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Perspectives

Relative deployment rates of renewable and nuclear power: A cautionary tale of two metrics

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ABSTRACT

Which can more quickly displace fossil-fueled electricity generation—nuclear power or modern renewables? Contrary to a persistent myth based on erroneous methods, global data show that renewable electricity adds output and saves carbon faster than nuclear power does or ever has. However, some literature asserts the contrary, based on a peculiar per-capita metric—perhaps useful for comparing countries but not technologies—applied to selected countries while ignoring others with the opposite outcome. Further flaws include cherrypicked and incomplete data, restrictive redefinitions, inconsistent comparisons, and omitted institutional lead times and dry-hole risks. Careful dissection of the reasons for contradictory results (even within the same paper) from absolute and per-capita metrics of growth in carbon-free electricity generation reveals the need for care in calculating and assessing claims about which technologies can and do deploy most quickly.

1. Introduction

The climate imperative to decarbonize the global energy system has sharpened conflicts between "energy tribes" favoring different technologies whose merits are keenly disputed in market, political, social, and academic fora. Among those disputes is which technologies can be deployed fastest at scale. Such comparisons [1,2] are complicated by diverse types, uses, unit sizes, scales of geographic adoption, costs, and other attributes [3]. Now, as the Intergovernmental Panel on Climate Change enters its sixth assessment cycle, the United Nations' Sustainable Development Goals and energy-access efforts ramp up, and the International Energy Agency's *World Energy Outlook* and US Energy Information Administration's *Annual Energy Outlook* describe an emergent global energy transition, clarifying facts and causes of relative deployment speeds could valuably inform public discourse. Fortunately, such a specific, timely, and well-focused comparison is at hand. Analyzing the observed deployment rates of nuclear and renewable ways of generating carbon-free electricity to displace fossil-fueled generation can now illuminate concealed analytic issues and help to test whether the global electricity system is at a "tipping point."

More than a dozen authors claim [4–9] that nuclear power plants now or soon available can scale up quickly enough to meet the global climate threat, while modular, mass-produced renewables "cannot scale up fast enough to deliver cheap and reliable power at the scale the global economy requires" [7]. Yet global (Fig. 1) and national data show the opposite. So who is right, and why? The answer turns on complex details: definitions of "renewable" and of output, sources and completeness of datasets, years and geographies included, and above all, the basic metric adopted. This paper illustrates how artful choices of these details can reverse Fig. 1's seemingly obvious conclusion.

2. Analysis

2.1. Conflating technologies with countries

The myth of faster nuclear growth comes from nuclear advocates [8] who compare how quickly different countries have raised different technologies' electricity production *not in absolute terms but per capita.* That novel metric might be useful for comparing how change occurs within different societies, but it's a misleading way to compare different technologies' contributions to reducing greenhouse gas emissions. Such decarbonization depends on technologies' total TWh supplied (or saved), not on the populations of their host countries. Absolute comparisons decisively show renewables outpaced nuclear.

A 2016 *Science* Policy Forum article by Junji Cao, Armond Cohen, James Hansen, Richard Lester, Per Peterson, and Hongjie Xu [9] illustrates the confusion caused by substituting per-capita for absolute metrics of growth in electricity production. We now clarify this issue, both to correct a widespread error and to suggest proper methodology.

Cao et al. use both absolute and per-capita metrics. They claim their

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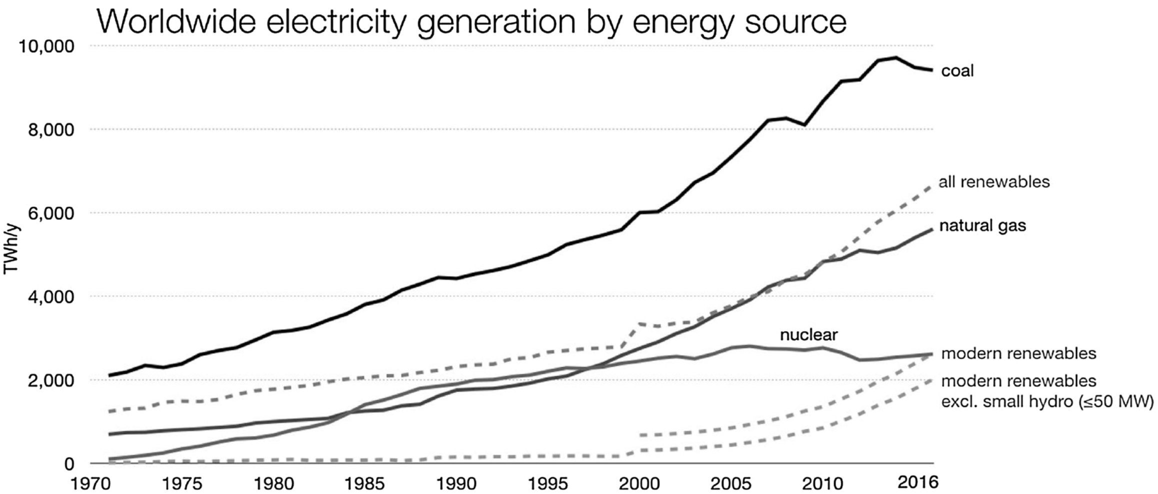

Fig. 1. Despite starting decades later, modern renewables' electricity output passed nuclear's in 2016, and has recently grown faster than nuclear output did in its heyday. "All renewables" include big hydropower (> 50 MW); "modern renewables" include only small hydro (≤ 50 MW). These best-available data, with annual rates of change, are detailed in Supplementary materials.

per-capita metric shows nuclear power in its prime grew far faster than renewables did later. A critique [10] notes seven assumptions biased against renewables. Cao et al.'s response [11] retains all seven, defends two, ignores five, and overlooks that a part of their own analysis using an absolute metric refutes their thesis, as we explain next.

2.2. *Different metrics give different answers*

Cao et al. agree that decarbonization requires renewable energy too, but denigrate its prospects using two graphs. Their first graph S1 shows that wind, solar, geothermal, and biomass produce only tiny fractions of four countries' total primary *energy* use—not surprisingly, since modern renewables produce 12% of global *electricity* [12], which in turn is just one-fourth of primary energy. Yet on close inspection, graph S1 also contradicts their second graph S2′s conclusion that nuclear power grew "much faster" than renewables. Rather, S1 shows nuclear power grew *more slowly* than the sum of two kinds of modern renewables (solar photovoltaics and windpower) for two of their four countries through 2014, three through 2015, and a different three with subsequent 2016 data [13]. Cao et al. don't recognize or admit this contradiction.

Instead, their second graph S2 switches to a per-capita metric so they can compare (Ref. [11] with emphasis added) "decarbonization performance of *countries* with different populations" using nuclear, solar, or windpower. "Historically," they assert, "the fastest growth of low-carbon power occurred during scale-up of national nuclear power programs" (eight nations during 1975–91, contributing to the nuclear growth phase we graph in Fig. 1 above, plus South Korea in 1995–2005). Yet contrary to our Fig. 1's global data, Cao et al.'s second graph S2 purports to show faster nuclear growth by applying a per-capita metric to 14 specific jurisdictions, chosen to support their thesis while omitting at least four well-known examples that sharply contradict it (Supplementary materials, pp. 6–8).

Even overlooking this improper cherry-picking, their per-capita metric yields strange results. Swedish nuclear power (which in 1976–86 grew 4.4× to 70 TWh/y) is shown as scaling 55× faster than Chinese windpower (which in 2004–14 grew 124× to 158 TWh/y)—because Sweden's population averaged 1/158th of China's. Conversely, China's unique addition in less than a decade (through 2016) of 25% of global solar photovoltaic (PV) and 35% of global windpower capacity is shown as the *slowest* national achievement—an odd description of the nation that in 2016 added over 40% of new global renewable electric capacity—because it's divided by 1.4 billion Chinese, of whom 0.3% or 4.25 million, half Sweden's population, directly or indirectly did that work [14]. Of Cao et al.'s nine nuclear countries, three (Slovakia, Belgium, Sweden) have < 10 million people and another (Taiwan) has < 20 million, exaggerating their per-capita nuclear growth rates, *vs.* one small population (Denmark) among eight shown for renewables. US population growth makes its windpower growth look 21% slower vis-à-vis US nuclear growth 23 years earlier. (Conversely, shrinking population, as in Japan, would boost the renewable metric.) And though all three nations (US, Japan, Germany) included in both datasets forced, subsidized, and got more nuclear than renewable growth, does faster per-capita growth from, say, French nuclear than Danish windpower really tell us something useful about those technologies, or more how those countries make energy policy?

2.3. *Switching metrics in midstream*

Ignoring such puzzles, Cao et al.'s Supplementary materials [13] jump from comparing *countries*' deployments per capita to a false generic conclusion about *technologies*:

> The available evidence does not support the notion that nuclear is inherently slower than renewables when it comes to scale-up of low-carbon electricity. Indeed, until now only nuclear power has delivered the sustained high rates of low-carbon electricity growth that will be needed to meet deep decarbonization goals by mid-century.

In fact, the evidence they cite shows a biased selection of per-capita *country* comparisons. Ref. [11] then misrepresents those as "evidence" of *technologies*' relative "actual deployment rates" meriting more nuclear investment. Yet the authors' own graph S1 shows their conclusion is untrue *even within the same country*—China—where solar and windpower, or even windpower alone [15], outpaced nuclear growth. The same occurred for Germany and India (plus subsequently the US through 2016). Cao et al. conceal this by showing in graph S2 renewable but not nuclear growth for China, neither for India, and both for Germany but with just 72% of its renewable growth, so only detailed data-diving reveals the contradiction.

2.4. *Further analytic distortions*

Even their per-capita analysis is flawed. It compares nuclear output with solar and windpower alone—just 45% of modern renewables' 2015 global output—although the authors' graph S1 also includes geothermal and biomass. Neither graph includes small hydro, as it has "not generally scaled as rapidly as wind and solar and [is] not expected to do so in the future"—but it has in China, as we'll show. Cao et al. compare net renewable output sent to the grid with gross nuclear