Carroll WK (2020) Fossil capitalism, climate capitalism, energy democracy: The struggle for hegemony in an era of climate crisis. *J Soc Soc Stud* 14: 1–26. https://doi.org/10.18740/ss27275
35. Harris J (2019) The future of globalisation: Neo-fascism or the Green New Deal. *Race Class* 61: 3–25. https://doi.org/10.1177/0306396819844121
36. Ajl M (2021) A people's green new deal. Pluto Press: London. Available from: https://library.oapen.org/handle/20.500.12657/48775.
37. Hamouchene H, Sandwell K (2023) Dismantling green colonialism: energy and climate justice in the Arab region. Pluto Press: London. Available from: https://openresearchlibrary.org/content/00f17fce-1221-4a50-bc6e-643d19f790f7.
38. Lenton TM, Pichler PP, Weisz H (2016) Revolutions in energy input and material cycling in earth history and human history. *Earth Syst Dynam* 7: 353–370. https://doi.org/10.5194/esd-7-353-2016
39. Zhang S, Yao Y, Yu Y (2021) Frontiers for room-temperature sodium-sulfur batteries. *ACS Energy Lett* 6: 529–553. Available from: https://pubs.acs.org/doi/10.1021/acsenergylett.0c02488.
40. Jiarui H, Bhargav A, Su L, et al. (2023) Intercalation-type catalyst for non-aqueous room temperature sodium-sulfur batteries. *Nat Comm* 14: 6568. https://doi.org/10.1038/s41467-023-42383-3

41. Nedopil C (2023) China belt and road initiative (BRI) investment report 2023 H1—The first ten years. Green Finance & Development Center, FISF Fudan University, Shanghai. Available from: https://greenfdc.org/china-belt-and-road-initiative-bri-investment-report-2023-h1/.
42. Wong T (2023) Belt and road initiative: Is China's trillion-dollar gamble worth it? *BBC News* October 1. Available from: https://www.bbc.com/news/world-asia-china-67120726.
43. Robinson WI (2023) The unbearable manicheanism of the "anti-imperialist" left. *Philosoph Salon* August 7. Available from: https://thephilosophicalsalon.com/the-unbearable-manicheanism-of-the-anti-imperialist-left/.
44. Robinson WI (2023) The travesty of "anti-imperialism". *J World-Systems Res* 29: 587–601. Available from: https://jwsr.pitt.edu/ojs/jwsr/article/view/1221.
45. Global China Unit (2024) Tensions grow as China ramps up global mining for green tech. *BBC News* April 29. Available from: https://www.bbc.com/news/world-68896707.
46. Hairong Y, Sautman B (2023) China, colonialism, neocolonialism and globalised modes of accumulation. *Area Develop Pol* 8: 416–449. https://doi.org/10.1080/23792949.2023.2259459
47. The State Council Information Office of the People's Republic of China (2023) The belt and road initiative: A key pillar of the global community of shared future. Available from: http://www.beltandroadforum.org/english/n101/2023/1010/c124-895.html.
48. Editorial (2023) China's belt and road initiative is boosting science—the West must engage, not withdraw. *Nature* 622: 669–670. https://doi.org/10.1038/d41586-023-03299-6
49. Schwartzman D, Engel-Di Mauro S (2022) Prefiguration and the emergence of the global subject. *Sci Soc* 86: 564–583. Available from: https://guilfordjournals.com/doi/10.1521/siso.2022.86.4.564.
50. World Bank Group (2021) List of countries by life expectancy. *Wikipedia*. Available from: https://en.wikipedia.org/wiki/List_of_countries_by_life_expectancy.
51. Jakimowicz A, Rzeczkowski D (2023) Contact zones in the energy transition: A transdisciplinary complex problem. *Energies* 16: 3560. https://doi.org/10.3390/en16083560