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Are the land and other resources required for total substitution of fossil fuel power systems impossibly large? Evidence from concentrating solar power and China

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ABSTRACT

The task of substituting the entire global fossil-fueled energy system by renewables is increasingly discussed in the energy literature, but in the social sciences academy it is widely viewed as impossibly large within any meaningful timeframe. In this article we argue that such pessimism is ill-founded. Taking as our starting point the material and energy requirements of existing operating systems such as the Shams1 Concentrating Solar Power plant, we scale these up to generate the real resource demands of a renewable electrical energy system to supply the entire planet – and find these to be feasible, particularly if it is China that takes on the manufacturing challenge. We argue that such results need to be promoted more vigorously by energy and carbon management scholars.
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1. Introduction: the major concerns arising from the transition toward renewable energy

One has to admit that the climate scientists, organized in their professional societies and in the UN-sponsored Intergovernmental Panel on Climate Change (IPCC), have done an excellent job in informing policy makers and the general public about the dangers and reality of climate change [1]. Many of them have gone further, and spelt out the implications for our global industrial civilization. But the problem is that this message then gets confused, and becomes either a call for drastic reductions in energy usage (which does not sit well with aspirations to develop on the part of China, India et al.) or grandiose schemes of industrial restructuring which are presented in a way that makes them look impossible.

There must be a better way to frame and illustrate the technical challenges involved in moving globally to a low-carbon energy- and industrial system. We address this challenge in this article.

There is by now widespread agreement amongst energy policy and carbon management experts on the need for a wholesale replacement of the current fossil-fueled power system by one operating on renewable energy sources. The IPPC in 2011 saw the possibility of alternative renewable energy systems resulting in 80% replacement of fossil fuels by 2050. Some recent contributions see such a transition as occurring by 2030 [2]; others by a bit later. Jacobson and Delucchi spelt out the scale of the technical challenge in meeting their energy system based on water, wind and sun – in terms of numbers of wind turbines, numbers of solar cells, numbers

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Table 1
Electricity generated from CSP plants as shares of total electricity consumption, by region, 2020–2050.
Source: International Energy Agency

Countries	2020	2030	2040	2050
Australia, Central Asia, Chile, India (Gujarat, Rajasthan), Mexico, Middle East, North Africa, Peru, South Africa, United States (Southwest) (%)	5	12	30	40
United States (remainder) (%)	3	6	15	20
Europe (mostly from imports), Turkey (%)	3	6	10	15
Africa (remainder), Argentina, Brazil, India (remainder) (%)	1	5	8	15
Indonesia (from imports) (%)	0.50	1.50	3	7
China, Russia (from imports) (%)	0.50	1.50	3	4

of heliostats in solar thermal systems etc. But what do such numbers mean? How to scale them so that they become comparable with existing kinds of manufacturing activity?

Amongst the wider intellectual community, there remains strong scepticism as to the feasibility of such a transition. The implicit (and sometimes explicit) objection to a wholesale change-over to non-fossil energy resources in the next two decades is the question of availability of land resources, and the construction of what appear to be impossibly large numbers of industrial products such as turbines, solar cells, mirrors and lenses.

Let us take the recent volume from world-renowned sociologist-historian Michael Mann as a case in point. We choose Mann not because he is an energy specialist but precisely because he is *not* such a specialist, and draws his data from the published energy policy literature. In his latest Volume Four of *Sources of Social Power* [3], in Chapter 12 on 'Global Crisis: Climate Change', he states:

> *The global economy currently uses about 16 TW of electric power generation. To get that total without the aid of fossil fuel from a mixture of current alternative technologies would involve massive industrial complexes spread over very large land masses. Solar cells in the required quantity might spread over about 30,000 [square] miles of land. Solar thermal sources might require about 150,000 [square] miles, biofuels might occupy over 1 million square miles. Then there are wind turbines, geothermal sources, and nuclear power plants. One can play with the relative weights of each of these but, overall, the currently available alternative energy sources would require a space about equal to that of the United States. This would be a theoretical possibility but not a practicable one (2012: 386).*

We cite this passage not to enter into a dispute with Michael Mann (who as a non-specialist relies on his sources) but to indicate the extent of the mismatch between the *potential* of currently available renewable energy technology and the public perception of their capacity. To state that a land area equal to that of the US would be required for complete substitution is to argue, in effect, that the project is impossible. This would be a depressing conclusion – if it were true. Mann himself is pessimistic.

When we investigate further, it is found that Mann has based his statements on a passage from a chapter by Barnes and Gilman [4] where they cite data presented by the Australian technologist/entrepreneur Saul Griffith on the kinds of technical feats needed to meet the renewable energy challenge.[1] Griffith is actually concerned to present the scale of the challenge as an exercise in realism, but he has been interpreted in decidedly pessimistic tone by Barnes and Gilman as presenting the impossibility of making a real transition. This then led Mann to make the pessimistic judgment alluded to above.

[1] See the talk by Griffith at the University of Sydney, 24 March 2013, available at: http://www.themonthly.com.au/video/2013/03/24/1364105156/personal-and-global-view-energy-and-climate-saul-griffith-p2.

2. Evidence from real operating data

So let us address this issue using some real operating data that can be scaled up. Let us take the task of moving to a new global power system at face value, as an engineering challenge. As explained by Barnes and Gilman, and clarified by Griffith, the actual task might be characterized as one of building a new power generating system rated at 11.5 TW over the next 20 years. For the sake of the argument, let us simplify a little, and call it a '10 terawatt challenge'. What would it imply? Using a capacity factor of 0.40, consistent with the literature, this would call for 25 TW of nominal capacity. To make the argument even simpler, let us assume that the entire global power system is to be replaced over the next two decades with one involving just concentrating solar power (CSP) – fields of mirrors and lenses reflecting and concentrating the sun's energy to generate electric power. We choose CSP because it is widely viewed as constituting the next big surge in the US, Spain, China, India, Australia, African countries, and elsewhere, as the CSP deployment projected by International Energy Agency (IEA) as shown in Table 1.[2] In addition, the CSP does not call for any major technological breakthroughs to achieve this. More to the point, it can be scaled; it is a manufactured system where economies of scale can be expected to kick in, thus driving down costs through the experience curve. This is a source of advantage of manufactured renewable energy systems that is not available to nuclear power (where plants are built one by one, without economies of scale or increasing returns) nor to "new" fossil fuels like coal seam gas and shale oil (which are subject to diminishing returns).

First, some facts, based not on calculations but on current operating systems. One of the largest CSP plants in the world, the Shams1 plant opened in Abu Dhabi in March 2013, is a 100 MW plant using a field of parabolic trough mirrors covering 250 ha, or 2.5 km^2, while the total mirror aperture of 258,048 mirrors used in the project accounts only for 627,840 m^2, or 0.63 km^2. This plant incorporates many innovative features, including a dry-cooling system to save on water consumption in the desert, and auxiliary burners to provide dispatchable power. But its bare essentials are that it generates power at a land 'cost' of 2.5 ha/MW. Scaling that up to 1 GW would require 25 km^2; to 1 TW would require 25,000 km^2; and to 25 TW would require fields of mirrors and arrays covering an area of 625,000 km^2 (and actual mirror surfaces of 157,500 km^2). Now the US has a total land area of 9.1 million km^2. So the land called for by 25 TW of currently operating CSP plants to substitute for the entire world fossil-fueled power system would require less than 1/14 of the US land area, i.e. less than 7%. And since it is generally recognized that deserts occupy around 5% of US land area, the CSP plants could fit within the

[2] Electricity generated from CSP is projected to account for up to 40% of total electricity consumption in Australia, Mexico, Peru, South Africa, Southwest region of America, and in the countries of Central Asia, Middle East, North Africa, by 2050. For the details, please see IEA, "*Technology Roadmap – Concentrating Solar Power*", available at http://www.iea.org/publications/freepublications/publication/csp_roadmap.pdf.

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