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Comment

Comment on Seibert, M.K.; Rees, W.E. Through the Eye of a Needle: An Eco-Heterodox Perspective on the Renewable Energy Transition. *Energies* 2021, *14*, 4508

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Abstract: This paper exposes the many flaws in the article "Through the Eye of a Needle: An Eco-heterodox Perspective on the Renewable Energy Transition, authored by Siebert and Rees and recently published in Energies as a Review. Our intention in submitting this critique is to expose and rectify the original article's non-scientific approach to the review process that includes selective (and hence biased) screening of the literature focusing on the challenges related to renewable energies, without discussing any of the well-documented solutions. In so doing, we also provide a rigorous refutation of several statements made by a Seibert–Rees paper, which often appear to be unsubstantiated personal opinions and not based on a balanced review of the available literature.

Keywords: renewables; solar; wind; sustainability; resources; challenges

1. Introduction

According to Seibert and Rees, their recently published Review paper entitled "Through the Eye of a Needle: An Eco-Heterodox Perspective on the Renewable Energy Transition" [1] highlights "*numerous collectively fatal problems with so-called renewable energy technologies*" and "*makes clear that the pat notion of affordable clean energy views the world through a narrow keyhole that is blind to innumerable economic, ecological and social costs*".

The renewable energy (RE) research community understands that assessing the sustainability of the rapid growth of RE necessitates the undertaking of a careful analysis because RE markets are largely enabled by its promise to produce reliable electricity with minimum environmental burdens. It is extremely important that, as humanity embarks on a necessary energy transition from clearly unsustainable sources such as fossil fuels (FFs), it does so while examining both positive and potentially negative impacts of alternative scenarios. Careful, level-headed thought on the implications of this transition is in order; the RE research community has conducted numerous studies over the last two decades addressing such implications, solutions and remaining challenges and a selection of these studies are cited in Section 2 below, as appropriate.

Unfortunately, Siebert and Rees did not reference any of these studies, but instead they chose to cherry-pick a few sources that exaggerated potential impacts and selectively quoted statements that do not represent the current scientific consensus at all, in order to advocate a drastic behavioral change and population reduction.

There is in fact broad agreement that both technological and behavioral solutions will be needed to achieve rapid decarbonization (or rather, "defossilization", i.e., freedom from the dependence on fossil carbon resources) and denigrating one approach to advance the other is self-defeating. Regardless of the speed at which the energy transition occurs, the more climate change mitigation that is achieved by a combination of technological and behavioral solutions, the less adaptation will be needed [2], making the authors' "eye of the needle" analogy less relevant. In addition, while some of the more general, high-level points made by the authors can, to some degree, be agreed upon, this is no excuse for their lack of due diligence, or for in fact perpetrating false myths. Since the Siebert and Rees paper was published as a Review, not an Opinion paper, this commentary shall be constrained to rebutting their major flaws in reviewing RE technologies.

2. Statements in the Seibert–Rees (S–R) Paper and Counter-Arguments

In Section 3, "Problems with So-Called Renewables", Seibert and Rees state that the "*espoused technologies are not renewable, that their production—from mining to installation—is fossil-energy-intensive*" and that "*producing them—particularly mining their metals and discarding their waste—entails egregious social injustices and significant ecological degradation*". In addition, they state that "*Green New Deal (GND) proponents are appallingly tolerant of the inexplicable. They fail to address how the gigatons of already severely depleted metals and minerals essential to building so-called RE technologies will be available in perpetuity considering typical five to 30-year life spans and the need for continuous replacement* [3–5]*. They offer no viable workarounds for the ecological damage and deplorable working conditions, often in the Global South, involved in metal ore extraction* [6,7]*. The waste streams generated by so-called renewables at the end of their short working lives are either ignored or assumed away, to be dealt with eventually by yet non-existent recycling processes* [8–10]".

Let us first stress that the phrase "so-called renewables" is misleading and fundamentally wrong from a scientific point of view. Solar energy is in fact renewable for all intents and purposes, as the rate of consumption of Hydrogen in the nuclear fusion reaction in the Sun is negligible on the human time scale. In addition, most of the materials used to produce the solar modules will still be recoverable at the end of their service life, rendering photovoltaic electricity as a whole effectively renewable to a very large degree. Therefore, the authors' systematic use of the phrase "so called renewables" comes across as a deliberate attempt to elicit a negative perception in the reader, lacking proper discussion.

Then, it is noteworthy that none of the papers cited to support such a viewpoint support the conclusions the authors propose as "final", namely that the solution to the raised problems is to "*reduce the global population to the one billion or so people that can thrive sustainably in reasonable material comfort within the constraints of a non-fossil energy future*" and stop the development of RE except for wood, biomass, and mechanical wind energy. Actually, Vidal et al. [3] note the increasing demand for metals and other resources in RE, but they offer solutions to such in the form of "green mining" operations in Europe that can become prototypes in global development. Sovacool [6,7] reports alarming cases of forced labor in Africa and mafia-like operations in Latin America, but concludes that "ample opportunities exist to make low-carbon world more pluralistic, demographic and just". The S–R's statement that the "*end of their short working lives are either ignored or assumed away, to be dealt with yet non-existent recycling technologies*" is even more elusive as their own references [8–10] do not support this argument. Chowdhary et al. [8] reviews several PV recycling technologies and highlights the need for recycling to become obligatory worldwide (it is already obligatory in the EU and solar modules are about to be included in a revision of the European Union's Eco-design Directive (Directive 2009/125/EC)). Xu et al. [9] provide a quantitative basis to support the recycling of PV panels. Liu and Barlow [10] admit that the recycling of the blades of wind turbines is still in development and estimate what the demand for recycling will be in the future, more or less the opposite of "ignored" or "assumed away."

Even more importantly, Siebert and Rees neither discussed nor cited any of the hundreds of peer-review articles that acknowledged the aforementioned challenges and documented quantitative solutions. For example, the availability of "critical materials" needed for building a very large RE infrastructure has been addressed by the European Commission (EC) [11], the US Department of Energy (DoE) [12], and the US Geological Survey [13].

Academic research addressing key potentially criticalities in 100% RE scenarios [14] identified several critical materials, but did so in a constructive rather than destructive fashion, as shown for Lithium [15], Neodymium and Dysprosium [16], Cobalt through the current phase-in of Cobalt-free batteries [17] and for solar PV in the scale of up to 170 TW total installed capacity towards the end of the century [18], a capacity target which is independently confirmed by a second research team [19].

It is widely recognized that individual photovoltaic (PV) technologies would experience material challenges for reaching very high levels of production, but such sustainability challenges do not appear before any technology reaches multi-GW annual production and multi-TW cumulative production. For example, CdTe PV is constrained by Te availability, but there is enough Te available from Copper anode slimes to support at least 4–5 times current production capacity [20] and cumulative TW-scale production by 2050 [21]. Similar constraints apply to In and Ga for CIGS PV, Ag for c-Si PV, and Cu for cables. However, a recent collective study on Indium showed that Indium availability is in fact not a limiting factor for sustaining large scale production of CIGS PV [22]. The authors show the feasibility of reducing the amount of critical materials in the devices for the same efficiency output, by reducing the thickness of the photoactive layers, or using microcells under light concentration [23]. In addition, in the case of Silver for c-Si PV, Ag is not actually an essential component for the PV cells, and it can be progressively replaced by more abundant metals, like Cu.

In a more general view, material availability and costs are metrics that are taken into consideration in the selection of individual technologies, and this is why the RE future is widely seen as comprising many RE technologies, which, when taken together, will be amply sufficient for providing the multi-hundred TW of RE installations needed worldwide by 2050–2100 [24–35]. In addition, metal mining and refining can be organized in a 100% RE environment, as showcased for the global Copper industry [36].

In Section 3.1.1, "Big Picture sanity check", the authors state that "*Transitioning the U.S. electrical supply away from FFs [fossil fuels] by 2050 would require a grid construction rate 14 times that of the rate over the past half century* [37]. *The actual installed costs for a global solar* *program would have totaled roughly $252 trillion (about 13 times the U.S. GDP) a decade ago* [38] *and considerably more today*".

It is appalling that the references cited here [37,38] are unsubstantiated, non-peer-reviewed reports from known climate change deniers; Siebert and Rees did not cite the US DoE SunShot Studies [39–41], which—in each edition since 2000—have been proven to be correct in their forecasting. The educated result from the DoE studies is that such transitioning will cost less than one trillion US$; a leading study published in Scientific American and Energy Policy 12 years ago estimated the total cost of increasing the penetration of RE into the US grid to 69% by 2050 at only 450 billion [42,43]. Other recent reports indicate how absurd the $252 trillion estimate really is. Even the recently published "Net Zero America" [44] report, a widely publicized non-peer-reviewed analysis of the energy transition by scholars at Princeton University, estimates that $2.5 trillion over the next decade would be needed in additional investments and that would be across all sectors involved in the energy transition (e.g., electricity grid, EVs and all other RE technologies). This is still roughly 100× smaller than the Siebert and Rees figure. Additionally, a recent report from researchers at the Institute for New Economic Thinking suggested that the cost of a transition to clean energy from renewables is likely to be much less expensive than the 'business as usual' pathway, without any substantial reduction in reliability [45]. Bogdanov et al. [46] show that the ratio of the total annualized energy system cost to the final energy demand of the entire North America can gradually decline while transitioning towards 100% RE by 2050, along a continued energy transition process. Earlier research concluded that a North American power system integration with Canada and Mexico would create further benefits and cost reductions for 100% RE supply [47], while an energy system integration across all Americas would be of limited additional benefit [48].

In the same section, Siebert and Rees go on to state that "the United States would have to quadruple its last annual construction of wind turbines every year for the next 15 years and triple its last annual construction of solar PV every year for the next 15 years—only to repeat the process indefinitely since solar panels and wind turbines have average lifespans of around 15 to 30 years [49,50]".

However, the cited reports actually specify the minimum expected lifespans of solar panels to be 25–30 years (not 15 years), and it is noted that modules are sold with a guaranteed power performance of 25 years and are expected to function even longer than 30 years.

The authors then say, "*In addition, Clack et al.* [51] *found that one of the most cited studies on 100% electrification in the United States is error-prone and laden with untenable assumptions*". Indeed, Clack et al. criticized the Jacobson et al. study, but the criticism was limited to methodological issues and not the notion of 100% RE scenarios per se. In addition, that was not the last word in the debate as Clack et al.'s criticism was rebuffed by other scholars [52]. Additionally, at least 56 peer-reviewed papers among 18 independent groups found 100% RE possible at low cost in different parts of the world [53], and, in later publications, an overview on 180 studies on 100% RE has been provided [54] and as of June 2021 at least 550 studies on 100% RE have been recorded [19]. There are also peer-reviewed papers that directly address the critics of 100% RE scenarios [55,56], but Siebert and Rees did not cite any of these.

In Section 3.1.2, "Heat for Manufacturing", the authors' statement that "*The manufacturing processes used today to make solar panels, high-tech wind turbines, batteries and all other industrial products involve very high temperatures that are currently generated using FFs*" appears to imply that the benefit of transitioning to RE is defeated by the fact that RE systems themselves require fossil fuels for their manufacturing. Firstly, such statement is misleading because it fails to take into account and compare the different orders of magnitudes involved. Even when the thermal energy required for the manufacturing of RE technologies is primarily supplied by FFs, the overall amount of fossil energy used per unit of delivered energy output is orders of magnitude lower than the amount currently used to generate the same useful energy using conventional technologies. This has been proven beyond any doubt by countless quantitative life cycle assessments (LCA) in the literature, e.g., [57–74]. Secondly, the same statement also incorrectly implies that RE cannot supply the high temperatures used in RE manufacturing. However, the high temperature processes in the life cycle of PV panels are powered by electricity, not directly by fossil fuels; there is no fossil fuel input connection, for instance, to a Siemens reactor for the production of semiconductor- and solar-grade Silicon or to the sub-atmospheric semiconductor deposition chambers used in any of the various PV technologies [57]. In fact, the overwhelming majority, around 80–90%, of energy inputs to the manufacture of solar PV come in the form of electricity, meaning that solar energy could be self-sustaining [75].

The authors then state "*more energy is required to produce and compress the product (Hydrogen) than it can later generate* [38,76–78]". However, of course, this can be said for ANY energy storage technology, otherwise one would have created a perpetual motion machine, which violates the second law of thermodynamics! Furthermore, the citations they have listed do not support the affirmation that "*there is scant information on whether or how it can be generated with RE alone*". Firedmann et al. [76], for instance, concludes that "*Hydrogen-based industrial heat provides an actionable pathway to start industrial decarbonization at once, particularly in the petrochemical, refining and glass sectors, while over time reducing cost and contribution of fossil sources*" [76]. Recent research on the role of Hydrogen [32] clearly indicates that first of all a comprehensive electrification of all energy services has to be the central aim; however, the remaining segments, which cannot be directly electrified, can be tackled for zero greenhouse gas (GHG) emissions with solutions typically based on Hydrogen. The required Hydrogen can be fully based on renewable electricity. This applies to Hydrogen-based steel [79], chemicals [80,81], further high-temperature industrial processes and long-distance marine and aviation transportation. In case Hydrogen-based solutions are used for applications which cannot be directly electrified, then this can be part of a cost-neutral energy transition [46].

Furthermore, the authors say, "*The only viable, large-scale feedstock for Hydrogen is natural gas and the gas reforming process requires temperatures ranging from 1300 °F to 1830 °F (700 °C to 1000 °C)* [38,77,78,82]". The authors did not list any of the hundreds of articles dealing with the production of "green H_2" by using RE to power water electrolyzers; electrolytic H_2 currently costs 2–3 times more than SMR H_2, but its learning curve shows that cost parity is being approached quickly. Recent studies on optimizing electrolyzer operation to follow electricity pricing patterns show that the levelized cost of Hydrogen can get as low as to $2/kg ($H_2$) with dynamic operation following simple enhancements in electrolyzer components [83]. This is supported by an IRENA 2019 analysis showing that Hydrogen produced from electricity can be competitive if the price of electricity falls to below USD 30/MWh, which is projected with increased solar energy penetration [84]. Global-local analyses for hybrid PV-wind based green Hydrogen indicates huge and low-cost upcoming Hydrogen potential all over the world [85]. Latest cost-optimized green Hydrogen for large utility-scale applications indicates that there is cost parity of green Hydrogen and SMR H_2 for the best solar resource regions and broad cost parity is expected worldwide by 2030 [86]. Furthermore, electrolyzer cost competitiveness is largely limited by policy obstacles that prevent electrolyzer participation in the wholesale electricity market [87]. Currently, electrolyzers are treated as industrial electricity consumers as opposed to wholesale market participants with exposure to low-priced solar energy. In the USA, access will be provided under Federal Energy Regulatory Commission (FERC) Order n. 2222, which will also open electrolyzers to additional revenue streams as dispatchable loads from the provision of ancillary grid services, such as demand response and congestion alleviation [88,89]. In an analysis using approximately 7000 actual electricity utility rates, an NREL study found that electrolysis-based Hydrogen production costs are already cost competitive and that dynamic rates and optimal sizing further reduce cost [90]. In addition, regardless of the price dynamics involved and whether or not price parity is reached between the technologies, the outright omission of any reference to the vast body of literature discussing green H_2 is misleading at best.

In addition, the authors claim that "*The only potential replacement for coal is charcoal derived from wood*". First of all, the authors' claim is of dubious validity due to the fact that it remains unproven, and, in fact, it is highly doubtful that enough wood could be sustainably harvested to even come close to replacing fossil coal in all industrial applications. Coal in the industry sector is mainly used for steelmaking and in the cement and chemical industries [91]. For these industries, renewable electricity-based solutions are instead available and are likely to see commercialization in this decade [79–81,92,93]. It has been shown that an energy-industry system based on 100% RE can fully phase out coal while reducing energy system cost and being stable for all hours of a year [94].

Section 3.1.3, "Problems with Solar Panels" is flawed in its entirety. The authors did a very good job of selectively finding and citing a handful of anti-solar articles that exist in the literature, while carefully avoiding to cite any of the hundreds of articles that show the evolution of the PV industry regarding increasing efficiencies, improving material utilization and reducing and controlling emissions. There are even meta-analyses of solar PV (and other renewable energy technologies) that have tracked reductions in environmental impacts throughout the lifetime of the industry [26,58,95,96]. In their assertion that "*solar panel uses toxic substances, large quantities of energy and produces toxic byproducts* [38,97]" they cited a report based on the premise that "*we don't have an energy crisis, we have a consumption crisis*" and a 2014 commentary alluding to actual episodes of Silicon Tetrachloride dumping in the early days of solar Silicon manufacturing in China, but without mentioning the epilogue of the commentary where the author noted the value of the environmental, health and safety (EH&S) studies by the National PV Environmental Research Center at Brookhaven National Laboratory [98–114] and the emerging, at the time, programs from major PV companies to prevent and control emissions in manufacturing.

The most impactful action that industries involved in PV recycling could take is to assume Extended Producer Responsibility (EPR) following the European initiative. Recycling end-of life systems then becomes an important aspect of sustainability and needs to be optimized to help, rather than hinder, the affordability of photovoltaic systems.

Seibert and Rees also state: "*The much-touted silver bullet of recycling is not the panacea is it purported to be. Recycling requires copious amounts of energy, water and other inputs and exposes workers to toxic materials that have to be disposed*".

Both thermodynamics and engineering practice have shown beyond a reasonable doubt that, in virtually all cases, recycling saves energy, water, and valuable materials, while reducing environmental impacts such as such as freshwater eutrophication, human toxicity, terrestrial acidification, and this is also demonstrated as being the case for photovoltaics [115–127]. Recycling of PV in Europe is regulated by the Waste Electrical and Electronic Equipment (WEEE) directive [128,129]; in addition, recycling facilities already take up all the rejects and waste from CdTe PV manufacturing and deployment [130]. Recycling technologies have been demonstrated for all commercial PV technologies; however, recycling infrastructure needs to be built to handle the large volumes of end-of-life PV down the road. The same challenge applies to solar glass, for which a capacity two times higher than the current capacity would be needed by 2030 to handle projected PV manufacture scaling-up [131]. However, the PV industry has proved in the past that it is well-equipped to rather quickly react to such market demands; this is illustrated by the multifold increase of solar silicon production between 2004 and 2008, as the supply from the rejects of the semiconductor grade silicon proved to be insufficient.

Finally, Seibert and Rees devoted just one sentence to the very important topic of Energy Return on Energy Investment (EROI or EROEI); they claimed that "*even without such drawbacks, solar PV has a low energy return on energy invested (EROEI)—too low to power modern civilization* [131–134]".

Again, the authors selected from an extensive literature on life cycle analysis three articles and a report from fossil fuel advocates. De Castro's PV EROI calculations [132,133] appear to be based on 30-year-old data corresponding to 400 μm-thick Silicon wafers and cement platform foundations of low efficiency photovoltaics in low irradiation regions and the worst conditions of severe weather during installations. Ferroni et al. [134] and Prieto et al. [135] used flawed methodologies with double counting and unbalanced boundary systems between fossil fuel and solar technologies. These two studies have been amply rebuffed [59,60], but Seibert and Rees did not present the papers that corrected the ones selectively cited, nor did they cite other independent studies pointing out that a renewable energy-based society can deliver the EROI required for long-term stability [62–69].

Seibert and Rees apparently did not examine the literature on EROI [62–69] and did not understand the associated context. Any postulation of a 'minimum' EROI that is supposedly required to support "modern civilization" is problematic, unless the same system boundaries may be reasonably assumed to remain in place consistently across the board of the energy resources being compared, which—critically—would have to include a common 'point of use'. However, this is clearly not the case. Instead, as already discussed elsewhere [70], "the requirement for a relatively high 'minimum' overall EROI has historically been due to the necessity to transport and refine (by means of additional energy investments) a mix of conventional fuels, before they are put to use in a range of unavoidably inefficient thermal processes, which are all ultimately limited by Carnot's principle. However, when looking at the future, part of the appeal of a major energy transition (besides the environmental benefits in terms of reduced carbon emissions and pollution) is precisely to side-step such inherent supply chain and conversion efficiency limitations, essentially by pushing for more electrification in all sectors, while producing a large share of this electricity using low-carbon, renewable resources [56]. A significantly lower 'minimum' EROI may therefore well suffice to support such a fundamentally different future society relying on renewable electricity for a larger share of its energy metabolism".

As shown in Figures 1 and 2, the energy pay-back time (EPBT) of PV systems has improved by an order of magnitude during 1990–2010 and by almost a factor of 2 during 2015–2020 [58,63–69,72–74]. The latest peer-reviewed LCA calculations [58,63] indicate that, for mono-crystalline Si PV systems, it takes from 0.6 to 1.3 years (depending on the assumed irradiation) to return an amount of electricity that is equivalent to the primary energy invested, whereas, for multi-crystalline Si PV it takes from approximately 0.6 to 1.5 years and, for CdTe PV, it takes 0.5 to 1.1 years. This translates to EROI values between 20 and 50 (Figure 3), when the energy return is expressed in terms of equivalent primary energy (based on an assumed average primary energy-to-electricity conversion efficiency of 0.3).

A recent study estimated that, even when adding up to 4 h of electrochemical storage to PV, the EPBT of the combined PV + storage system would only increase by 30% at worst [69], which translates to no more than a 23% decrease in EROI.

In Section 3.1.4, "Problems with Batteries" S&R claim that "*Storing only 24 h worth of U.S. electricity generation in lithium batteries would cost $11.9 trillion*". This statement is problematic in two fundamental ways. Firstly, the authors' estimate fails to take into account the rapidly declining trend in the cost of electrochemical storage that has been underway for more than a decade and the fact that such trend is widely expected to continue [136]. Secondly, and even more importantly, the assumption that 24 h of total U.S. electricity generation would need to be stored is unsubstantiated.

An energy system analysis in full hourly resolution for the entire energy system covering all energy sectors for North America structured in 20 regions [46] found that, for a 100% RE system in 2050, 1809 GWh_{cap} of battery capacity would suffice for about 90% of all electricity storage, for a total electricity generation of 19,200 TWh. This is equivalent to about one hour of average storage, which is enabled by resource complementarity [137], dispatchable renewables (hydropower, bioenergy), grids interconnection, sector coupling, storage and less than 10% curtailment, while the total energy system cost steadily declines, from the present to 2050. It is also noted that oversizing photovoltaic power plants is a cost-effective way of controlling minute-to-minute solar resource fluctuations and in addition provide grid frequency and voltage stability services [138–140].

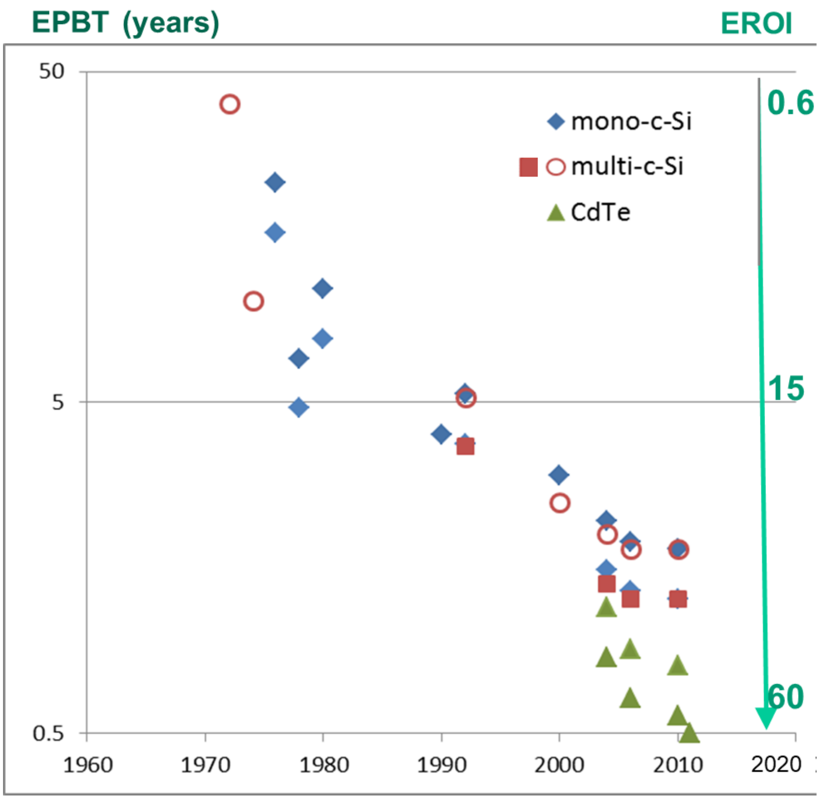

Figure 1. Historical evolution of Energy Payback Times (EPBTs) of PVs, from 50 years down to half a year and corresponding Energy Return to Energy Investment (EROI); published estimates corresponding to insolation of 1700 and 2300 kWh/m^2/year—updated from Fthenakis and Lynn [57].

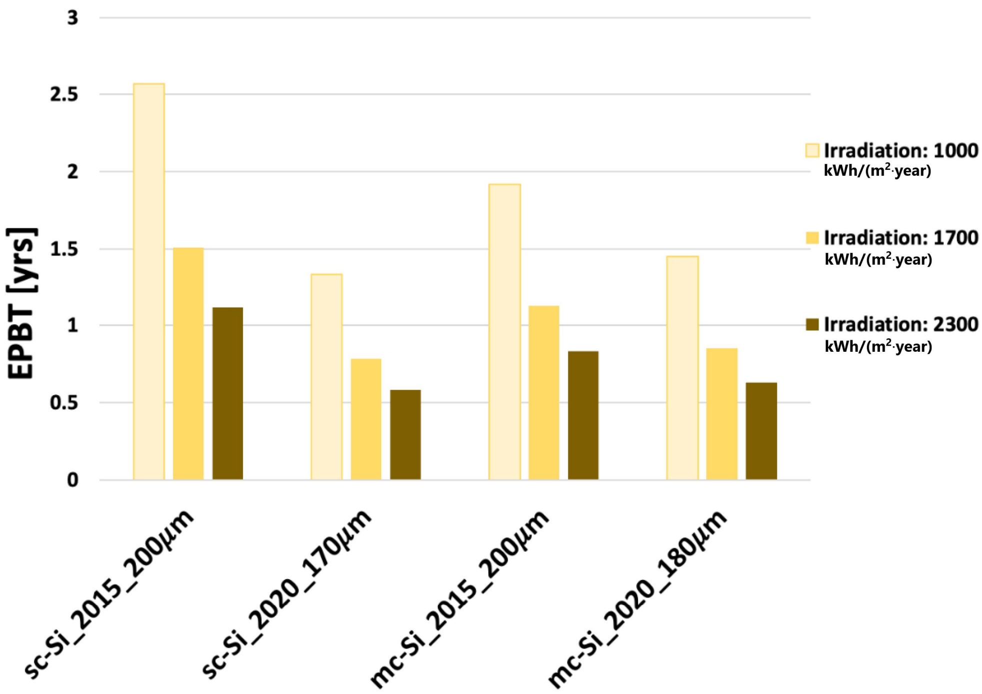

Figure 2. EPBTs reductions from 2015 to 2020, under three irradiation levels: 1000 kWh/(m^2·year), 1700 kWh/(m^2·year), and 2300 kWh/(m^2·year). Performance ratio: 0.85. Efficiencies: 17% and 20.5% for 2015 and 2020 single-crystalline Si (sc-Si) photovoltaic (PV), respectively, and 16% and 18% for 2015 and 2020 multicrystalline Si (mc-Si) PV, respectively—from Fthenakis and Leccisi [58].

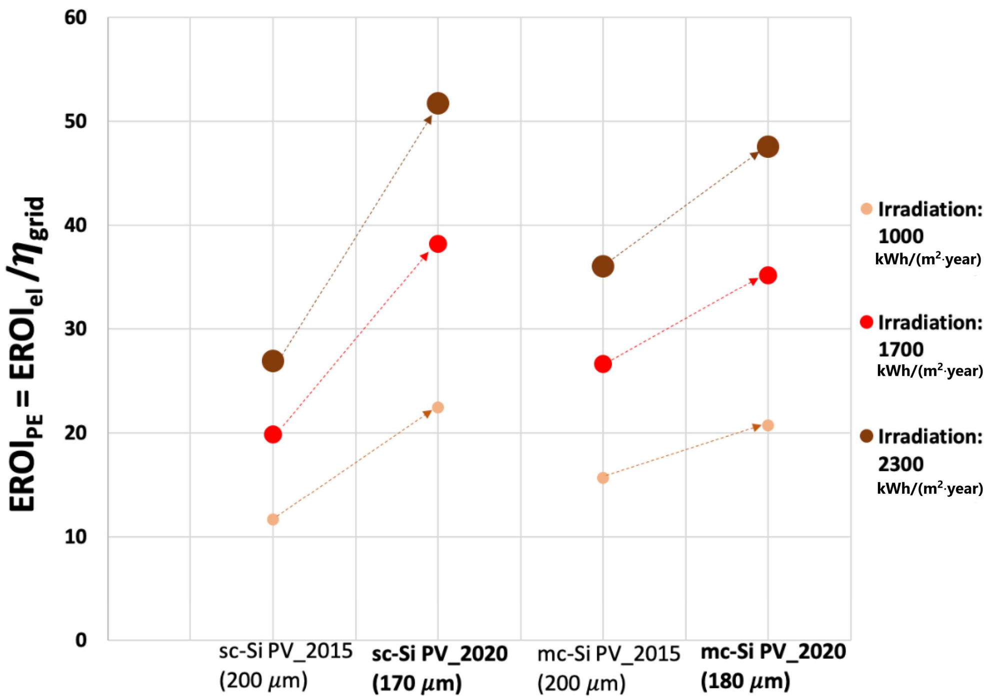

Figure 3. EROIs increases from 2015 to 2020, under three irradiation levels: 1000 kWh/(m^2·year), 1700 kWh/(m^2·year) and 2300 kWh/(m^2·year). Assumed η_{grid} = 0.30; lifetime = 30 years. Performance ratio: 0.85. Efficiencies: 17% and 20.5% for 2015 and 2020 single-crystalline Si (sc-Si) photovoltaic (PV), respectively, and 16% and 18% for 2015 and 2020 multi-crystalline Si (mc-Si) PV, respectively–from Fthenakis and Leccisi [58].

Another recent analysis focusing on California and based on a detailed 1 h-resolution power dispatch model informed by actual historical demand and generation data found that a projected 80% RE generation mix relying heavily on PV would be capable of meeting the domestic demand profile while only requiring 6 h of storage capacity [65]. A follow-up study further calculated that a similar amount of storage (in terms of duration) would suffice while also meeting the additional demand created by 10 million EVs on California roads [141].

Seibert and Rees also claimed that heavy-duty trucks could not be powered by batteries; unfortunately for them, the major truck manufacturers in the world are already transforming their production lines to enable an almost entirely battery-powered truck fleet [142–146], as this is the least cost option per driven kilometer. In addition, it is claimed that batteries would have a lifespan of 5 to 15 years, whereas leading manufacturers such as Samsung provide guarantees of 6000 cycles [147], which leads to approximately 20 years of life for about 300 full charge cycles per year, which is equivalent to almost a full charge cycle per day. Battery lifetimes up to 30 years are expected [148].

Furthermore, the text about grid storage focuses entirely on Li-ion battery technologies, ignoring the fact that Li-ion batteries have only gained a major market share since about 10–15 years ago and that other battery technologies (e.g., Na-ion, redox-flow) also present viable options for grid-scale energy storage.

Finally, the authors state that: "*Batteries have a life span of around 5 to 15 years, creating an additional, significant waste management problem* [6]. *They cannot be disposed of in landfills due to their toxicity and are one of the fastest-growing contributors to e-waste streams. Only 5% of all Lithium batteries are recycled*". However, the recycling problem is only starting to become relevant in terms of scale, and the industry is already developing solutions. The currently available pyrometallurgical recycling is proven to provide benefits to the environment [149] and even more efficient hydrometallurgical methods [150] are expected to become mainstream in the coming decades [151], when sufficiently large end-of-life quantities enable economies of scale.

Section 3.1.5, "Problems with Wind" picks one single study to claim that the EROI of wind is below 3, despite numerous meta-analyses which have demonstrated that wind electricity has an EROI greater than 20—even when the numerator of the EROI ratio is expressed in straight units of electricity and obviously even higher EROI values are calculated when the electricity output is instead consistently converted to units of primary energy equivalents [152–154]. While wind does generate some waste products, the largest of these from an energy perspective comes from the steel in the tower, which can be recycled using a process that relies on electricity as its main energy input and which may therefore be decarbonized to a large extent. The use of fossil fuels (and associated carbon emissions) within construction equipment is also not an essential characteristic. Many companies, e.g., Komatsu and Liebherr, are starting to offer battery-electric alternatives, where the mass of the battery is actually beneficial to counterbalance cranes and backhoes. Finally, while there is still the issue of cement, which does entail GHG emissions in its production, wind electricity is still one of the low carbon emitters, with a carbon intensity of around 11 g CO_2-eq per kWh, i.e., orders of magnitude lower than fossil fuel based technologies, even when the latter are equipped with carbon capture and sequestration (CCS) [155,156].

Section 3.1.9, "Problems with Technological Carbon Sequestration" discusses challenges with CCS and direct air capture (DAC) of CO_2. It is claimed that "*it would cost around $600 billion to capture and sequester 1 Gt of carbon* [157]". Analyses based on the latest technology characteristics of renewable electricity-based DAC [158] performed in hourly temporal and high geo-spatial resolution for the Maghreb [159] and globally [160] find that, by 2050, CO_2 DAC should be possible for about €50 billion per Gt of CO_2, or less. Nevertheless, CCS has additional sustainability constraints, in particular for the case of bioenergy with CCS (BECCS), which could be overcome by applying DAC-based CCS [161]. It has been estimated that a global energy system largely based on solar PV could enable net-negative CO_2 emissions on the scale of about 30 Gt of CO_2 per year, enabling rebalancing to about 350 ppm of atmospheric CO_2, which is regarded as a more sustainable CO_2 level [162]; this would require about 10% of the total installed PV capacity [19], which is deemed energetically affordable.

Section 3.1.10, "Hidden Fossil Fuel Subsidy" is written under the underlying assumption that fossil fuel inputs are inherent to renewable energy technology pathways, which is not the case. Clearly, in a world dominated by fossil fuel energy, every process will be dependent upon fossil fuels to some extent, even if indirectly, but that does not mean that the system cannot change. To draw a parallel, in the early days of oil discovery, drilling rigs were transported by horse, but of course that does not mean that fossil fuels were necessarily dependent on animal traction. Unless there is an inherent reason why some specific inputs are dependent on fossil fuels, then the technological system can (and probably will) change. While it is possible that a few specific activities may always be partly dependent on coal, a world in which coal was only used for materials production (which represents a small fraction of its current overall use) would be far preferable to the world of today, in terms of reduced environmental impacts. Be that as it may, recent research has indicated that most, if not all, industrial sectors can be shifted fully to renewable energy [94], which includes the global cement and steel industries [79,92,93].

Section 3.1.12, "The Liquid Fuels Question" claims that "*it is highly unlikely that synthetic liquid fuel substitutes for FFs [fossil fuels] can be produced sustainably in any more than small quantities for niche applications*". Vast literature has been published in recent years on e-fuels and e-chemicals, such as green Hydrogen [85,86,163], e-Methane [164,165], Fischer–Tropsch fuels [166,167], e-Ammonia [168,169] and e-Methanol [170,171], all showing that electricity-based fuels are in reach. In a global energy system transition analysis reaching 100% RE in 2050 [46], with 90% electricity share in primary energy (mainly PV, wind and some hydropower) and strong growth in energy service demands, it has been shown that the total energy system cost can be kept at present levels, while the overall energy system efficiency can be increased by a factor of two [46], mainly due to the phase-out of combustion processes which can be substituted by direct electricity-based processes. The segments which cannot be directly electrified can be indirectly electrified with Power-to-X processes and e-fuels, such as for long-distance marine [172] and aviation transportation and high temperature industrial processes. The transport sector can be expanded for more passenger and freight transportation, while the total final energy demand can be kept stable and primary energy demand would grow only moderately, but for three times more transportation, until 2050, since the additional energy demand for e-fuels is counterbalanced by less energy demand for road transportation due to the increased energy conversion efficiency of electric power motors [173]. This documents that stable cost, net-zero CO_2 emissions, high energy system efficiency, e-fuels and 100% renewable energy can be achieved [46] and for higher societal welfare with less air pollution and related health costs; and such a transition would also lead to more jobs than for the present energy system [32,174].

3. Conclusions

This rebuttal has exposed the many flaws in the so-called review of renewable energy (RE) presented by Siebert and Rees and in so doing it has cited just a sample of the many peer-reviewed studies which the original "review" paper did not mention. Perhaps the most fundamental flaw of that paper is an unacceptable non-scientific approach that includes selective (and hence biased) screening of the literature focusing on the challenges related to technologically enabled renewable energy solutions, without discussing any of the proposed solutions. Then, such a biased perspective is used to reject the possibility that RE may have a sustainable, rather than simply transitional, role in humanity's future. Instead, Seibert and Rees adopt the fatalistic and unimaginative perspective that the only way to solve the problem is to reject technological renewable energy solutions entirely and adopt an alternative "one-earth sustainability strategy" paradigm whereby just 1 billion people would inhabit the Earth, due to a forced reduction of population and RE would be derived only from wood, biomass, animal energy, and mechanical (not electric) wind energy.

It is unfortunate, counterproductive, and ethically deplorable that the authors turn a legitimate discussion of the challenges of defossilizing the global economy into a political diatribe, castigating the potential for renewables to contribute to the overall solution.

It is therefore absolutely necessary to stress that analyses like Siebert and Rees' present not only a distorted perspective by cherry-picking references and ignoring the mainstream literature in almost every section of the paper; in fact, their analysis is fundamentally flawed in design. It views the energy transition in the abstract, divorcing it from the realities of the world and the energy context in which policy-makers must make decisions. Currently, each year humans use 173,000 TWh of energy, roughly 75% of which comes from fossil fuels. The pertinent question therefore is not whether renewables are perfect, rather it is whether renewables and the energy transition in general will be better than the existing system. These authors do not acknowledge the obvious counterpoint that our current energy system is wholly unsustainable and unviable even in the short run. Where is the "Problems with Oil" section? It is the contention of these authors, and again the weight of the academic consensus in general, that renewable energy technologies will improve livelihoods compared to a continued fossil fuel-dominated world.

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