Article

Climate "Code Red" at COP26 and the Diversification of Decarbonization Narratives

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Abstract

The 26th meeting of the Conference of the Parties (COP26) confirmed a watered-down commitment to phase out coal and pursue decarbonization. The agreement is deemed unlikely to achieve a 1.5 degree celsius scenario, notwithstanding evidence that climate change is accelerating. This paper asks why the COP26 meeting avoided serious discussion of critical minerals and nuclear energy, in spite of their enormous and growing importance in decarbonization. We conclude that reality is likely to diversify narratives of decarbonization pathways and reduce the 100% renewable definition of what is desirable and feasible.

Introduction

Between October 31 and November 13 of 2021, the 26th meeting of the Conference of the Parties (COP26) met in Glasgow, UK, to deliberate on climate goals.[1] Animating the agenda was the initial IPCC AR6 report on the physical science basis, released on August 9, 2021.[2] The IPCC report provided the scientific context against which decarbonization narratives clashed. The good news was that virtually all major stakeholders agreed on the need for accelerated decarbonization, though of course there are myriad narratives on how decarbonization can and should be achieved. In this paper we shall examine the assertion that global power generation and mobility – currently heavily reliant on coal and other fossil fuels[3] – can be transformed into 100% renewable energy (RE) largely via solar, wind, bat-

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1) The details concerning COP26 can be found at the United Nations Climate Change site: https://unfccc.int/conference/glasgow-climate-change-conference-october-november-2021

2) See "Climate Change 2021: The Physical Science Basis, Working Group 1, IPCC, August 9, 2021: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

3) For example, global power generation in 2020 was 61.3% fossil fuels, 16% hydropower, 10.1% nuclear, followed by 5.9% wind power, and 3.2% solar, with the remainder comprising other renew-

tery storage and electric vehicles (EV). Hereafter we refer to this narrative – which is powerful within the EU countries, North America, and Japan – as "100% RE/EV," and contrast it with arguments that nuclear power has to be part of the decarbonizing energy mix.

Returning to the IPCC report, it posed – as UN Secretary-General António Guterres put it – a "code red for humanity."[4] The report showed that 2019 atmospheric concentrations of CO2 were at their highest over the past 2 million years, with methane and nitrous oxide levels exceeding their highs over the previous 800,000 years. The report deemed that the human-caused share of these concentrations of greenhouse gases (GHGs) was already responsible for 1.1 degree of warming. The evidence also indicates that warming is virtually certain to exceed 1.5 degrees over the coming 2 decades. The report's language was unprecedentedly blunt. In contrast to previous, qualified reports, AR6 stated that "[i]t is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred."[5]

One strong indicator of how serious the climate challenge has become was evident in the sudden emergence of a Global Methane Pledge, a centrepiece of COP26. The Pledge is a commitment to slash methane emissions by 30% compared to 2020 levels. Over 100 countries adopted the Pledge, representing 70% of global GDP and half of global methane emissions. Though methane is well-known to be a greenhouse gas, its rapid increase in concentrations and reevaluations of its impact have made it a focus of high-level action. As we see in figure 1, AR6 deemed methane emissions to be responsible for roughly 30% of anthropogenic warming.

Even so, the COP26 did not result in binding commitments to methane reductions. Indeed, though agriculture is the source of between 40% to 53% of anthropogenic methane emissions, it was not on the agenda at COP26. Nor did China and India adopt the Global Methane Pledge. The latter country's reason for not adopting the Pledge was explained by Shashi Tharoor, former U.N. undersecretary-general and former Indian minister of state for external affairs and minister of state for human resource development. Now a member of

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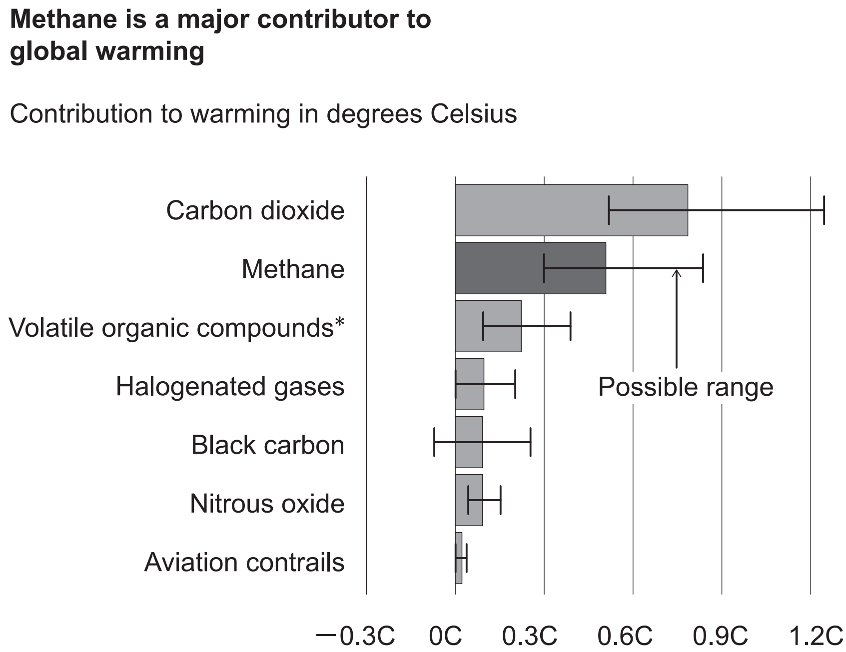
ables. See "World Electricity Generation," World Energy Data, December 2021: https://www.worldenergydata.org/world-electricity-generation/

4) Quoted in Marcus Kauffman, "IPCC report: 'Code red' for human driven global heating, warns UN chief," *UN News*, August 9, 2021: https://news.un.org/en/story/2021/08/1097362

5) See item A.1 in IPCC, "Headline Statements from the Summary for Policymakers," Intergovernmental Panel on Climate Change, August 9, 2021: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Headline_Statements.pdf



Figures are for contributions to 2010–2019 warming relative to 1850–1900
*Volatile organic compounds and carbon monoxide
Source: IPCC Sixth Assessment Report 2021
Source: McGrath, 2021[6)]

Figure 1 Methane and global warming

parliament, Tharoor pointed out that "because of India's high dependence on agriculture, which engages nearly two-thirds of its population and its vast number of cattle, the country did not sign the global deal announced at COP26 to reduce methane emissions."[7)]

The result is that the Pledge's impact is almost certain to be limited, even though strong action on methane is imperative and could lead to significant mitigation in the short run. Indeed, the 2021 Global Methane Assessment[8)] called for a 45% reduction in methane emissions by 2030, in order to keep warming below 2 degrees.[9)]

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6) Matt McGrath, "COP26: US and EU announce global pledge to slash methane," *BBC News*, November 2, 2021: https://www.bbc.com/news/world-59137828

7) Shashi Tharoor, "Global coal hypocrisy," *Japan Times*, December 26, 2021: https://www.japantimes.co.jp/opinion/2021/12/26/commentary/world-commentary/ending-coal-use/

8) See "Global Methane Assessment," Climate and Clean Air Coalition (CCAC), United Nations Environment Programme (UNEP), 2021: https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report

9) IEEP, "Agriculture left out of the Global Methane Pledge at COP26," Institute for European En-

Compounding the COP26 problems, no clear commitments were made on coal, the greatest source of GHG emissions. The Glasgow Climate Pact merely agreed on "efforts towards the phase-down of unabated coal power and phase-out of inefficient fossil fuel subsidies."[10] To be sure, this commitment was the first-ever COP agreement to reduce coal consumption, but given the urgency of climate change's "code red," the agreement was widely derided as inadequate and irresponsible. One reason for the inability to adopt very ambitious measures on coal is that India – acting on behalf of many countries in the Asia-Pacific, whose coal dependence is very high – blocked stronger language against coal. The Indians certainly agreed that climate change is accelerating, but they also point out that coal provides 70% of India's power mix. Their argument reflects the reality that the Asia-Pacific region is quite different from the EU, which has ample low-carbon baseload hydro and nuclear power linked together by a continental power-trading grid. The Asia-Pacific does not possess these structural advantages, and it also has to find the means to provide abundant energy to continue industrializing. Concerning these realities, R.R. Rashmi, India's director of the Earth Science and Climate Change programme at The Energy and Resources Institute, noted that "[c]oal is a key domestic fuel for India and is important right now from an energy security point of view. India will need to burn some coal now because it needs to grow and industrialise to lift people out of poverty."[11]

A second reason for the limited goals is that COP26 took place against a backdrop of increasing coal consumption, driven by global economic recovery and the under-performance of solar and wind in key areas of the EU. The International Energy Agency's (IEA) December 17, 2021 report on coal confirmed the trend, warning that global coal use was expected to leap by 9% in 2021, reaching "an all-time high of 10,350 terawatt-hours." Unsurprisingly, the report pointed out that "[i]n China, where more than half of global coal-fired electricity generation takes place, coal power is expected to grow by 9% in 2021 despite a deceleration at the end of the year. In India, it is forecast to grow by 12%. This would set new all-time highs in both countries, even as they roll out impressive amounts of solar

vironmental Policy, November 9, 2021: https://ieep.eu/news/climate-change-and-energy/agriculture-left-out-of-the-global-methane-pledge-at-cop26

10) Rhyannon Bartlett-Imadegawa, "Nations strike climate deal after India-led compromise on coal," *Nikkei Asia*, November 14, 2021: https://asia.nikkei.com/Spotlight/Environment/Climate-Change/COP26/Nations-strike-climate-deal-after-India-led-compromise-on-coal

11) Aathira Perinchery, "'Phase Down' Over 'Phase Out': India's COP26 Coal Stand Necessary, Say Experts," The Wire Science, November 17, 2021: https://science.thewire.in/environment/cop26-india-coal-phase-down-necessary-just-transition/

and wind capacity."[12]

But less well-known was the fact that coal consumption also climbed outside the big Asian countries, as power demand recovered from 2020 lows. For example, German electricity consumption in 2021 increased by 2.6% over the previous year. Over the same period, Germany's 2021 wind output declined by a surprising 16%.[13] Poor performance by both wind and solar saw German reliance on coal power climb, with consumption of both hard coal and low-quality lignite coal up by 18%.[14] In the US, as we see in figure 2, coal consumption increased in favour of more expensive and scarce natural gas. The US Biden Administration had promised to eliminate all carbon emissions from the power sector by 2035, so the nearly 20% increase in coal burning was especially embarrassing. The outlook for coal in the US power sector is for declining use in 2021-22, but that would still leave coal's share in the power mix greater than nuclear. The great irony for the Biden Administration is that "the rise in coal use bucks a downwards trend that endured even during four years under Donald Trump, whose administration promised to revive the American coal industry."[15]

Thus did the EU's dominant narrative of 100% RE/EV run into the inconvenient reality that the EU and other developed regions enjoy significant structural advantages over the Asia-Pacific. As we shall see, the 100% RE/EV also sought to preclude action on nuclear power and critical minerals. This is in spite of abundant and growing evidence that nuclear power is essential for backing up renewables and that critical minerals are crucial to building 100% RE/EV.

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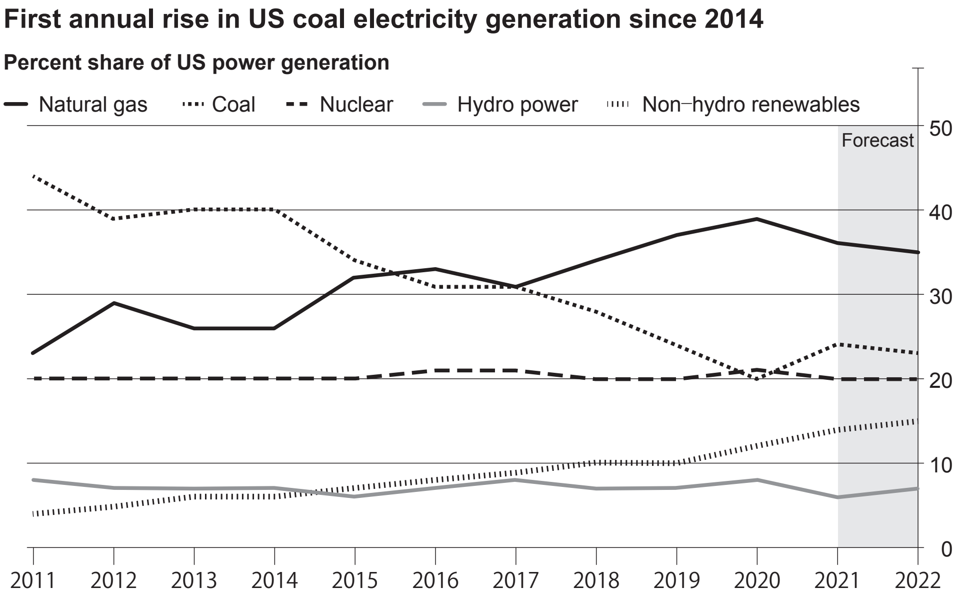
12) See "Coal power's sharp rebound is taking it to a new record in 2021, threatening net zero goals," International Energy Agency's December 17, 2021: https://www.iea.org/news/coal-power-s-sharp-rebound-is-taking-it-to-a-new-record-in-2021-threatening-net-zero-goals

13) Nora Buli and Stine Jacobsen, "Weak winds worsened Europe's power crunch; utilities need better storage," *Reuters*, December 22, 2021: https://jp.reuters.com/article/power-prices-europe-wind-analysis-idCAKBN2J10C9

14) See Benjamin Wehrmann, "Germany's energy consumption rising, renewables share falling in 2021," Clean Energy Wire, December 21, 2021: https://www.cleanenergywire.org/news/germanys-energy-consumption-rising-renewables-share-falling-2021

15) Derek Bower, "US coal use jumps as power generators switch from natural gas," *Financial Times*, November 1, 2021: https://www.ft.com/content/5363e473-c283-4a58-8ded-37358aa7e33b



Source: US Energy Information Administration
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Source: Bower, 2021[16)]

Figure 2　Coal consumption in the US, 2011-2022

The Silence on Nuclear Power and Critical Minerals

As noted, two other very important issues were largely ignored at COP26: the role of nuclear energy in the power mix and the importance of critical minerals for achieving decarbonization through high levels of renewable energy (RE) and electric vehicles (EV). Because both areas are underpin any credible decarbonization pathways, in the wake of COP26 they have dominated specialist debate and become a staple even in mainstream media. But we shall examine that fact later, and first explore why there was inattention.

One clear reason for the inattention to nuclear power was the politicized conviction that it has no future. This perspective is very strong in Europe, parts of North America and Japan, at least among climate activists if not the general public (as we shall see below). One notable and oft-quoted representative of the 100% RE/EV anti-nuclear perspective is *The World Nuclear Industry Status Report*, which annually surveys the global fortunes of nu-

16) Derek Bower, "US coal use jumps as power generators switch from natural gas," *Financial Times*, November 1, 2021: https://www.ft.com/content/5363e473-c283-4a58-8ded-37358aa7e33b

clear energy. In its 2021 edition, the report again declared nuclear too expensive and dangerous to be a solution for decarbonization. It also dismissed new technology as unrealistic. The *Bulletin of the Atomic Scientists* quickly produced a summary of the report, emphasizing that:

> "[a]s of mid-2021, there were 415 nuclear reactors operating in 33 countries, seven reactors more than a year earlier. Their total capacity was 1.9 percent higher than a year earlier. But in 2020, the worldwide nuclear fleet generated 3.9 percent less electricity than in the previous year. That was the first decrease in output since 2012, when many reactors remained shut down in the wake of the Fukushima nuclear disaster.
>
> Without China, where most of the new construction is happening, the decrease in production would look even bigger. In 2020, China for the first time produced more nuclear electricity than France, which relies heavily on nuclear energy. Only the United States produced more." [17)]

As we see in **figure 3**, the report's data on China suggest that the clear desire to dismiss it as an outlier case is misguided. China not only derives a great of decarbonizing power from nuclear energy, but does it a low cost in terms of material inputs.

For one thing, **figure 3** in fact shows that the installed capacity of nuclear in China rose from only 2 GWe in 2000 to 48 GWe in 2020. To be sure, China's installed capacity for producing electricity with wind and solar greatly outpaced nuclear. But interestingly, the same figure shows that China's still moderate share of nuclear capacity in generation capacity overall actually produced a prodigious 345 TWh of electricity in 2020. This amount of power dramatically exceeded the 261 TWh number for solar, even though solar capacity in 2020 was nearly 6 times that of nuclear (254 GWe versus 48 GWe). The key reason for the difference is that generation capacity does not equal actual generation, since solar does not produce power at night or in inclement weather. Yet both wind and solar have enormous critical mineral footprints per GWe of capacity, which means that compared to nuclear power they have very poor efficiency in the use of scarce critical minerals. That patent fact was not addressed in *The World Nuclear Industry Status Report* nor at the COP26.

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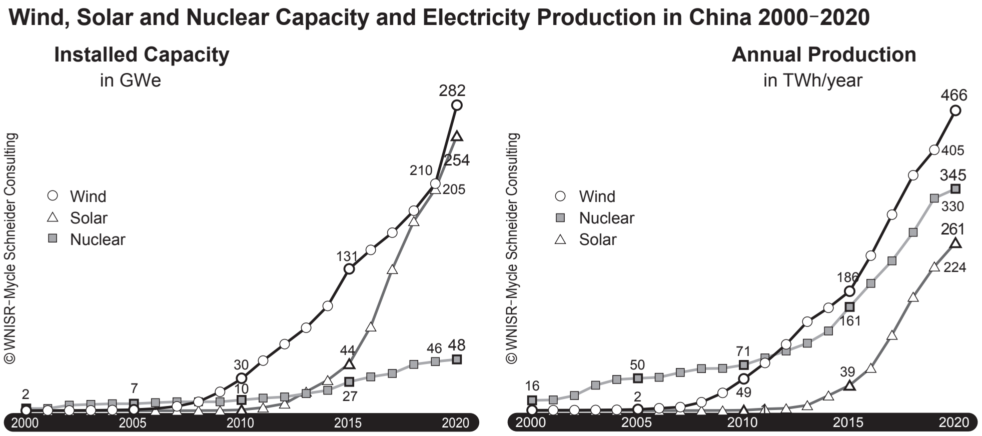
17) Dawn Stover, "Four takeaways from the 2021 World Nuclear Industry Status Report," Bulletin of the Atomic Scientists, October 1, 2021: https://thebulletin.org/2021/10/four-takeaways-from-the-2021-world-nuclear-industry-status-report/



Source: Schneider, et al., 2021[18)]

Figure 3 Decarbonizing power in China, 2000-2020

This lack of serious debate on key issues is lamentable, as China is becoming the global leader in nuclear deployment in addition to increasing its effective use. Even during COP26, *Bloomberg News* reported that China plans to build 150 nuclear reactors over the next 15 years, exceeding what the entire world has installed in the past 35 years. Moreover, China's nuclear investment is expected to be about USD 440 billion, in an unprecedented transformation of its power mix and power technology export portfolio. The article also noted that nuclear's reliability had become especially evident – during COP26 – as renewable output stalled in European countries and power prices climbed. Moreover, the article pointed out that Chinese nuclear is not expensive – contrary to the dominant narrative supporting 100% RE/EV – because interest rates are low, resulting in a cost that is about 1/3 of nuclear in the United States and France.[19)]

Moreover, China is rapidly moving ahead in nuclear technology. The December 21, 2021 *Bloomberg News* discussed this in depth:

"China continues to stake its claim as the world's biggest proponent of new nuclear energy technology, connecting its first small modular reactor to the power grid. China

18) Mycle Schneider, et al., *The World Nuclear Industry Status Report 2021*, September, 2021: https://www.worldnuclearreport.org/IMG/pdf/wnisr2021-hr.pdf

19) Dan Murtaugh and Krystal Chia, "China's Climate Goals Hinge on a $440 Billion Nuclear Buildout," *Bloomberg News*, November 2, 2021: https://www.bloomberg.com/news/features/2021-11-02/china-climate-goals-hinge-on-440-billion-nuclear-power-plan-to-rival-u-s

> Huaneng Group Co.'s 200-megawatt unit 1 reactor at Shidao Bay is now feeding power to the grid in Shandong province, the China Nuclear Energy Association said in a WeChat post. A second reactor is undergoing tests before being connected and putting the plant into full commercial operations in the middle of next year. The plant is the world's first pebble-bed modular high-temperature gas-cooled reactor, heating up helium instead of water to produce power. It's a so-called fourth generation reactor, designed to shut down passively if something goes wrong - in contrast to active systems that may not be able to trigger safety."[20]

In addition, the Chinese are using nuclear power in increasingly innovative ways. For example, Chinese sources report that nuclear's waste heat is being used in local heat networks, and is displacing coal in that roles:

> "Nuclear heating extracts part of the steam generated by the nuclear power unit as the heat source before conducting multi-stage heat exchange through the heat exchanger, and finally transferring the heat to the consumers, explained Zhao Shouxia, senior engineer with Shandong Nuclear Power Co., Ltd. Wu Fang, board chairman of the company, said Haiyang nuclear power unit 1 replaced 12 local coal-powered boilers, cutting 180,000 tonnes of carbon dioxide every winter and drastically lowering the heat emitted to the environment, adding that it can effectively improve the local air quality and marine ecology."[21]

In short, the use of nuclear in China is achieving significant decarbonization and other benefits, at far lower critical mineral costs than a 100% RE scenario.

The 2021 edition of T*he World Nuclear Industry Status Report* was also dismissive about nuclear power in India, even though 70% of India's electricity is mostly generated by coal and needs to be displaced to address climate change. As in China, the challenge of decarbonizing India's emissions-intensive power sector seems likely to require a portfolio of solutions, including nuclear. If climate change is – as the IPCC and UN warn – at a "code-red"

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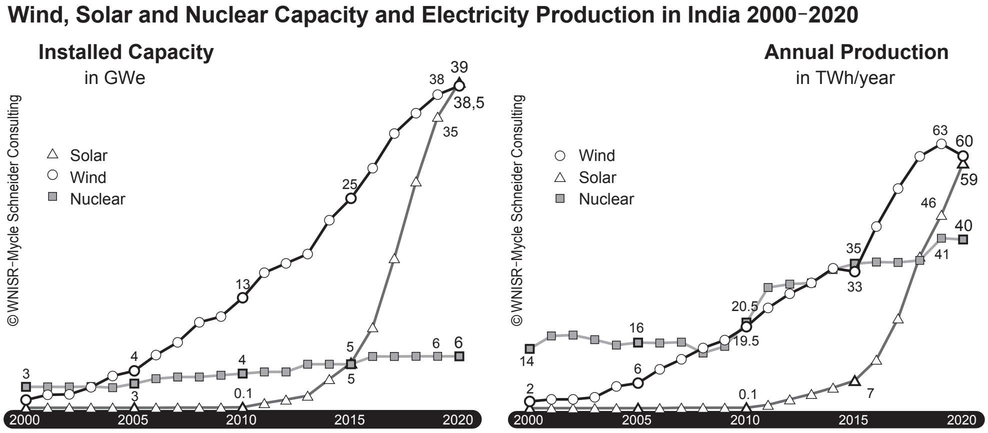
20) "China is Home to World's First Small Modular Nuclear Reactor," *Bloomberg News*, December 21, 2021: https://www.bloombergquint.com/china/new-reactor-spotlights-china-s-push-to-lead-way-in-nuclear-power

21) Xinhua, "Across China: A 'zero-carbon' winter with nuclear heating," Xinhua Net, December 7, 2021: http://www.news.cn/english/2021-12/07/c_1310357420.htm



Source: Schneider, et al., 2021[22]

Figure 4 Decarbonizing power in India, 2000-2020

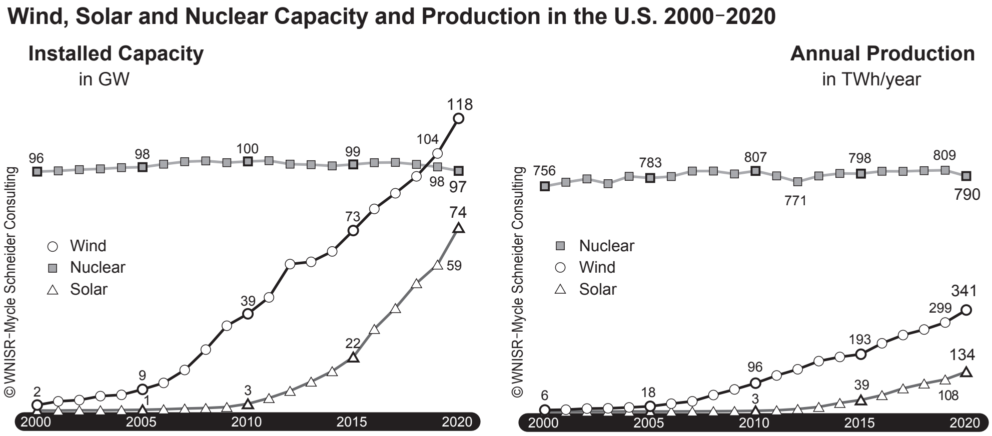
stage, then surely unbiased attention to the data on decarbonization is imperative.

To be sure, figure 4 shows that wind and solar capacity in India grew significantly between 2000 and 2020, whereas nuclear only doubled from 3 GWe to 6 GWe. Yet India generated a lot of power with that low deployment of nuclear, compared to the output from solar and wind. Indeed, in 2020 India had nearly 13 times as much installed wind and solar capacity than nuclear, yet only generated 3 times as much power with it. That appears to be one reason the Indian Government has announced plans to increase the country's nuclear assets from 6.78 GWe at present to 22.48 GWe by 2031.[23]

The United States is also a notable case that confounds the narrative that nuclear has no future and decarbonization will be via 100% RE. As we see in figure 5, that country maintained over 90 GWe of nuclear from 2000 to 2020. That amount was about 1/3 of total global nuclear capacity. Over the same period the deployment of solar and wind capacity grew to exceed nuclear, achieving a total of 192 GWe. Yet the actual amount of power generated by nuclear was an impressive 790 TWh in 2020 (about half of America's low-carbon power), compared to 341 TWh for wind and 134 TWh for solar.

22) Mycle Schneider, et al., *The World Nuclear Industry Status Report 2021*, September, 2021: https://www.worldnuclearreport.org/IMG/pdf/wnisr2021-hr.pdf

23) See "Nuclear reactor close to Delhi among 9 new ones by 2024: Govt to RS," *The Times of India*, December 3, 2021: https://timesofindia.indiatimes.com/india/nuclear-reactor-close-to-delhi-among-9-new-ones-by-2024-govt-to-rs/articleshow/88060770.cms



Source: Schneider, et al., 2021[24)]

Figure 5 Decarbonizing power in the United States, 2000-2020

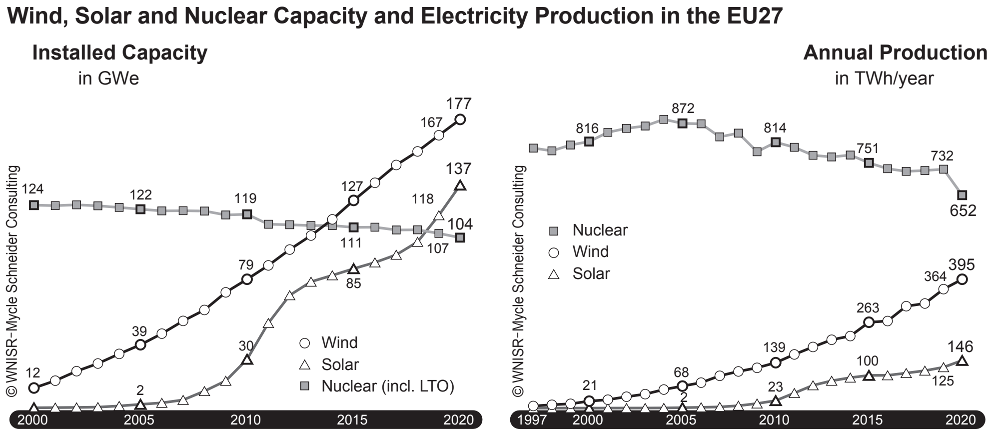
Moreover, even before COP26 the Biden Administration conceded that nuclear was essential to decarbonization. Thus the Administration's infrastructure investment bill earmarked USD 6 billion to support nuclear assets' competitiveness in the face of cheap natural gas and other alternatives. As *Bloomberg News* pointed out on August 2, 2021, "[t]he Biden administration has said maintaining the nation's fleet of nuclear power is needed to help meet its ambitious climate goals, which include a carbon-free electric grid by 2035, and a carbon-free economy by 2050. Another proponent of incentives for nuclear reactors is Senator Joe Manchin, the West Virginia Democrat who is chairman of the Senate Energy and Natural Resources Committee and who serves as a powerful swing vote."[25)]

In addition, as China's nuclear ambitions expand, policymakers in the United States are reassessing their country's opportunities. They do not want to lose leadership in a major area of clean power. Indeed, the competition is extending to nuclear fusion, no longer considered a "pipe dream."[26)] The fact is "[f]rom a climate perspective, nuclear and renewables are not in competition. There will be enough growth in electricity demand to support significant expansion of every zero-carbon power generation technology. Some of that expansion could

24) Mycle Schneider, et al., *The World Nuclear Industry Status Report 2021*, September, 2021: https://www.worldnuclearreport.org/IMG/pdf/wnisr2021-hr.pdf

25) Ari Natter and Will Wade, "Nuclear Plants to Get $6 Billion Lifeline in Infrastructure Deal," *Bloomberg News*, August 2, 2021: https://www.bloomberg.com/news/articles/2021-08-02/nuclear-plants-targeted-for-6-billion-lifeline-in-senate-bill

26) Andy Ridgway, "Why the promise of nuclear fusion is no longer a pipe dream," *Science Focus*, December 3, 2021: https://www.sciencefocus.com/future-technology/fusion-power-future/



Source: Schneider, et al., 2021[27)]

Figure 6 Decarbonizing power in the EU27, 2000–2020

even come from fusion, as the investors who recently placed $1.8 billion into Commonwealth Fusion Systems hope.[28)]

The nuclear profile of the EU27 was also discussed in the 2021 edition of *The World Nuclear Industry Status Report*, as we see in figure 6.

The figure shows that nuclear in the EU27 declined from 124 GWe in 2000 to 104 GWe in 2020, increasingly exceeded by wind and solar from about 2014–15. Even so, nuclear power remained the key provider of actual power generation, its 652 TWh in 2020 dwarfing the 395 TWh of electricity derived from wind and 146 TWh of solar in the same year.

Diversifying Narratives in the EU27

Even though COP26 did not discuss nuclear in any depth, it clearly weighed on many minds. In the wake of the conference, attention turned to the EU green taxonomy and whether or not to include nuclear as green. France, Poland, and several other EU27 countries are quite aggressive in the efforts to get nuclear included, because it is a reliable source of decarbonizing power and the Chinese are making such headway. However, the Germans and the Austrians are deeply opposed to including nuclear in the green taxonomy, particularly as

27) Mycle Schneider, et al., *The World Nuclear Industry Status Report 2021*, September, 2021: https://www.worldnuclearreport.org/IMG/pdf/wnisr2021-hr.pdf

28) Nathaniel Bullard, “The year in Review: Ten Charts,” *Bloomberg News*, December 16, 2021: https://www.bloomberg.com/news/articles/2021-12-16/the-year-in-review-ten-charts

the latter are committed to leaving nuclear by the end of 2022. As *Reuters* pointed out on December 17, "France wants to be able to attract green finance to fund the construction of new nuclear power plants in France, while Germany is phasing out nuclear and keen on switching to gas – a fossil fuel." [29)]

The EU thus put off a decision on "green" nuclear until January of 2022, but as of this writing seemed likely to rule in favour.[30)]

There is a long background to this concern about including nuclear in the taxonomy. As the English-language version of Japan's *The Mainichi* discussed on December 18, 2021:

> "[t]wo years ago, EU leaders agreed that nuclear could be part of the bloc's solution to making its economy carbon neutral by 2050. Leaving the possibility of using nuclear energy in their national energy mixes reassured the bloc's coal-reliant countries, which are expected to suffer the most during the transition.
>
> However, making future nuclear power projects eligible for billions in euros available as part of the European Green Deal while avoiding 'greenwashing' remains a controversial issue.
>
> Countries that want nuclear power to remain ineligible for green financing often cite the EU's guidance that all investments financed by the pandemic recovery fund should not harm the bloc's environmental goals.
>
> 'The lack of agreement shows how lively this is, not only in our country, but throughout Europe,' Belgian Prime Minister Alexander De Croo, who faces a domestic crisis over how to phase out nuclear plants and still maintain energy security to his citizens.
>
> De Croo suggested that amid the energy price crunch, nuclear energy and gas could be temporarily eligible for funds.
>
> 'You have to be able to look sufficiently ahead, and if you do so you can assume that technologies like nuclear and gas can be useful technologies in the medium term to bridge the gap until we have fully sustainable energy,' De Croo said early Friday [December 17]." [31)]

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29) Stephane Mahe, "France, Germany to look for gas, nuclear energy compromise – Macron," *Reuters*, December 17, 2021: https://www.reuters.com/world/europe/france-germany-look-gas-nuclear-energy-compromise-macron-2021-12-17/

30) On this, see Jillian Deutsch, "EU Likely to Put Gas, Nuclear in Green Lists, Commissioner Says," *Bloomberg News*, December 19, 2021: https://www.bloomberg.com/news/articles/2021-12-19/eu-likely-to-put-gas-nuclear-in-green-lists-commissioner-says

31) See "EU faces nuclear rift in decision on energy funds, future," *The Mainichi*, December 18, 2021:

A more recent reason for the increasingly bitter politics of nuclear within the EU27 is the very poor performance of German and other EU27 renewables in 2021, contributing to massive price spikes in the power sector. In its December 22, 2021 summary, the data service Refinitiv reported that "Europe's largest wind producers Britain, Germany and Denmark harnessed just 14% of installed capacity, in the third quarter, when gas prices hit record highs, compared with an average of 20-26% seen in previous years."[32] Thus the 100% RE/EV vs nuclear debate has become quite politically and emotionally charged, leading to myriad articles in the global quality press such as the *Financial Times, The Wall Street Journal, The New York Times*, the *Washington Post, Bloomberg News*, and other media. In addition, past news coverage – with the exception of *The Wall Street Journal* – tended to dismiss nuclear as too costly and dangerous. But as concern about the pace of climate change has grown, along with doubts about the scalability of wind and solar, so too has the appreciation for nuclear's decarbonizing role.

A notable example is the *Washington Post.* On December 18, it carried an article that cited French experts on their concern that "Germany's anti-nuclear stance and continued reliance on fossil fuels are at odds with its self-image as a leader on climate…[and that]…Germany is largely responsible for an air pollution death toll that amounts to 'multiple Chernobyls every year.'" The article continued with the assertion that "Germany emits about twice as much carbon dioxide per capita as France does. When it phases out its last nuclear power plants next year, it will be forced to rely on coal and other polluting energy sources to fill much of the gap for years — which helps explain why the country continues toraze villages to make way for coal mines."

The article added that a "new generation of cheaper, safer and smaller nuclear reactors – known as small modular reactors, or SMRs – is reawakening interest in parts of Europe, in the United States and elsewhere. 'The terms of the conversation around nuclear energy in Europe are changing,' E.U. Energy CommissionerKadri Simsonsaid in a speech in November. France's export hopes largely rest on those small models, which would compete with SMRs being developed by the United States, Britain and Canada. 'The small modular reactors that are coming in the next decade all guarantee high safety,' said Renaud Crassous, the director of EDF's small nuclear reactor project. He expressed hope that skeptical coun-

https://mainichi.jp/english/articles/20211218/p2g/00m/0in/018000c

32) See "Inside Commodities," Refinitiv, December 22, 2021: https://share.refinitiv.com/assets/newsletters/Inside_Commodities/IC_12222021.pdf

tries could be swayed by the novel technology to regain trust in nuclear energy."[33)]

The emphasis on safety seems quite deliberate. Comparative opinion polls of European countries and the United States released on December 13, 2021 showed that publics in all countries support nuclear more than they oppose it. Even in Germany, 53% of poll respondents agreed that nuclear should be used while only 28% were opposed. The highest level of opposition to nuclear was recorded in Denmark, at 37%, but even there 40% of respondents believed nuclear to be necessary for decarbonization.[34)] Yet the poll also found a great deal of concern about nuclear safety.

While safety concerns are being addressed, the EU27 are also confronting the need to expand nuclear to bolster the reliability of low-carbon power sources. *Bloomberg News* highlighted this fact on December 16, 2021, at a time when EU27 power and energy prices were skyrocketing:

> "[t]he French nuclear fleet is a crucial round-the-clock source of power not just nationally but at peak times in markets such as Germany, Italy and Britain. Plant availability was already low as the pandemic delayed works on some reactors, and now EDF is halting two units and extending stoppages at two others after discovering a fault at a plant during regular maintenance."[35)]

Subsequent moves by EU27 governments have confirmed this turn to building up nuclear capacity as opposed to simply let nuclear decline. This shift to expansion is contrary to the narrative in the 2021 edition of *The World Nuclear Industry Status Report.* A December 15, 2021 report on Holland's policies was one example:

> "the Netherlands' new coalition government has placed nuclear power at the heart of its climate and energy policy. Some EUR500 million (USD564 million) has been ear-

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33) Rick Noack, "Is nuclear energy green? France and Germany lead opposing camps," *Washington Post*, December 18, 2021: https://www.washingtonpost.com/world/2021/12/18/nuclear-energy-climate-france-germany/

34) Matthew Smith, "What do Europeans and Americans think about nuclear energy?" YouGov, December 13, 2021: https://yougov.co.uk/topics/international/articles-reports/2021/12/13/what-do-europeans-and-americans-think-about-nuclea

35) Rachel Morison and Jesper Starn, "Europe Faces Dire Winter as Nuclear Outages Deepen Energy Crunch," *Bloomberg News*, December 16, 2021: https://www.bloomberg.com/news/articles/2021-12-16/eu-power-markets-face-precarious-january-as-supply-risks-mount

marked to support new nuclear build in the period to 2025.

It anticipated that cumulative support for new nuclear power stations would reach more than EUR 5 billion by 2030 which is likely to still be in the construction period for the plants. A date for revenue service for the reactors has not been set.

The preparations for the construction should start in two-to-three years according to Dutch English language media reports. The existing nuclear power plant in Borssele will initially remain open longer.

The Borssele 485 MWe nuclear power plant was built by Siemens in 1973. It was built to supply electricity to an aluminum smelting facility that for many years used two-thirds of the output of the power plant. In July 2011 Borssele began burning MOX fuel. It provides about 3% of the country's needs for electricity.

The new power stations are anticipated to be used for the production of electricity and hydrogen. By building new nuclear power stations, the Netherlands will also become less dependent on gas imports in terms of energy. The plants will coordinate their power production with renewable sources like solar and wind."[36)]

The Dutch initiatives are consistent with Chinese and other countries' efforts not only to maintain or increase nuclear energy's share of the power mix, but also to expand its role as a means of decarbonization. We see this in the Dutch plans to use nuclear to produce hydrogen in addition to baseload backup for intermittent renewable energy such as solar and wind. The need for accelerated decarbonization coupled with the Chinese lead on nuclear innovation clearly drove a shift in many countries' policymaking during 2021, a shift that is virtually certain to accelerate in 2022 and subsequent years. Even so, the the 100% RE/EV narrative insists that nuclear is not decarbonizing, is too expensive, and too dangerous to use against climate change. It is lamentable that these points were not confronted at COP26. So let us examine below what the best scientific studies suggest concerning nuclear power's past, present and future role as a decarbonizing energy source in addition to its low material-intensity and other possible merits (eg, low land requirement). To this end, we shall examine the most recent analyses by the IEA, UN, OECD, and other sources. Where applicable, we shall compare this work with recent anti-nuclear studies, in order to determine whether the 100% RE/EV narrative is built on scientific evidence.

36) "Dutch Govt Commits to Build Two New Nuclear Reactors," Neutron Bytes, December 18, 2021: https://neutronbytes.com/2021/12/18/dutch-govt-commits-to-build-two-new-nuclear-reactors/

Comprehensive Evidence

We have seen that there are good reasons to question the anti-nuclear narrative detailed in the 2021 edition of *The World Nuclear Industry Status Report.* A more reliable source of information on nuclear power and its role in decarbonization is found in the September, 2021 OECD/NEA report to the G20 on “Nuclear Energy in the Circular Carbon Economy.”[37] The report presented the data on nuclear power’s performance in various power mixes in addition to its decarbonizing contribution. The report was virtually ignored by the news media and organizations promoting the 100% RE/EV narrative.[38] As we see in **figure 7**, nuclear power plays an especially strong role in France, accounting for over 70% of actual power generation in 2018. The Slovac Republic and several other Easter European countries follow, with over half of the electricity from nuclear. Other notable cases include climate-leader Sweden, with nuclear providing about 40% of its power.

This volume of nuclear generation strongly contributes to decarbonizing the power sector (and primary energy in general, as nuclear is increasingly used for producing hydrogen and heat for district energy systems). The evidence is seen in **figure 8**, which compares the average lifecycle emissions of generation technology. These calculations include the carbon emissions involved in mining and processing the material for building capacity, and not just the fuel used to generate fossil or nuclear power. The resulting calculation shows that nuclear is on par with wind, at 12 grams of CO2 for each kWh of power generated.

This level of carbon emissions from nuclear is well below solar and hydro. But the differences between nuclear and renewables are in fact trivial compared to the 820 grams/kWh from coal and 490 grams/kWh from gas. Yet it is important to highlight nuclear’s emissions in a comparative light, as the December 13, 2021 poll of the United States and several European countries found that “[s]ignificant minorities – including a majority of people in Spain – believe that nuclear energy produces either moderate or high levels of carbon emissions. One in three Americans (36%) are also convinced that nuclear energy produces size-

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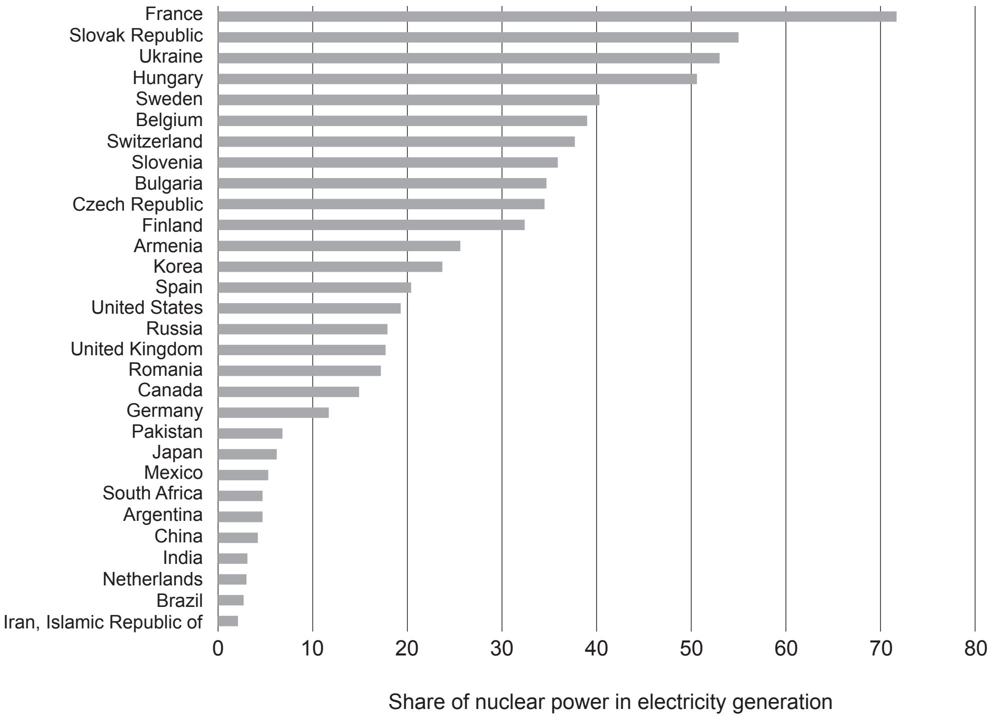
37) OECD/NEA, “Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20,” OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf

38) The present author’s searches of various databases reveal no citations of the report outside of the nuclear industry and related associations (eg, the American Nuclear Society).



Source: OECD/NEA, 2021[39)]

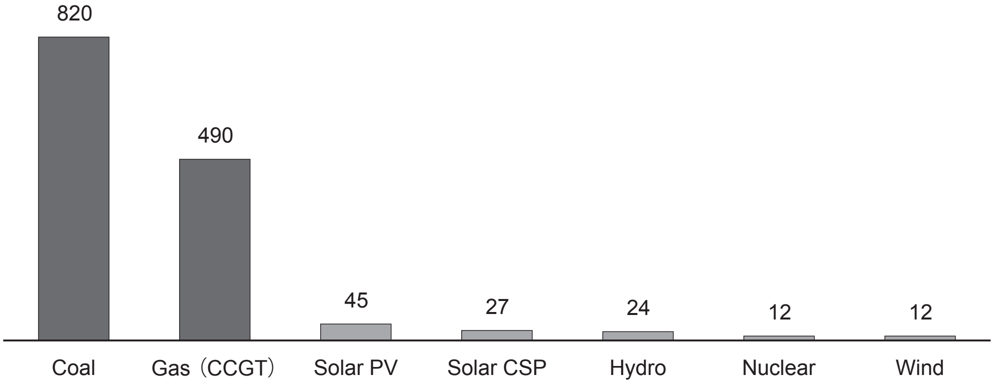
Figure 7 Comparative shares of nuclear power in electricity generation, 2018

able carbon emissions." [40)]

One reason for the confusion on whether nuclear is as low-carbon as renewable energy is that anti-nuclear groups routinely overstate emissions from nuclear power. Moreover, they generally get a pass on this from much of the media. For example, the November 29, 2021 edition of *Deutsche Welle* published a widely disseminated article on whether nuclear is decarbonizing or not. Ignoring the OECD/NEA report to the G20, citied above, the article included a claim that "[s]tudies that include the entire life cycle of nuclear power plants, from uranium extraction to nuclear waste storage, are rare, with some researchers pointing out that data is still lacking. In one life cycle study, the Netherlands-based World Information

39) OECD/NEA, "Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20," OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf

40) Matthew Smith, "What do Europeans and Americans think about nuclear energy?" YouGov, December 13, 2021: https://yougov.co.uk/topics/international/articles-reports/2021/12/13/what-do-europeans-and-americans-think-about-nuclea



Source: OECD/NEA, 2021[41)]

Figure 8 Comparative lifecycle emissions of electricity generation

Service on Energy (WISE) calculated that nuclear plants produce 117 grams of CO2 emissions per kilowatt-hour. It should be noted, however, that WISE is an anti-nuclear group, so is not entirely unbiased.”[42)]

Yet high-level and actually unbiased scientific evidence shows that the WISE study is not just “not entirely unbiased,” but in fact quite biased. The WISE study is also quite dated, being released in 2017, and does not include comparative assessments of the lifecycle cost of mining and processing the copper, lithium, and other critical minerals needed in solar and wind generation, let alone the back-up battery and other systems they require.[43)]

Even though the *Deutsche Welle* article alluded to the possibly compromised objectivity of WISE, it still used the organization's data to produce a comparative chart on lifecycle emissions. And the article followed up with even more questionable data. It asserted that “[a]ccording to new but still unpublished data from the state-run German Environment Agency (UBA) as well as the WISE figures, nuclear power releases 3.5 times more CO2 per kilowatt-hour than photovoltaic solar panel systems. Compared with onshore wind power, that figure jumps to 13 times more CO2. When up against electricity from hydropower in-

41) OECD/NEA, “Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20,” OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf

42) Joscha Weber, “Fact check: Is nuclear energy good for the climate?,” *Deutsche Welle*, November 29, 2021: https://www.dw.com/en/fact-check-is-nuclear-energy-good-for-the-climate/a-59853315

43) See Jan Willem Storm van Leeuwen, “Climate change and nuclear power: An analysis of nuclear greenhouse gas emissions,” World Information Service on Energy (WISE) Amsterdam, The Netherlands, 2017: https://wiseinternational.org/sites/default/files/u93/climatenuclear.pdf

stallations, nuclear generates 29 times more carbon."[44)]

Because the UBA data are unpublished, it is impossible to assess their assumptions about the environmental cost of mining materials for nuclear in comparison with other technologies. We do not know if the UBA included the emissions cost of mining and processing critical minerals for wind, solar and other renewable energy in addition the network infrastructure they require. But we do know that the UBA results are very much at odds with IPCC, OECD/NEA, and other assessments. Indeed, the UBA data are quite different from new and readily available data available from the European Commission's highly respected Joint Research Commission（JRC）. The JRC undertook a detailed study of lifecycle costs of nuclear power, releasing their results in September 2021, finding that nuclear's lifecycle emissions are comparable to wind and hydro. The report added that nuclear's impacts in other areas – water, non-CO2 emissions, ozone depletion – are on par with renewables, but that nuclear's land requirements are far below wind and solar.[45)]

In addition, the United Nations Economic Commission for Europe（UNECE）examined the lifecycle carbon produced by all technologies. Its results confirmed the other studies we have seen, and indeed found that that the lifecycle emissions of nuclear power were less than any otherelectricitysource.[46)] Concerning critical minerals, the UNECE report argued that:

> "The resource use indicator characterises the elementary flows of resources extracted from the ground with a coefficient of scarcity. It aims at conveying one dimension of the criticality of materials, namely the supply risk…This coefficient is calculated from the estimated reserves of each element（e.g. gold, copper, chromium…）and compared to that of antimony, hence the unit in kg Sb equivalents. Photovoltaic systems contain slight amounts of gold and silver, used in power electronics, which shows the high score for this indicator as these elements have a factor orders of magnitude higher than copper or alu-

44）Joscha Weber, "Fact check: Is nuclear energy good for the climate?," *Deutsche Welle*, November 29, 2021: https://www.dw.com/en/fact-check-is-nuclear-energy-good-for-the-climate/a-59853315

45）European Commission Joint Research Centre, "Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation（EU）2020/852（'Taxonomy Regulation'），" JRC Science for Policy Report, September, 2021: https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/210329-jrc-report-nuclear-energy-assessment_en.pdf

46）Dimitris Mavrokefaldis, "UN hails nuclear as the lowest carbon electricity source," Energy Live News, November 22, 2021: https://www.energylivenews.com/2021/11/22/un-hails-nuclear-as-the-lowest-carbon-electricity-source/

minium. No rare earth element is accounted for in the characterisation method, and using bulk materials like gravel, iron, and even aluminium barely has no influence on this indicator – which supports the low score of some infrastructure-intensive technologies such as hydropower.

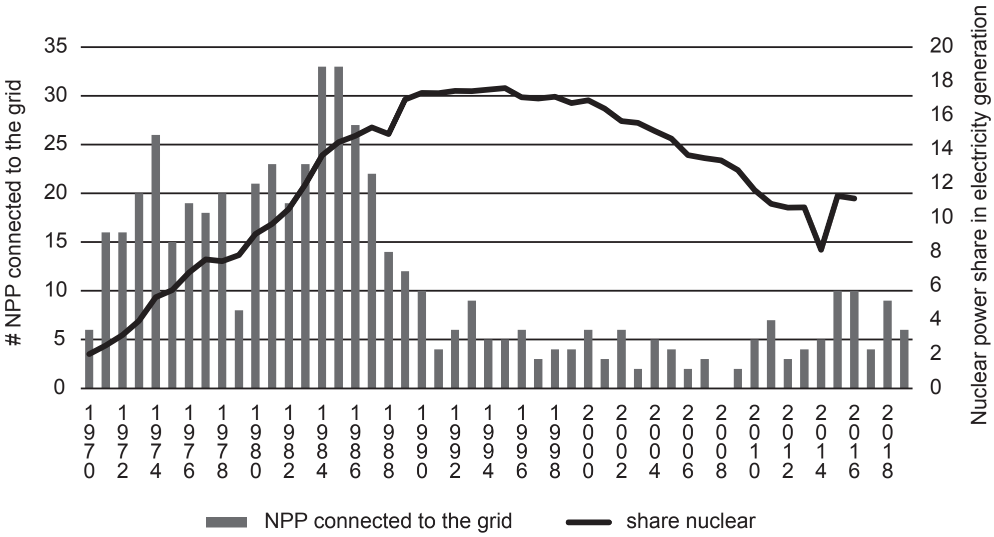
With the "scarcity" caveat in mind, another way to represent resource use is to list the uncharacterised inventory for each technology, i.e. to lump sum the list of materials directly from the life cycle inventories. Figure 47 shows the lifecycle amount of materials required, in g per MWh, using the same selection as International Energy Agency [24], namely: chromium, cobalt, copper, manganese, molybdenum, nickel, silicon, and zinc – to which we choose to add aluminium, given its very low abiotic depletion characterisation factor (i.e. it has virtually no influence on the results in Figure 46). Results exhibit wide disparities between technology. Regarding chromium, concentrated solar power consumes the most of it due to the stainless steel embodied in the infrastructure, namely the solar field for the trough design (300 g/MWh). Wind turbines are relatively steel-intensive and show a demand of 60-70 g of chromium per MWh. All technologies demand aluminium and copper, for infrastructure, connections and cabling. Photovoltaics appear as the most copper-intensive technology of the portfolio, because of electric equipment (general installation, inverter). Copper demand for nuclear appears through the use of copper canisters for high-level waste deep repository disposal and reflects the data sources used for this report."[47]

These publicly available data were available for the *Deutsche Welle* article, but were ignored. That failure to include reliable JRC and other research results strongly suggests a bias on the part of *Deutsche Welle*, a common feature of media reports and a major reason the YouGov poll found that many people mistakenly believe nuclear power is emissions-intensive.

The OECD/NEA report to the G20 also offers a better summary of where nuclear is likely to go in the future. As we see in figure 9, nuclear peaked at just a little over 18% of total power in the mid-1990s, declining over the years to a low in 2014. Afterwards, its contribution continued a general increase.

The major factors driving the developments in figure 9 are explained thus: "As de-

47) "Life Cycle Assessment of Electricity Generation Options," United Nations Economic Commission for Europe, October 29, 2021: https://unece.org/sites/default/files/2021-10/LCA-2.pdf



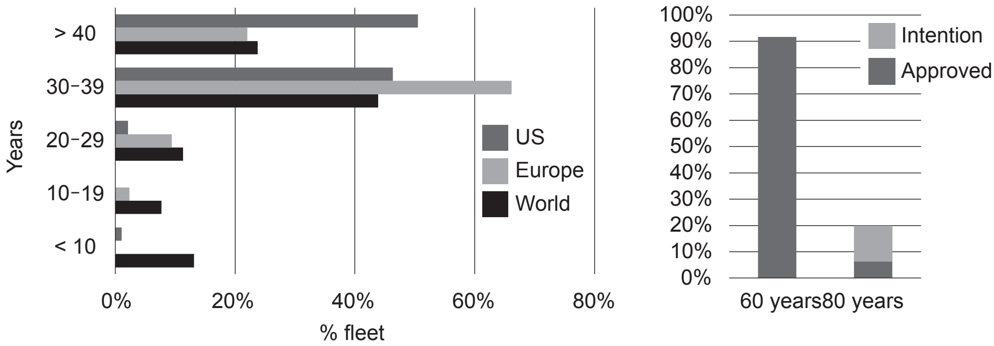
Source: OECD/NEA, 2021[48)]

Figure 9　Nuclear reactor projects, 1970–2018

mand for electricity levelled off and the cost of natural gas-fired generation capacity dropped significantly, nuclear new build activities were significantly reduced during the 1990s. The advance of Gen-III nuclear reactor since the 2000s partly reversed this trend, in particular in China where 37 nuclear reactors (39.6 GW) have been built over the last decade. However, economic and market factors such as the emergence of shale gas in North America and challenges of completing first-of-a-kind (FOAK) projects in several OECD countries, have contributed over the last few years to a reduction in the rate of nuclear new build."[49)] This narrative of advanced nuclear designs coming into play in a contest against gas and as a vehicle for satisfying increasing power demand is supported by empirical evidence.

Figure 10 confirms that ageing of the global reactor fleet is centred in the United States and Europe. Their lack of success in undertaking new build seems to be changing as recent developments suggest. They are also extending the life of existing nuclear plant, thus maintaining a base of decarbonizing nuclear. We also see that Chinese projects compose the majority of plant whose service life is under 10 years. The Chinese advantage is apparently adding to competitor countries' incentives to accelerate the design and deployment of new nuclear.

48), 49) OECD/NEA, "Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20," OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf



Source: OECD/NEA, 2021[50)]

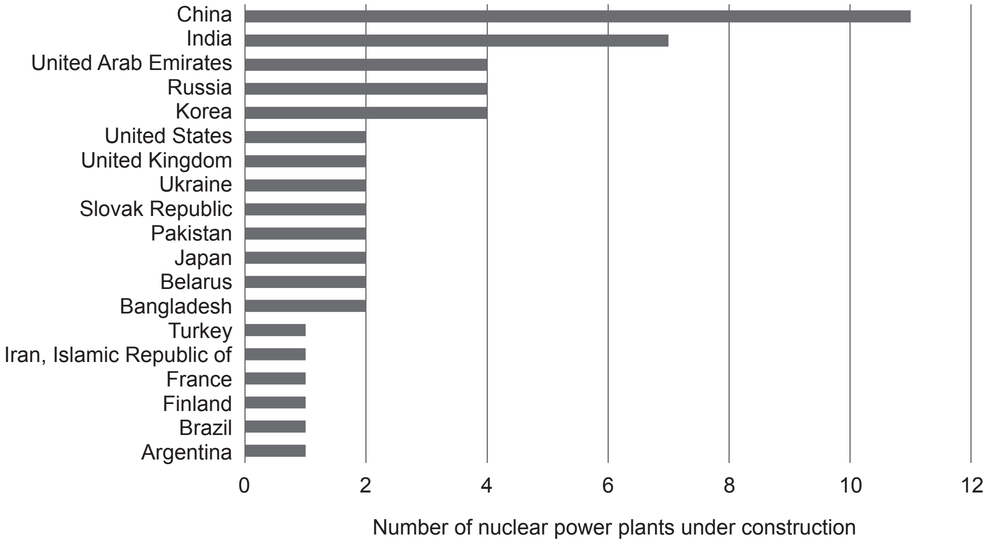
Figure 10 Nuclear reactor age comparisons

Figure 11 provides greater detail on this latter aspect of new plant. It shows that China is undertaking the largest number of new reactors. But it also shows that China is hardly the only country doing so. India's 7 plants (as of 2020) are a significant addition, which we saw earlier is slated for major additional expansion to 2031. And the United Arab Emirates, Russia, and Korea are undertaking multiple projects, followed by a long list of countries doing between 1 and 2 reactors.

Figure 12 also helps put nuclear in perspective by assessing its 2018 contribution to low-carbon electricity in the OECD. The data show that it provided 2,000 TWh compared to the next largest contribution of 1,500 TWh from hydro. Wind, solar, and other renewables were quite far behind. In aggregate terms, nuclear provided 40% of OECD countries' low carbon electricity in 2018. Displacing nuclear would thus require an enormous deployment of renewable capacity just to achieve the decarbonization that nuclear power already contributes. The 100% RE/EV narrative would be more persuasive if it were to address the critical mineral, land, and other constraints that are increasingly impeding the diffusion of wind and solar, in tandem with the battery, transmission, and other networks needed.

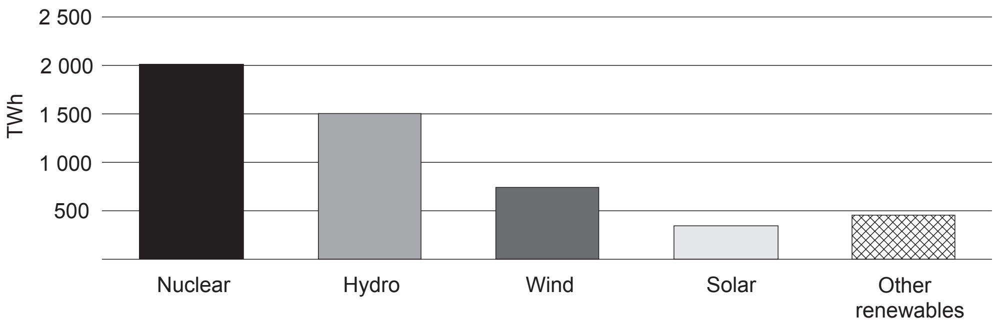
Figure 13 further underscores that point. It reveals that nuclear provides the highest level of decarbonization per GW of generating capacity.

50) OECD/NEA, "Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20," OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf



Source: OECD/NEA, 2021[51)]

Figure 11 Nuclear reactors under construction, 2020

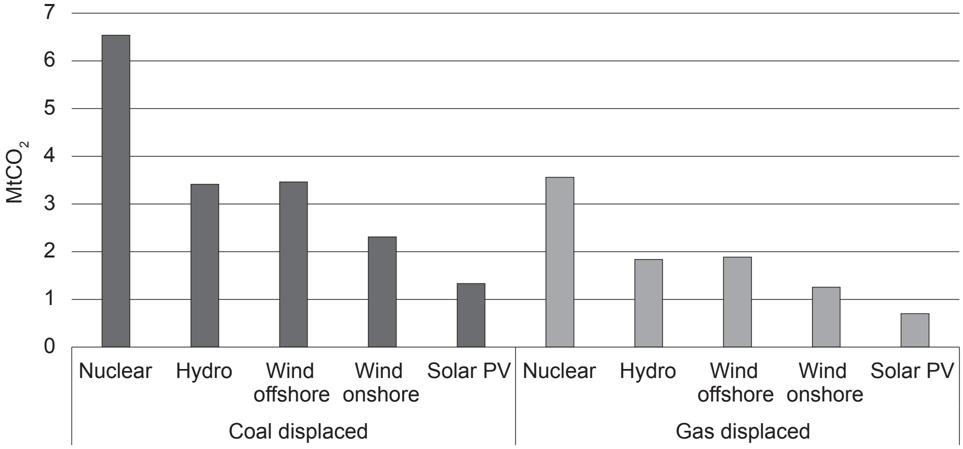


Source: OECD/NEA, 2021[52)]

Figure 12 Low-carbon electricity in the OECD, by source, 2018

Indeed, the decarbonizing contribution is higher than outlined in the figure. This is because the data do not "take into account the need for back-up capacity to support the integration of variable renewables, in particular natural gas in countries with limited hydropower

51), 52) OECD/NEA, "Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20," OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf



Source: OECD/NEA, 2021[53)]

Figure 13 Avoided emissions by power technology, per GW

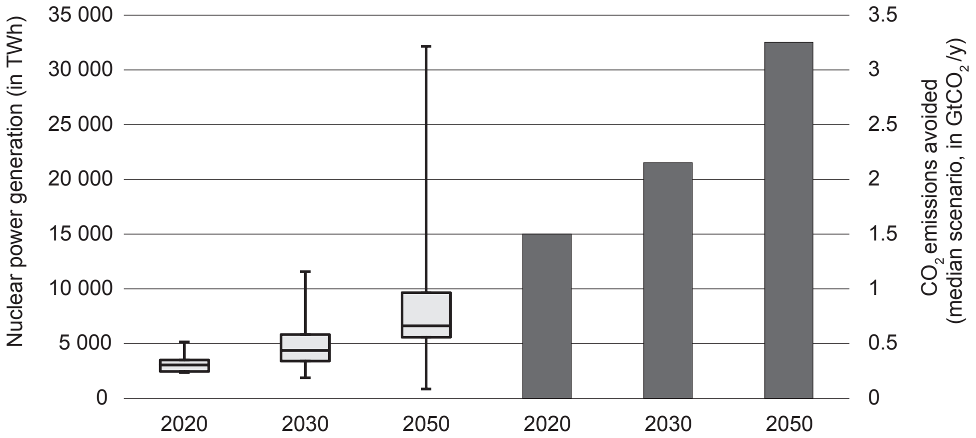
capacity and that do not include nuclear in their mix of low-carbon energy solutions.”[54)] These issues are not an exaggeration. We saw earlier that in Germany and other countries, the back-up for nuclear is coal and gas. And one reason Polish public opinion is greatly in favour of nuclear power projects – 74% versus 20% against – is that they will displace a great deal of coal and gas. The poll, released on December 15, 2021, by the Polish Ministry of Climate and Environment, also indicates that 78% of Poles believe nuclear will help fight climate change and that 82% believe it will enhance the country’s energy security.[55)] These issues are clearly of major import in a country whose power generation in 2020 was 86.7% coal, 7.1% natural gas, and 1.1% oil, with only minimal contributions from hydro, wind, and solar.[56)]

Figure 14 shows why the IPCC, the IEA, and other agencies are convinced that nuclear power is crucial to decarbonization. The IPCC has 78 decarbonization scenarios in its decarbonization database. The figure’s left-hand side presents the total TWh volume of nuclear

53), 54) OECD/NEA, “Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20,” OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf

55) See “Poles and Belgians See Nuclear Energy As Necessary Low-Carbon Source,” European Nuclear Society, December 15, 2021: https://www.euronuclear.org/news/poles-and-belgians-citizens-support-nuclear-energy-as-lowcarbon-energy/

56) Adriana Sas, “Structure of electricity sources in Poland in 2020,” Statistica, December 9, 2021: https://www.statista.com/statistics/1080936/poland-structure-of-electricity-sources/



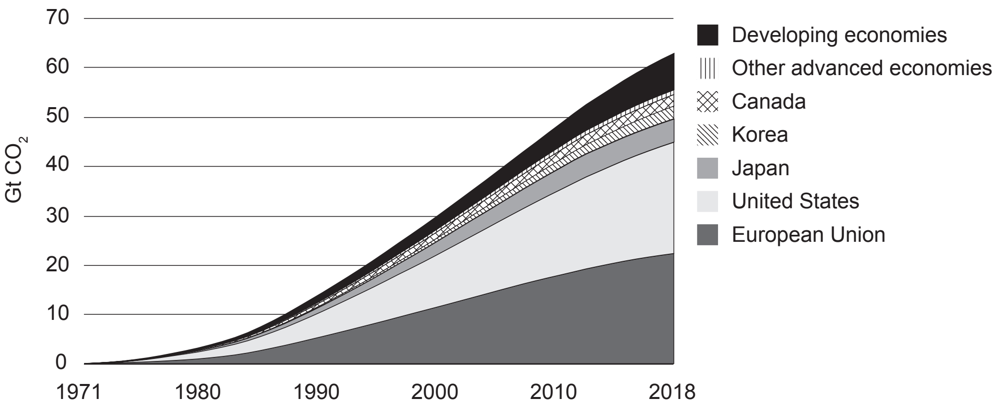
Source: OECD/NEA, 2021[57)]

Figure 14　Nuclear power's contribution to IPCC scenarios

power production in all scenarios for 2020, 2030 and 2050. These data are "presented in box-and-whisker summary charts that report the medium, first and third quartiles, as well as minimum and maximum values." The right-hand side shows the avoided carbon emissions "based on the median IPCC scenario and assuming that nuclear would be displacing gas." The very significant emissions reductions of 1.5 Gt of CO2/year in 2020 and well over 2 Gt of CO2/year in 2030 would double if nuclear were displacing coal. And none of these calculations include the extra decarbonizing effect of using nuclear to produce hydrogen or deliver heat to district heating systems.[58)]

The data in **figure 14** also need to be seen in historical terms, as **figure 15** provides. The figure shows that between 1971 and 2018 nuclear power led to 60 Gts of avoided CO2 emissions. That numbers is roughly two years' worth of total anthropogenic energy-related emissions. The IEA study on this aspect of nuclear was undertaken in 2019 and titled "Nuclear Power in a Clean Energy System." That report warned that "[w]ithout additional nuclear, the clean energy transition becomes more difficult and more expensive – requiring $1.6 trillion of additional investment in advanced economies over the next two decades. Critically, a major clean energy shortfall would emerge by 2040, calling on wind and solar PV

57), 58) OECD/NEA, "Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20," OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf



Source: OECD/NEA, 2021[59)]

Figure 15 Cumulative avoided emissions by global nuclear, 1971-2018

to accelerate deployment even further to fill the gap.”[60)]

Critical Minerals

In the above, we have seen that nuclear power was sidelined at COP26, even though it is a powerful tool for decarbonizing in an era of “code red” for humanity. We have also seen numerous references to nuclear’s comparatively low cost of critical minerals, and that critical minerals were also largely ignored at COP26. As the UK Critical Minerals Association argued on November 18, 2021, “[t]he disappointment of COP26’s lack of consideration of critical minerals and raw materials is difficult to hide. As world leaders gathered to discuss grand plans for decarbonisation, the focus was solely on the ambitions, with little consideration of the how, where and when this decarbonisation would take place. How will we extract all the necessary materials to create the green technology and associated infrastructure as responsibly as possible? Where will all these raw materials be coming from? Will we get all the raw materials out of the ground in time to make a difference and build the wind tur-

59) OECD/NEA, “Nuclear Energy in the Circular Carbon Economy (CCE): A Report to the G20,” OECD/NEA, September, 2021: https://www.oecd-nea.org/upload/docs/application/pdf/2021-09/7567_nuclear_energy_in_the_circular_carbon_economy_cce_-_a_report_to_the_g20.pdf

60) See “Nuclear Power in a Clean Energy System,” IEA, May, 2019: https://www.iea.org/reports/nuclear-power-in-a-clean-energy-system

bines, electric vehicles, solar panels we need for renewable energy?"[61)]

It is hard to explain why COP26 ignored critical minerals. Well before the COP26 meeting, the IEA had been paying close attention to copper, nickel, rare earths, and other critical mineral constraints. It noted that ambitious policies on 100% RE/EV imply demand for cobalt, lithium, nickel and other critical minerals that exceed current supply. The IEA's concerns were paralleled by those of the Swedish Mining Industry,[62)] the Canadian Province of Quebec,[63)] the European Union,[64)] the California Business Roundtable,[65)] and a steadily growing number of other actors. Many of the critical minerals are used at far greater density, per unit of energy consumption or production, in green technologies as compared to conventional power systems, automobiles, and the like. And supplies of these materials have other competing sources of demand, including smart phones, jet engines, health care, and multiple other areas. The IEA and other analyses discussed supply constraints, geostrategic risks, human rights concerns, environmental damage (from harvesting and processing critical materials), and other issues. These challenges are all central to sustainable development and the circular economy. The emerging evidence suggested that any credible, rapid shift to 100% RE/EV sustainable energy and efficiency would require prioritizing the use of constrained critical materials.

This issue of critical minerals supply and demand was taken up by the European Environmental Bureau and Friends of the Earth (EEB/FOE) in their joint October 5, 2021 publication "'Green mining' is a myth: the case for cutting EU resource consumption."[66)] It should be noted here that both these organizations are huge and influential, and are opposed

61) "Environmental Social Governance (ESG): Track, Trace & Provenance – Where is the future headed?" Critical Minerals Association, November 18, 2021: https://www.criticalmineral.org/post/environmental-social-governance-esg-track-trace-provenance-where-is-the-future-headed

62) See "Critical Raw Materials," SveMin, 2020: https://www.svemin.se/en/swedish-mining-industry/societys-need-for-metals/critical-raw-materials/

63) See "Minerals for the Future," Government of Quebec Agriculture, environment and natural resources, October 5, 2021: https://www.quebec.ca/en/agriculture-environment-and-natural-resources/mining/critical-and-strategic-minerals

64) See, for example, EURACTIV's November 2018 work on "Metals in the circular economy": https://www.euractiv.com/section/circular-economy/special_report/metals-in-the-circular-economy/

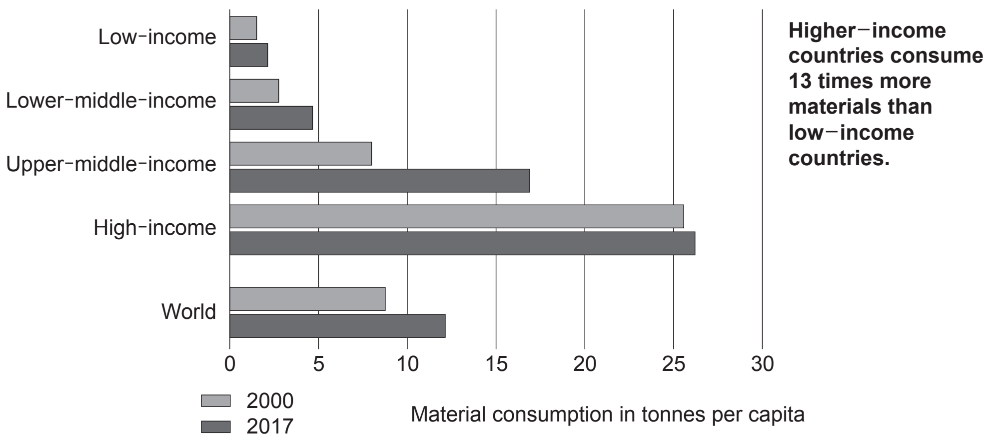
65) See "A Closer Look at California's Cobalt Economy," California Business Roundtable, January 2019: https://centerforjobs.org/wp-content/uploads/A-Closer-Look-At-Californias-Cobalt-Economy-2.pdf

66) The report is available at the European Environmental Bureau site: https://eeb.org/library/green-mining-is-a-myth/

to nuclear energy and other options outside of the 100% RE/EV narrative. The EEB itself is the largest network of environmental groups in Europe, and includes over 170 member organizations in over 35 European countries, with a total of about 30 million individual members and supporters.[67] For its part, the European section of the FOE bills itself "the largest grassroots environmental network in Europe, uniting more than 30 national organisations with thousands of local groups."[68]

Figure 16 from the report shows that total per-capita material consumption (critical minerals, plus other materials) rose dramatically between 2000 and 2017 globally and in the upper-middle-income countries (or "emerging economies"). The lower-middle-income countries also showed significant increases. But the EEB/FOE study used the data to emphasize that achieving developed-country status implies massive per-capita material footprints.

Figure 17 from the EEB/FOE release seeks to put the critical mineral demand in a larger context than is usually the case. They highlight the fact that critical minerals are used in all aspects of daily life, and not just in energy or electric mobility. They do this to draw attention to the likely increases in demand for critical minerals, in contrast to the many sur-



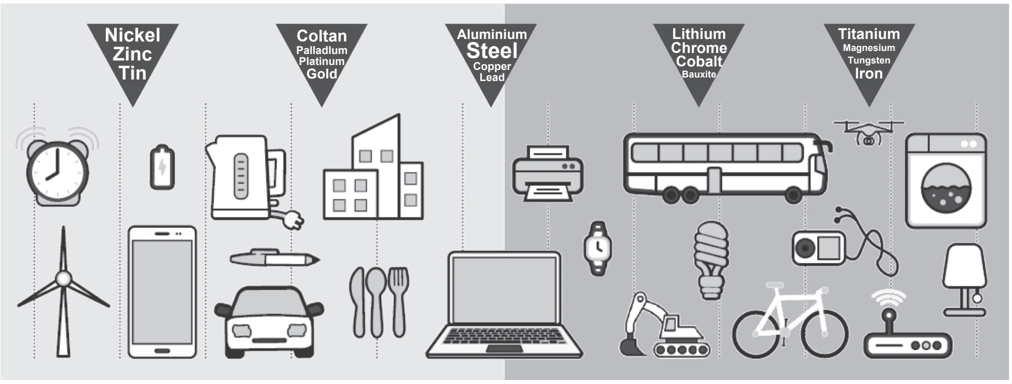
Source: EEB/FOE, 2021[69]

Figure 16 Material consumption, tonnes per capita, 2000 and 2017

67) See the description at the EEB site: https://eeb.org/homepage/about/

68) See the description at the European FOE site: https://friendsoftheearth.eu/who-we-are/

69) EEB/FOE, "'Green mining' is a myth: the case for cutting EU resource consumption," European Environmental Bureau and Friends of the Earth Europe, October 5, 2021: https://eeb.org/library/green-mining-is-a-myth/



Source: EEB/FOE, 2021[70)]

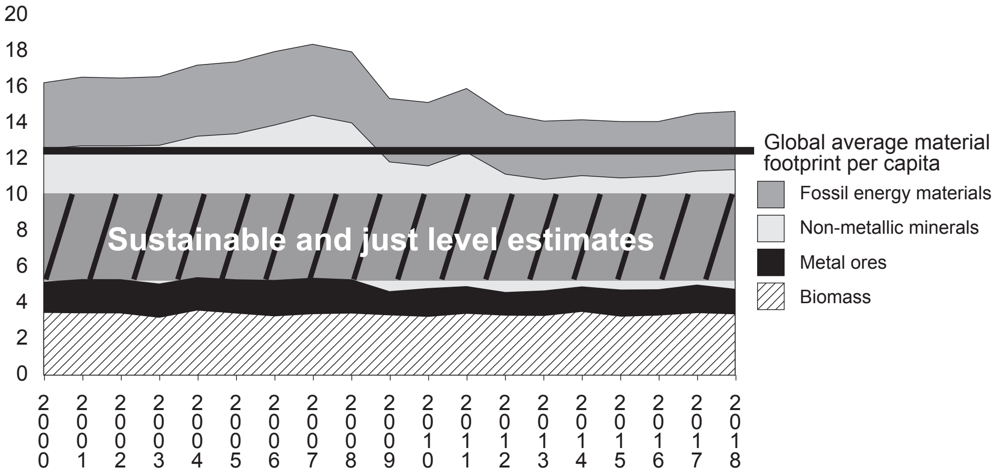
Figure 17 Critical mineral consumption in daily life

veys that merely focus on EV batteries and other items.

The EEB/FOE data in **figure 18** draw attention to the fact that material consumption in developed countries exceeds estimates of what is sustainable and just. They warn that "European economies were built, in large part, through the colonisation of the Global South, channeling natural resources towards Europe. The EU continues to extract and exploit resources and labour from poorer countries and regions today, and has been consuming more than its fair share, and beyond ecological limits, for decades. The EU's material footprint (i.e. total consumption of fossil fuels, biomass, metals and non-metallic minerals, including embodied in imports) is currently 14.5 tonnes per capita, well over the global average, and about double what is considered a sustainable and just limit." Hitherto, virtually all 100% RE/EV narrative has completely ignored the critical minerals challenge, but the EEB/FOE find the evidence of limits too compelling to dismiss.

In **figure 19**, the EEB/FOE quantify earlier studies. They emphasize that "at projected overall material demand following historical trends, current patterns of production and consumption, and excluding consequences of potential policy changes, the UN International Resources Panel (UN-IRP) projected that global material use will more than double between 2015 and 2060. This would mean an increase from 88 billion tonnes in 2015 to 190 billion tonnes in 2060 – that's an increase of 55% per capita, from 11.9 tonnes to 18.5 tonnes per year." The data are quite persuasive about the limits of material demand, and build a strong case for emphasizing material-efficiency.

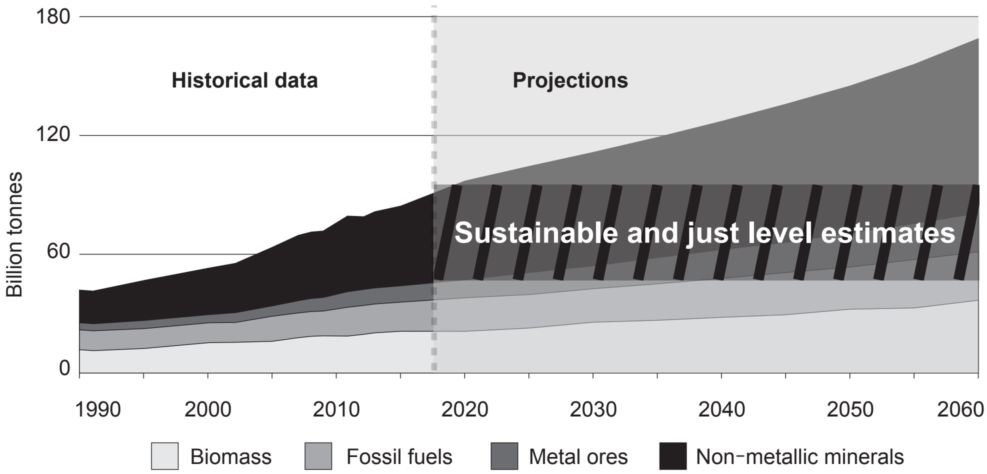
70) EEB/FOE, "'Green mining' is a myth: the case for cutting EU resource consumption," European Environmental Bureau and Friends of the Earth Europe, October 5, 2021: https://eeb.org/library/green-mining-is-a-myth/



The EU material footprint (tonnes per capita), after growing for decades, has recently been relatively stable, but is still well above sustainable and just levels and the global average. Adapted from Eurostat, 'Material flow accounts'.

Source: EEB/FOE, 2021[71)]

Figure 18 Material footprint in the EU, by sector



Growth in global material use to 2060 unless action is taken. Meaning more extraction than ever before just levels. Adapted from OECD (2019), 'Global Material Resources Outlook to 2060'.

Source: EEB/FOE, 2021[72)]

Figure 19 Historical and projected global material footprint, by sector

71), 72) EEB/FOE, "'Green mining' is a myth: the case for cutting EU resource consumption," European Environmental Bureau and Friends of the Earth Europe, October 5, 2021: https://eeb.org/library/green-mining-is-a-myth/

Table 1 Historical and projected global material footprint, by sector

	Predicted values (tonnes per capita)			Predicted growth from 2017 levels	
	2017	2030	2060	2030	2060
Total extraction	**11.9**	**13.0**	**16.4**	**10.0%**	**38.0%**
Biomass	2.9	3.0	3.6	4.2%	23.7%
Fossil fuels	2.0	2.0	2.4	Almost no increase	17.6%
Metals	1.2	1.4	2.0	17.6%	63.0%
Non-metallic minerals	5.9	6.6	8.4	12.3%	42.7%

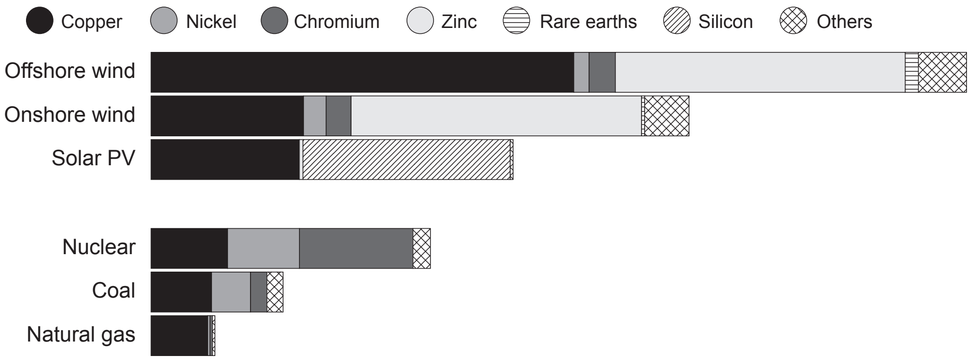
Predicted growth in extraction of specific material groups to 2060 unless action is taken. Extraction of metals will grow the fastest. Numbers taken from OECD (2019), 'Global Material Resources Outlook to 2060'.
Source: EEB/FOE, 2021[73)]

Table 1 represents the EEB/FOE warning of the implications of business as usual. The EEB/FOE argue that these numbers would be unsustainable and unjust, since the bulk of metal mining is undertaken in the Global South.

Figure 20 is drawn from IEA work on critical minerals, work that highlights the dependence of wind and solar on massive quantities of copper, lithium, and other materials for a given unit of generation capacity. The EEB/FOE argues that looking at energy is not enough. They are concerned about the supply capacity of critical minerals, and question analyses that focus on demand from energy systems only. They warn that critical mineral demand growth "would be even higher when economy-wide demand is taken into account (for example, lithium used in portable electronics, e-bikes, data centres and base stations). The predictions also do not include the significant quantities of other metals like copper and steel needed for secondary infrastructures, such as power lines and transformers/converters. Furthermore, mining machinery, the mining itself, metals processing and transportation are all dependent on fossil fuels. This is another blind spot, and challenge to unraveling the reality of the green transition."

The EEB/FOE conclude with a laundry-list of recommendations that have profound and contradictory implications for critical minerals. They emphasize the need for justice in mining regions, which would lead to higher costs as critical mineral mining would have to spend more on local environmental protection, community engagement, wages and salaries, and related matters. Those objectives are all laudable, of course, but their effect on costs for

73) EEB/FOE, "'Green mining' is a myth: the case for cutting EU resource consumption," European Environmental Bureau and Friends of the Earth Europe, October 5, 2021: https://eeb.org/library/green-mining-is-a-myth/



Source: EEB/FOE, 2021[74)]

Figure 20 Critical mineral dependence, by power technology

a 100% RE/EV transition should also be considered. The EEB/FOE also use the larger data on biomass and other material consumption to argue that huge reductions can be achieved in the EU. There seems little doubt of this, but reducing the per-capita footprint of biomass and other materials does not equate to lower per-capita consumption of critical minerals in a 100% RE/EV scenario. Indeed, the EEB/FOE discussions of overall material demand seem a distraction from the very particular issue of critical minerals needed in decarbonization and other aspects of the modern economy. They do not show that adequate efficiency gains can be made to allow for a 100% RE/EV decarbonization, and especially a transition that reduces costs. The result is that the EEB/FOE analysis only highlights the myriad problems of critical mineral-intensive approaches, leaving the difficult recommendations and hard policy choices for others. Notably, the EEB/FOE completely ignore the question of whether nuclear needs to be maintained in the EU, or even expanded, considering the amount of critical minerals that would be required to substitute for it with wind, solar, and other forms of renewable energy.

And these issues are not part of some future many years away, but rather of the present. The IEA *World Energy Outlook 2021* made that clear when it was released in October of 2021.[75)] The IEA study warned that the shift to clean energy, though necessary, also brought with it a host of pecuniary, geopolitical, and other risks. It describes the massive

74) EEB/FOE, "'Green mining' is a myth: the case for cutting EU resource consumption," European Environmental Bureau and Friends of the Earth Europe, October 5, 2021: https://eeb.org/library/green-mining-is-a-myth/

75) See *World Energy Outlook 2021*, IEA, October, 2021: https://www.iea.org/reports/world-energy-outlook-2021

differences between the current policies of the STEPS scenario compared to the much more aggressive approaches in the net-zero, or NZE, scenario for 2050:

> “Energy geopolitics are typically associated with oil and gas. However, clean energy technologies are not immune from geopolitical hazards. The production and trade of critical minerals provide a case in point. Overall mineral requirements for clean energy technologies almost triple between today and 2050 in the STEPS, and up to sixfold in the NZE. However, today’s supply and investment plans point to a risk of supply lagging behind projected demand in the NZE. Higher or more volatile prices for critical minerals could make global progress towards a clean energy future slower or more costly. Recent price rallies for critical minerals illustrate the point: all other things being equal, they could make solar panels, wind turbines, EV batteries and grid lines 5-15% more expensive, with ripple effects on the costs of transitions.
>
> The challenges are compounded by a lack of geographical diversity in critical mineral extraction and processing operations. In many cases, the supply of critical minerals is concentrated in a smaller number of countries than is the case for oil and natural gas. This is inevitably a source of concern because it means that supply chains for solar panels, wind turbines and batteries using imported materials could quickly be affected by regulatory changes, trade restrictions or even political instability in a small number of countries. Early attention from policy makers is required to develop a comprehensive approach to mineral security that encompasses measures to scale up investment and promote technology innovation together with a strong focus on recycling, supply chain resilience and sustainability.”[76)]

In short, the IEA warns that a much more comprehensive and strategic approach to critical minerals is essential. In contrast to the 100% RE/EV narrative, the IEA understands quite well that the more decarbonization is to be undertaken by renewable energy and electric cars, without nuclear and other options, the more critical minerals will be required.

And the more demand there is for scarce commodities, the more their price increases. The *Financial Times* warned of this patent fact in a December 9, 2021 “data drill” on commodities. Its survey of the evidence highlighted that “commodity costs are making the clean

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76) See “Report extract: Energy security and the risk of disorderly change,” IEA, October, 2021: https://www.iea.org/reports/world-energy-outlook-2021/energy-security-and-the-risk-of-disorderly-change

energy transition more expensive. A new analysis from the International Energy Agency estimates that investment costs for solar and onshore wind plants have increased 25 per cent, threatening to erase the past few years of cheaper production costs. The IEA found that since the start of 2020, the cost of polysilicon, a key material for solar modules, has more than quadrupled and shipping fees have increased six-fold. Steel, aluminium, and copper are also more expensive. Higher input costs have already driven up prices for modules and wind turbines by at least 10 per cent, according to the IEA. Still, the IEA found that given higher natural gas and coal prices, solar and wind remained competitive. The renewable sector saw record growth in 2021, largely driven by solar and wind additions. Higher commodity prices, however, could affect the speed of deployment. If higher prices continue, countries will have to pay an additional $100bn in investment costs.”[77)]

These reports from the IEA and other agencies have thus been making it into the mainstream, quality media. But these is still a great deal of reluctance to interrogate decarbonization narratives (especially the 100% RE/EV variant) in light of this evidence.

The IEA is hardly the only agency taking notice. Other items on critical mineral demand provide deep insight into the challenges that already serious and certain to worsen in short order. A November 10, 2021 summary of the Bloomberg New Energy Finance (BNEF) and other data pointed out the following:

> “BNEF estimates that it takes 10,252 tons of aluminum, 3,380 tons of polysilicon and 18.5 tons of silver to manufacture solar panels with 1 GW capacity. With global installed solar capacity expected to double by 2025 andquadruple to 3,000 GW by 2030, the solar industry is expected to become a significant consumer of these commodities over the next decade.
>
> It takes about 154,352 tons of steel, 2,866 tons of copper, and 387 tons of aluminum to construct wind turbines and infrastructure with the power capacity of a gigawatt as per BNEF estimates. The Global Wind Energy Outlook (GWEO) has forecastinstalled wind capacity to hit 2,110GW by 2030, representing a 185% growth over the timeframe.
>
> BNEF estimates that it takes 1,731 tons of copper, 1,202 tons of aluminum, and 729 tons of lithium to manufacture 1 GWh Li-ion batteries.
>
> In its June report, BNEF says the supply of lithium is likely to remain tight through 2022 as demand from the battery sector builds. But unlike solar and wind where key defi-

77) Amanda Chu, “Data Drill,” *Financial Time*s, December 9, 2021: https://www.ft.com/content/03dc48c8-c09b-43c2-bf80-f6c14d151cac

cits are expected to be more ephemeral in nature, BNEF says that lithium hydroxide, the chemical favored for premium Li-ion cells, could see shortages by 2027.

A single fast, public electric vehicle charger typically needs 25 kilograms of copper, while a smaller charger to use at home needs around 2 kilograms of copper, according to BloombergNEF estimates. That might not seem like much, but it could be significant when you consider that global charge points are expected to increase from 1.3 million units in 2020 to 30.8 million units by 2027, good for a CAGR of nearly 50%."[78)]

The material volumes cited in the above have to be seen in terms of the low capacity factors of wind and solar. As we have seen, those low capacity factors mean that achieving enough actual generation to displace nuclear as well as fossil would require truly prodigious deployments of copper, nickel, cobalt, and other materials. We see this fact reflected in a November 24, 2021 summary of reports about critical mineral demand for the United States:

"According to S&P Global Market Intelligence estimates, EVs manufactured in the U.S. will demand nearly 150 gigawatt-hours of battery capacity by 2025, a roughly 750% increase over the 20 GWh of batteries that went into American EVs last year.

Roughly 30,000 metric tons of cobalt, 165,000 metric tons of graphite, 125,000 metric tons of lithium, and 95,000 metric tons of nickel will be needed each year to manufacture these batteries.

In comparison, all sectors of the U.S. economy consumed approximately 8,700 metric tons of cobalt, 35,000 metric tons of mined graphite, 2,000 metric tons of lithium, and 200,000 metric tons of nickel during 2020, according to the United States Geological Survey.

This means that the batteries powering EVs will singlehandedly increase U.S. cobalt consumption by roughly 260%, graphite by 470%, lithium by 2,500%, and nickel by 50%.

It is a similar story for the neodymium and praseodymium – two in the suite of 17 rare earth elements – used for permanent magnets that make EV motors and wind turbine generators more efficient.

The price of neodymium has rocketed 280% over the past year, from US$69.10 per kilogram in November 2020 to US$193.70/kg today.

Likewise, praseodymium has shot up 289% from US$67.05/kg to US$194/kg over the same span.

78) Alex Kimani, "Metals Will Be The Oil Of The Future," Oil Price, November 10, 2021: https://oilprice.com/Energy/Energy-General/Metals-Will-Be-The-Oil-Of-The-Future.html

> While U.S. automakers, policy leaders, and mining companies have begun to address the skyrocketing need for the minerals and metals critical to the EV revolution, many market experts believe these initiatives may be too little, too late.
>
> 'Policymakers and industry actors are working to secure a healthy EV mineral supply chain; however, those efforts might pale in comparison to the scale and pace of mineral demand growth,' Reed Blakemore penned in 'The role of minerals in realizing US transportation electrification goals,' a November report by the Atlantic Council." [79)]

The numbers cited in the above summary are simply incredible. They demonstrate that most analytical work on decarbonizing with renewables and electric vehicles has focused on the downstream technologies. Attention to the urgent need for raw materials has been a casualty of the breathless assertions that 100% RE/EV could lead to decarbonization of power and mobility in a decade or two, leading to lower investment costs and a host of other benefits. The predictable result of these blind spots (not to mention blind spots on demand for land, exposure to climate threats, and related items) has been price spikes.

Price increases of course get attention, and are instructive about the need for massively ramped-up supply. But even though eyes have turned to mining, most stakeholders are reluctant to confront the myriad issues at that upstream end of the supply chain. There is in consequence a generalized sense that more mining will simply happen, in spite of the political, geologic, and other challenges confronting new or expanded mining of critical minerals.

An example of how these issues are emerging in the present is seen in the December 18, 2021 *Bloomberg News* warning that "The World Wants More Lithium But Doesn't Want More Mines":

> "Prices for lithium, the building block of electric-vehicle batteries, shot to a record this year, amplifying concerns there won't be enough of the metal to fuel the switch away from combustion engines. In that climate, now should be a prime time to build a mine.
>
> Rio Tinto Groupis finding out otherwise. Within months of unveiling plans for a $2.4 billion mine in western Serbia, local opponents organized a movement that's rocked the government and brought cities to a standstill as thousands of protesters march in the

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79) Shane Lasley, "EV cart ahead of critical minerals horse," Metal Tech News, November 24, 2021: https://www.metaltechnews.com/story/2021/11/24/tech-metals/ev-cart-ahead-of-critical-minerals-horse/773.html

streets. Authorities subsequently suspended a land-use plan for the proposed mine, though they didn't reject the project completely.

And it's not just lithium that's becoming problematic. Copper is an essential metal for the energy transition, with demand expected to grow by almost 50% in the next decade, according to Chilean minerAntofagasta Plc. Mines typically take about 15 years to go from discovery to production.

Even so, many of the best prospects are in limbo. Rio's proposed Resolution copper mine in Arizona, which could satisfy a quarter of U.S. demand, is being reviewed by the federal government after opposition from the San Carlos Apache tribe, whose leader refused to meet Rio's CEO earlier this year.

"Despite mining's contribution to almost every aspect of modern life, the industry is still seen as one that takes more than it gives," Mark Cutifani, CEO ofAnglo American Plc, said in a speech in London this month.

Rio's challenge now is to convince Serbs the Jadar mine won't be like the mines of old. The company says it will be built to the highest standards, reuse nearly all its water, and use electric trucks."[80)]

In the event, Rio Tinto finally put the Jadar project on hold as of December 24, 2021. Rio Tinto will seek to negotiate with local interests, but it seems likely that they can overcome opposition from "green groups" that "have launched protests and blocked roads across the country in recent weeks, urging authorities to close the project. The groups claim that the project could have a destructive environmental impact."[81)]

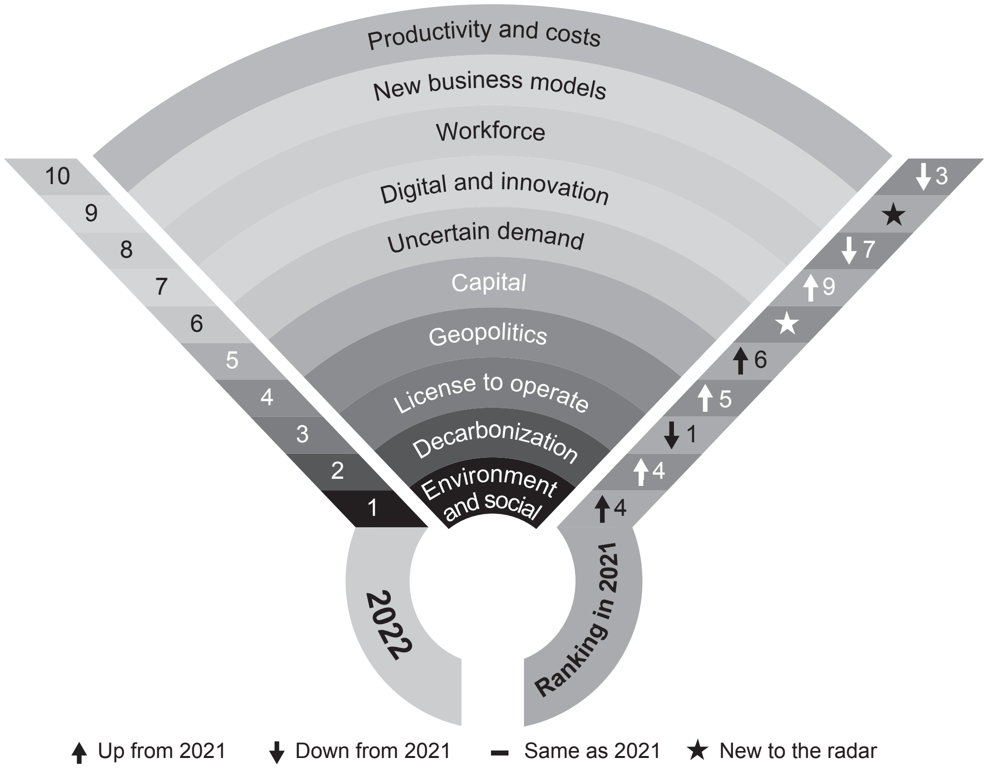
The ESG Challenge

The mining community is thus quite wary of new projects. This fact was evident in the October 7, 2021 release of the EY Global Mining survey on the most pertinent business risks for 2022 in contrast to 2021.

As we see in **figure 21** from the survey, the greatest change was in environmental and

80) Thomas Biesheuvel and Misha Savic, "The World Wants More Lithium But Doesn't Want More Mines," *Bloomberg News*, December 18, 2021: https://www.bloomberg.com/news/articles/2021-12-18/even-a-mine-needed-to-fight-climate-change-isn-t-proving-popular

81) "Rio Tinto to temporarily halt Serbian lithium project," Mining Technology, December 24, 2021: https://www.mining-technology.com/news/rio-tinto-halt-serbian-lithium/



Source: Mitchell, 2021[82)]

Figure 21　Top 10 business risks and opportunities for mining and metals, 2121 and 2022

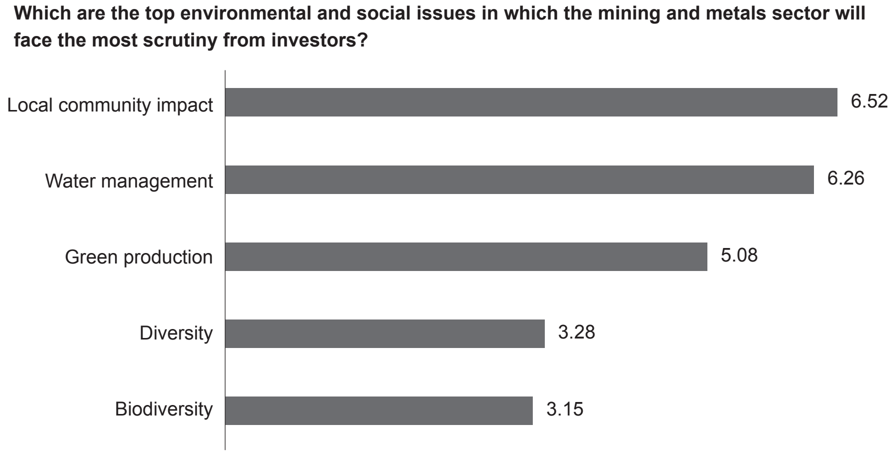
social risks for mining projects, In 2021, these had been the 4th highest risk, but quickly went to 1st as the pressure against projects mounted.

Figure 22 offers precise detail on these environmental and social issues.

Not surprisingly, considering the protests examined earlier, the main issue was local community impact. This was closely followed by water management, as mining from critical minerals has a comparatively high impact on water resources. Unfortunately, most of the best reserves of copper and other critical minerals are located in water-stressed areas. And these areas' water stress is projected worsen due to climate change.

It is thus no surprise that mining firms have made only limited progress on net-zero commitments, particularly Scope 3 emissions (meaning emissions that are "the result of activities from assets not owned or controlled by the reporting organization, but that the orga-

82) Paul Mitchell, "Top 10 business risks and opportunities for mining and metals in 2022," EY Global Mining, October 7, 2021: https://www.ey.com/en_gl/mining-metals/top-10-business-risks-and-opportunities-for-mining-and-metals-in-2022



Source: Top 10 business risks and opportunities in mining and metals for 2022 survey respondents.
Source: Mitchell, 2021[83)]

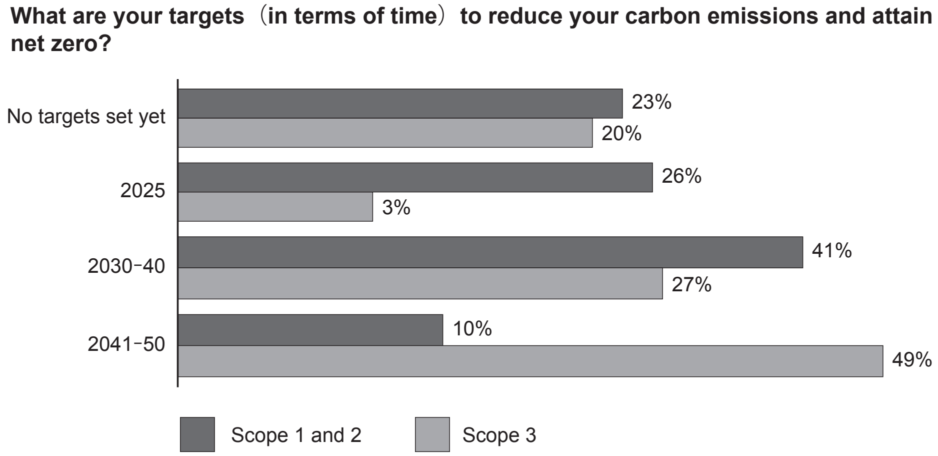
Figure 22 Top environmental and social issues for mining, 2022

nization indirectly impacts in its value chain").[84)] The mining firms are under scrutiny, and hence are compelled to commit to net-zero. But it is very difficult to devise strategies that credibly encompass the whole value chain.

Thus as we see in figure 23, a majority of miners have either set no targets at all or have pushed them out to mid-century. Only 26% have net-zero scope 1 and 2 targets for 2025, and only 3% have scope 3 decarbonization goals for that year. And it is actually rather fanciful to assume that these targets are built on robust assessments as opposed to wishful thinking. In this regard, S&P Global Market Intelligence warned on December 9, 2021, that ESG reporting in the mining industry was very lax: "Mining companies are under pressure to prove to investors and clients that they are following through on their commitments. Companies have an array of options for their ESG reporting, but the lack of a single format to follow often makes these reports difficult to compare company-to-company, and the reports have significant inconsistencies across collecting and reporting data. The high costs of reporting along with the lack of regulatory and industry guidance is slowing the sector's

83) Paul Mitchell, "Top 10 business risks and opportunities for mining and metals in 2022," EY Global Mining, October 7, 2021: https://www.ey.com/en_gl/mining-metals/top-10-business-risks-and-opportunities-for-mining-and-metals-in-2022

84) "Scope 3 Inventory Guidance," United States Environmental Protection Agency, no date: https://www.epa.gov/climateleadership/scope-3-inventory-guidance



Source: Mitchell, 2021[85)]

Figure 23 Miners' ambitions for decarbonization

progress."[86)]

These facts return our attention to the EEB/FOE criticism of the entire concept of "green mining" as a myth. The EEB/FOE rightly aimed their analytical focus at the inconsistencies in the literature on critical minerals and mining. But as we noted, they failed to ask what their conclusions mean for the role of nuclear power in decarbonization.

COP26's inattention to critical minerals thus led to an empty argument about decarbonization options, divorced from material requirements. This problem was heavily criticized by mining expert Frik Els, who was astounded when UN Secretary General António Guterres was applauded for his comment that in mining, "we are digging our own graves."[87)] Els pointed to the October 26, 2021 report by Wood Mackenzie, that argued critical minerals need to be on the COP26 agenda. Wood Mackenzie emphasized in particular that "[a]chieving global net zero is inextricably linked to increased base metal supply. Simply put, base metals are essential to the technology that will be used in the generation, transmission, storage and

85) Paul Mitchell, "Top 10 business risks and opportunities for mining and metals in 2022," EY Global Mining, October 7, 2021: https://www.ey.com/en_gl/mining-metals/top-10-business-risks-and-opportunities-for-mining-and-metals-in-2022

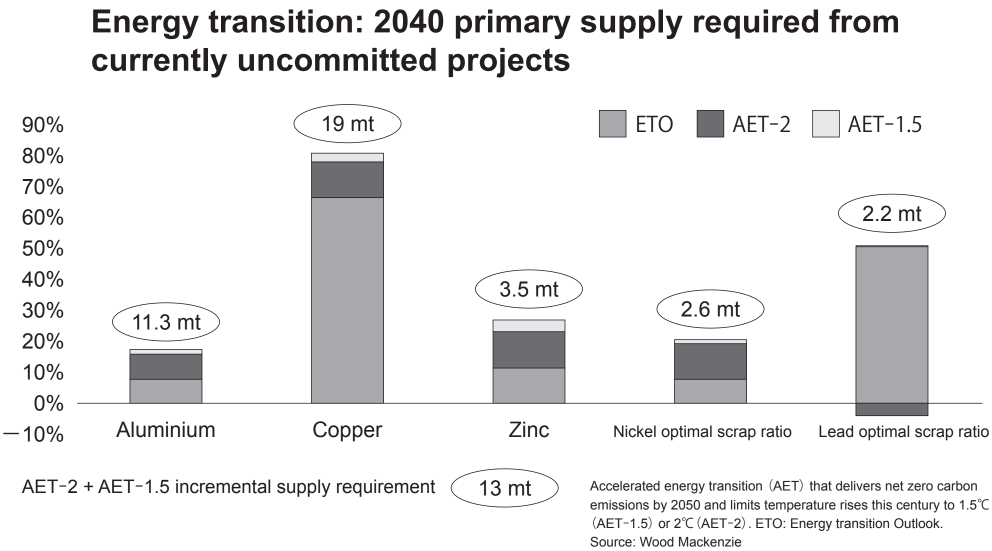
86) Camille Erickson, "ESG reporting in mining industry the 'Wild West,'" S&P Glocal Market Intelligence, December 9, 2021: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/esg-reporting-in-mining-industry-the-wild-west-67803988

87) Frik Els, "UN at COP26: 'Enough of mining...we are digging our own graves,'" Mining.com, November 2, 2021: https://www.mining.com/un-at-cop26-enough-of-mining-we-are-digging-our-own-graves/

consumption of low-carbon electrical energy."[88)]

In his own article, Els cited Wood Mackenzie's document extensively. Figure 24 is from Els but also from Wood Mackenzie. Els used it in noting that:

> "Woodmac gets straight to the point: 'delivering the base metals to meet [net zero 2050] pathways strains project delivery beyond breaking point from people and plant to financing and permitting.'
>
> Copper, which Woodmac emphasizes 'sits at the nexus of the energy transition' stands out particularly.
>
> The 19 million tonnes of additional copper that need to be delivered for net-zero 2050 implies a new La Escondida[89)] must be discovered and enter production every year for the next 20 years.



Source: Els, 2021[90)]

Figure 24　Critical mineral demand implied by decarbonization

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88) Kamil Wlazly, "COP26: Why base metals should be high on the agenda," Wood Mackenzie, October 6, 2021: https://www.woodmac.com/news/opinion/cop26-why-base-metals-should-be-high-on-the-agenda/

89) La Escondida is the world's largest producer of copper concentrates and cathodes: https://www.bhp.com/what-we-do/global-locations/chile/escondida

90) Frik Els, "UN at COP26: 'Enough of mining…we are digging our own graves,'" Mining.com, November 2, 2021: https://www.mining.com/un-at-cop26-enough-of-mining-we-are-digging-our-own-graves/

> Even if you focus on just one of the obstacles bringing new copper supply online – the time it takes to build a new mine – and leave aside all other factors, net-zero 2050 has zero chance.”[91)]

In the face of this kind of empirical evidence, the fact that decarbonization narratives are struggling with nuclear seems absurd. Many critical materials are used at far greater density, per unit of energy consumption or production, in green technologies as compared to conventional power systems, automobiles, and the like. And supplies of these materials have other competing sources of demand, including smart phones, jet engines, health care, and multiple other areas. The IEA and other analyses do not adequately discuss supply constraints, geostrategic risks, human rights concerns, environmental damage (from harvesting and processing critical materials), and other issues. These challenges are all central to sustainable development and the circular economy. The emerging facts suggest that any credible, rapid shift to sustainable energy and efficiency will require prioritizing the use of constrained critical materials. Since nuclear power clearly makes efficient use of critical minerals, it seems essential to minimizing demand (not to mention environmental impacts and other issues).

Further Blind Spots at COP26

A further item overlooked by the COP26 was evidence of the enormity of the “Global Cooling Challenge” in the context of climate change, population increases, and expanding urbanization. The Clean Cooling Collaborative sought to raise awareness of air conditioning at COP26,[92)] but there were no serious agreements.

Yet air conditioning is especially crucial to human health in the midst of rising heat and humidity and increasingly frequent heat waves. It is also very energy intensive and requires massive amounts of critical minerals. So air conditioning increases the pressure on low-carbon power sources in addition to copper, aluminum, and other critical minerals.

Note for example that current comparative data on the global average use of room air

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91) Frik Els, “UN at COP26: ‘Enough of mining…we are digging our own graves,’” Mining.com, November 2, 2021: https://www.mining.com/un-at-cop26-enough-of-mining-we-are-digging-our-own-graves/

92) See, for example, the list of events undertaken at the COP26 meeting: https://www.cleancoolingcollaborative.org/blog/a-guide-to-cooling-at-cop26/

conditioners (RACs) is that it was about 720 hours/yr in 2017. Due to climate differences, RAC usage hours per year in China average 545, in Japan 720, but 1,600 in the US. Usage equals or exceeds 1,600 hours/yr in India, Mexico, Brazil, Indonesia and the Middle East (the latter is an astounding 4,672). Because of global climate change, these usage hours are increasing at an estimated 0.7%/yr (leading to a 25% increase by 2050).

The Rocky Mountain Institute (RMI) and other partner agencies, including many elements of the Indian Government (eg, the Ministry of Power), organized an initiative to cope with the unsustainable power demand posed by conventional air conditioning in a warming climate. The RMI analysts and their collaborators pointed out that the global number of RACs in 2016 was roughly 1.2 billion (over 400 million in China alone), and that this figure is likely to increase to 4.5 billion by 2050. This assessment seems reasonable, as 2020 global sales of RACs was apparently 107.9 million units, and likely to increase to 148.7 million units by 2026.[93)]

The RMI draw on IEA and other data indicating that supplying the power demand for this growth in RAC stock, much of which will be concentrated in growing global megacities, will require roughly USD 1.2 trillion in new generation capacity. This is because the 2016 global RAC power demand of 2,300 TWh will likely more than triple over the same period, reaching 7,700 TWh in 2050 (about 16% of global electricity demand). That 5,400 TWh increase in power demand between 2016 and 2050 would require an astounding addition of 2,000 GW of generation capacity, equivalent to "the current annual electricity consumption of the US, Japan, and Germany combined." And the cumulative GHG emissions (from power demand as well as the effect of refrigerant gases), projected at between 132 GT and 167 GT, would likely exhaust 25–50% of the remaining carbon budget.

India is an instructive case. RAC penetration in India in 2017 was only 7%, but sales were already increasing at 15%/yr, meaning about 7 million new units. And the RMI and IEA estimates indicate a more than 20-fold increase in Indian power demand for RAC, from 94 TWh in 2016, to 1,890 TWh in 2050. Seen in per-capita terms, urbanization in India is projected to raise RAC demand from a current global low of 72 kWh to 1,140 kWh. Satisfying that level of power demand would require India to install fully one-third of the global 2,000 GW of needed new generation capacity. The RMI is a staunch advocate of renewable energy and efficiency. Hence it is not deliberately bearish in warning that "[w]e cannot solve this

93) See "Global Air Conditioning Systems Market to Reach 148.7 Million Units by 2026," Global Newswire, June 24, 2021: https://www.globenewswire.com/news-release/2021/06/24/2252363/0/en/Global-Air-Conditioning-Systems-Market-to-Reach-148-7-Million-Units-by-2026.html

magnitude of growth by adding renewables alone.” It points out that the in 2017 the total global increase of 94 GW in solar generation capacity was less than that year’s RAC incremental demand growth of 100 GW.[94] And agreements on an India Cooling Action Plan in 2018 have yet to see much progress.[95]

Meanwhile, sales of RACs continue to climb, requiring increasing power and critical minerals. Most of the new sales of RACs are in Asia, where power is largely supplied by coal. The RMI and other assessments have already shown that RAC power demand cannot be met by conceivable diffusions of renewable. So to dismiss nuclear power as part of the decarbonizing portfolio means that the power will have to come from coal and other fossil fuels. That hard math is surely one reason the decarbonization narratives are broadening past the 100% RE/EV variant.

Conclusions

We have seen that COP26 overlooked nuclear and critical minerals, even though the evidence strongly indicates they are essential to any credible scenario of decarbonization. The 100% RE/EV narrative would – as the Germans are slated to do in 2022 – displace nuclear in favour of renewables and gas (and some coal). But the costs of the approach can increasingly be measured in power prices, environmental damage, and perhaps even the credibility of decarbonization proposals per se.

If one takes the IPCC reports seriously, then humanity indeed confronts dire circumstances where decisions in the present irrevocably shape future choices in myriad areas. As China, India, and other global players increase their deployment of decarbonizing nuclear assets, it seems likely that decarbonization narratives will diversify.

94) See Ian Campbell, et al., “Solving the Global Cooling Challenge,” The Rocky Mountain Institute, November 2018: https://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf

95) Flavia Lopes, “How air cooling technologies are making rising global temperature worse,” *Business Standard*, November 23, 2021: https://www.business-standard.com/article/current-affairs/how-air-cooling-technologies-are-adding-fuel-to-rising-global-temperature-121112300270_1.html