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Article

# Heavy Metal: Critical Raw Materials and the Energy Transition

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Abstract

The historic Covid-19 pandemic that erupted early in 2020 profoundly disrupted virtually every aspect of the global political economy. Climate, energy and critical raw material challenges and policies were prominent among the affected sectors. Covid-19's economic effects have accordingly driven "green recovery" onto the global agenda, in an acceleration of the climate mitigation and adaptation aims of the 2030 Agenda (UNIDO, 2020). We examine the implications of these developments generally and with respect to Japan's material-efficiency.

## Introduction

The historic Covid-19 pandemic that erupted early in 2020 profoundly disrupted virtually every aspect of the global political economy. Climate, energy and critical raw material challenges and policies were prominent among the affected sectors. Covid-19's economic effects have accordingly put "green recovery" onto the global agenda, in an acceleration of the climate mitigation and adaptation aims of the 2030 Agenda (UNIDO, 2020). "Green recovery" has thus become a generalized term encompassing decarbonization, sustainability, equity, and other imperatives. This paper inquires into the basics of a green recovery, focusing on the Japanese model. We examine recent Japan-oriented proposals for a solar and wind-centred green recovery from Covid-19. We argue that rapid decarbonization is critical to slowing the acceleration of climate change (WMO, 2020), in addition to ameliorating local pollution and other impacts from fossil fuels. But we also argue that, it is imperative that all relevant aspects be considered in order to maximize the effective use of scarce fiscal, human, material and other resources, including time. Though critical material issues have indeed been used by critics of RE and EVs[1], that does not invalidate the underlying data. If VRE

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1) One example of this is seen in the "Powering the Future, 2020," which presents a well-re-

confront a range of challenges, it is prudent to be honest about them and consider what ought to be done. After all, the goal is equitable and sustainable decarbonization rather than merely building as much VRE and other renewables as possible, no matter the impacts.

The paper also details why this resource-efficiency is essential in the critical raw materials[2) ] (hereafter, CRM) sector. We show that the challenges are of such enormity that seabed mining may be required to mitigate risks of zoonotic disease, geopolitical crises, price fluctuations, and other patent challenges. We suggest that Japan's initiatives could be an important indicator of how to maintain momentum against climate change and other hazards. Japan's measures integrate the UN 2030 Agenda's three pillars of the Paris Agreement, Sustainable Development Goals (SDGs), and the Sendai Framework of Disaster Risk Reduction (SFDRR).

We would also ask why social science is minimally engaged on this issue of the material underpinnings of decarbonization. Most argument focuses on advocacy groups' claims that vested interests are the problem. Certainly, vested interests are part of the problem in tackling climate change. But there is also an enormous material reality that requires attention from public finance, political economy, political science, and other spheres of academe. After all, the core issues of justice, cost, and sustainability are implicated in CRM efficiency.

## Organization

We organize this paper into three sections. The first section examines decarbonization proposals for Japan, inquiring into their background and main points. The second section centres on global cooling needs, and includes comments on the critical raw materials (CRM) that are necessary for any decarbonizing economic transformation. The third section examines Japan's national resilience and other integrated policy as an example of how to achieve material-light decarbonization.

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searched summary of CRM issues but uses it to insist that RE goals are impossible and unwise.

2) Critical raw materials are composed of rare earths in addition to cobalt, copper, nickel and other minerals and metals. The list of critical raw materials varies by country/region and over time. A summary of the European Commission's work on critical raw materials and announcement of its expanded 2020 list is at EC (2020).

## Section 1 :

### Green Proposals in Japan

On August 6, 2020 Japan's Renewable Energy Institute (REI) released a lengthy and ambitious "Proposals for the 2030 Energy Mix" (REI, 2020). The REI proposals are aimed Japan's strategic energy policy, currently under review. The proposals centre on the power sector, perhaps the most crucial element of any "green recovery" from Covid-19's massive economic impacts. The REI surveys Japan's electricity system and outlines a "sustainable electricity generation mix" consistent with what the REI views as Japan's principal challenges in the context of global energy trends and climate policy. In the REI's estimation, Japan could and should achieve a dramatic revamp of its power mix by 2030. The REI argue that more aggressive policy could allow Japan – in a decade – to attain a 45% share of renewable electricity generation (tripling solar and octupling wind). Over the same period, this massive and rapid expansion of renewable power would be backed up by a huge increase in power generation from natural gas. In tandem, both nuclear power and coal-fired generation would be completely eliminated from the power mix. The proposals rank among the world's most far-reaching renewable energy programs.

And the REI proposals are certainly the most ambitious renewable-energy roadmap ever advanced by one of Japan's top energy think tanks, and thus merit a detailed assessment. Hence we first outline the REI proposals and their immediate context. We then ask whether the proposals are a credible and cost-effective route towards the urgent imperative of rapid decarbonization. Drawing on research from the International Renewable Energy Association, the Japanese PV Association, and other agencies, we tentatively conclude that the proposals are impaired by numerous unstated assumptions and omissions. A conspicuous problem is the emphasis on eliminating low-carbon nuclear, even though virtually all decarbonization scenarios maintain a role for nuclear energy (World Energy Council, 2019; IRENA, 2018). Another area of concern is the REI's failure to confront critical material logistics, in spite of their prominence in Japanese, EU, and other clean-energy industrial policies. We therefore suggest the proposal needs to be rethought, with at the very least a broader portfolio of renewables and much less natural gas. We then proceed to link the REI plan with its predecessors, asking whether there are common problem areas.

### The REI and its Proposal

Japan's Renewable Energy Institute (REI) is a key stakeholder in the post-Fukushima energy debate. The REI was established on August 12 of 2011, specifically to promote renewable energy, by Softbank CEO Son Masayoshi, who remains its chairperson. The REI includes a globally active network of directors and advisors, and advances renewable energy via research and collaborative action. Since its founding the REI has undertaken numerous international conferences, published multiple studies and policy papers, maintained ongoing research initiatives, and offered policy advice at all levels of government. It has undertaken very detailed and informative analyses of Japanese power markets, the "Asia Super Grid," and related matters. And among Japanese energy-related think tanks, it is notable for producing an abundance of high-quality work in both Japanese and English.

As noted in the introduction, the REI "Proposals for the 2030 Energy Mix" (hereafter "REI 2030") was released on August 6. The August release coincides with ongoing high-level discussions on Japan's next Strategic Energy Plan. At just under 100 pages, REI 2030 is much more than a quick set of recommendations. It builds on the REI's considerable outreach and activism concerning a green recovery from the Covid-19 crisis, and addresses the global debate to a significant extent. REI 2030 is divided into 5 separate sections, with a very professional use of well-designed, reader-friendly graphics in addition to extensive but unobtrusive footnoting of assertions on prices and other relevant matters. In short, REI 2030 is a serious study of Japan's energy issues in light of global trends and challenges, and clearly aimed at influencing debate on the next Strategic Energy Plan.

Before critiquing REI 2030's assumptions and omissions, we shall briefly examine its main arguments and their context. The core proposal of REI 2030 is to massively increase variable[3)] renewable energy (VRE, meaning solar and wind) and make VRE the core of a 45% renewable energy power mix by 2030. The REI also want to eliminate coal and nuclear from the power mix over the same period. That ambition means natural gas has to fill virtually all the gap that renewables cannot. Hence the REI 2030 emphasis on using gas for 54% of power in 2030, with the remaining 1% of power supply from burning oil and oil product. The details are displayed in a separate section below, in a series of tables (1-3) and discussion of their content.

The REI justifies their ambitions for VRE by repeated emphasis that renewable energy is rapidly diffusing globally and that wind and solar are the cheapest power options. The

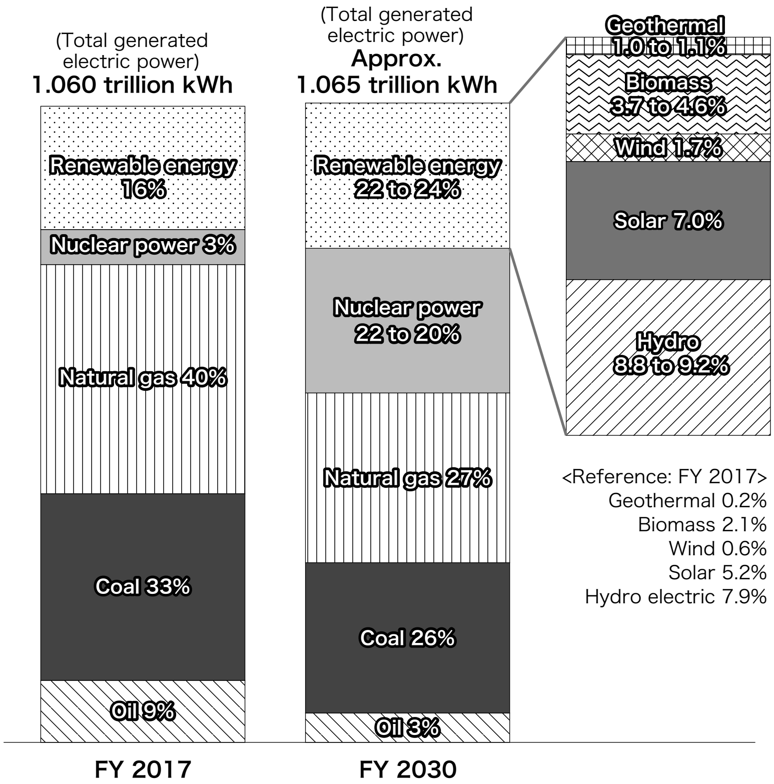
3) Another term is "intermittent," and both variable and intermittent refer to the fact that power output from solar and wind assets fluctuates with levels of sunlight and wind-speed.

latter assertion is not true everywhere, and especially in Japan, but we shall also take up those details later. The REI are indisputably correct that renewable energy is diffusing rapidly. The REI are also right in pointing out that several Japanese business associations, municipalities, and other actors have called for the government to substantially raise its current triennial Strategic Energy Plan target of 22-24% renewables by 2030 (with nuclear being 20-22% of a decarbonizing tandem).

That Japan's 2030 renewable target per se could and should be increased is REI 2030's most credible argument. It is indeed so credible that it is not particularly controversial in Japan. Yet simply raising the renewable target is just one item, with content being a much bigger issue. Hence, Japan's REI 2030 and other "power-shift" proposals vary greatly on which renewable generation (eg, wind, solar, hydro, biomass, and geothermal) they emphasize, what percentage of renewable is possible by 2030 (or 2050, and other years), whether or not to include nuclear, the role of carbon capture for thermal power (ie, coal, gas, and oil), and other extremely important details.

One reason for the uncertainty is lack of political leadership. The Abe Shinzo LDP government (December 2012-September 2020) was politically smart but economically imprudent in its unwillingness to touch the power-mix targets (ie, the relative shares of electricity generation) in official energy policy. Hence Japan's Strategic Energy Plan's 2030 targets for renewables, nuclear, and other power generation have remained essentially unchanged since 2015. Those targets are displayed in figure 1. The figure is taken directly from the English-language version of the Japanese Agency for Natural Resources and Energy (ANRE) publication "Japan's Energy 2019." The left-hand column shows the 2017 power-generation shares of renewable energy (including hydro), nuclear, natural gas, coal, and oil (which includes oil products). The middle column portrays the 2030 goals – which were first announced in July of 2015, as a supplement to the April 2014 4th Strategic Energy Plan – next to the 2017 numbers. In the right-hand column, the figure provides a breakdown of "renewable energy," via a summary of the relative contributions from geothermal, biomass, and other renewables. And below that summary are the 2017 reference values for each category of renewable energy.

The ANRE figure indicates that the current Strategic Energy Plan goals for 2030 project a moderate increase in renewables, to between 22 and 24%, with a much larger increase in nuclear, going from 3% in 2017 to between 20 and 22% in 2030. The nuclear role depends on the restart of remaining nuclear assets, and is a substantial decrease from pre-Fukushima nuclear shares that were 25-30% of the power mix. The Strategic Energy Plan's combination




Source: ANRE, 2020

Figure 1 Japan's Power Mix, 2017 and 2030 Strategic Energy Plan Targets

of low-carbon renewables and nuclear is posited as the principal means to reduce reliance on carbon-intensive natural gas (from 40% in 2017 to 27% in 2030), coal (from 33% to 26%), and oil (from 9% to 3%). The figure also shows that, among renewables, the biggest projected growth is in geothermal, quintupling to about 1% from a low base of 0.2% in 2017. Wind is slated to more than double, from 0.6% in 2017 to 1.7% in 2030, followed by less ambitious increases in biomass, solar, and hydro.

Again, almost no one in Japanese energy policymaking circles – whether academics, technocrats, business interests, or activists – believes these 2030 targets are credible. The current Strategic Energy Plan is version 5, adopted in July of 2018, while the next plan is already under debate and slated to be revised and adopted in the summer of 2021. The next Plan's targets for the 2030 power mix will almost certainly be amended. Presumably, there will be a higher projected share for renewables – particularly 24/7 hydro, geothermal, and biomass – and a lower share for nuclear together with shifts among the fossil-fuel generation mix.

There are many reasons the next Strategic Energy Plan's 2030 targets must be changed, and these reasons lend support to REI 2030's emphasis on the targets as problematic. Principally, since the 2015 announcement of the current power targets, global energy trends have accelerated, along with climate change. There are three main drivers to consider:

First, solar and wind generation costs have cheapened dramatically, resulting in what the International Renewable Energy Association (IRENA) describes as a "virtuous cycle of falling costs, increasing deployment and accelerated technological progress" (IRENA, 2020a). The highly respected analysts at Wood Mackenzie forecast an addition 400 gigawatts (GW) of solar and wind capacity to be added in Asia alone by 2025, slightly over the 380 GW installed over the past five years (Davis, 2020). And in 2018, Japan's energy technocrats declared renewable energy a "principal power source" (*shuryoku dengen*) and further ramped up the investments and policy changes to accelerate its expansion.

A second development has been increasing pressure against investments in conventional coal-fired generation, the most carbon-intensive source of power. Among the major economies, only China seems to have the diplomatic and financial autonomy to buck the pressures and ramp up domestic projects and external coal finance even as it proclaims its renewable energy goals (Shepherd and Findlay, 2020). Indeed, in early July of 2020 the Japanese government announced that it would seek to close 100 low-efficiency coal plants by 2030, out of a total of 140 coal plants, 110 of which are low-efficiency (S&P Global, 2020a). It remains to be seen how much of Japan's coal generation will be substituted for by higher-efficiency coal, natural gas, renewables, or nuclear.

A third factor is Japan's questionable capacity to meet its 2030 nuclear targets. This seems very difficult without new build, due to decommissioning of many reactors and the slow pace in gaining regulatory approval and local-community assent to restarts.

So, while Japan's official 2030 targets have remained static for several years, the facts on the ground have changed considerably, both within Japan and globally. This context means that Japan's targeted renewable share in the 2030 power mix may come close to 30%, if not exceed it, versus the 22-24% envisioned in the current Strategic Energy Plan. Wood Mackenzie surveyed Japanese prospects in August 2020 and suggested renewables would achieve 27% by 2030 (Wood Mackenzie, 2020a). The likelihood of nearing 30% renewables in Japan's power mix now seems obvious, but we should recall that just a couple of years ago it was considered bold in Japanese circles to suggest that 30% renewables might be achievable. Powerful momentum is evident in the renewable space, both within Japan and globally.

This momentum explains why we now see serious, high-level arguments for over 40% renewables in Japan's power mix.

But the devil is in the details, so let us drill down on what REI 2030 is advocating. The REI 2030 depicts its sustainable scenario as 45% renewables, and cautions that meeting this target will require aggressive carbon pricing, regulatory changes, and other supportive measures. Table 1 (table 4.6 in the Japanese original), displays the REI 2030 Sustainable Energy Mix scenario. We see from the right-hand column that in 2030 coal and nuclear are eliminated, leaving natural gas to provide 54% of power supply, renewables (largely solar and wind) 45%, and oil a marginal 1%.

Table 2 (table 4.6 in the original) is the REI depiction of the implications of Japan's current policy environment. The table 2 numbers on power generation (in terawatt-hours, or TWh) for 2010 and 2018 are the same as in table 1, as those data on power demand, sup-

Table 1 REI 2030 Sustainable Energy Mix (units: TWh)

| Year | 2010 | 2018 | 2030 | % 2030 Power Mix |
|---|---|---|---|---|
| Power Demand | 1,035 | 946 | 850 | |
| Power Supply | 1,149 | 1,051 | 890 | |
| Renewable | 109 | 177 | 400 | 45 |
| Nuclear | 288 | 65 | 0 | 0 |
| Coal | 320 | 332 | 0 | 0 |
| Gas | 334 | 403 | 480 | 54 |
| Oil, others | 98 | 74 | 10 | 1 |

Source: REI, 2020 (Author's translation)

Table 2 REI 2030 Current Policy Implied Energy Mix (units: TWh)

| Year | 2010 | 2018 | 2030 | % 2030 Power Mix |
|---|---|---|---|---|
| Power Demand | 1,035 | 946 | 980 | |
| Power Supply | 1,149 | 1,051 | 1,070 | |
| Renewable | 109 | 177 | 320 | 30 |
| Nuclear | 288 | 65 | 30-80 | 3-7 |
| Coal | 320 | 332 | 280 | 26 |
| Gas | 334 | 403 | 370-420 | 35-39 |
| Oil, others | 98 | 74 | 20 | 2 |

Source: REI, 2020 (Author's translation)

Table 3 Renewables in the 2030 Power Mix, by Scenario

| | Energy | 2018 | 2030 Scenario | | |
|---|---|---|---|---|---|
| | | | SEP | Implied | REI |
| Capacity (GW) | Solar | 56 | 64 | 102 | 145 |
| | Wind | 4 | 10 | 23 | 29 |
| | Geothermal | 1 | 1-2 | 1 | 2 |
| | Biomass | 5 | 6-7 | 8 | 8 |
| | Hydro | 21 | 49 | 23 | 24 |
| Generation (TWh) | Solar | 63 | 75 | 123 | 173 |
| | Wind | 7 | 18 | 65 | 82 |
| | Geothermal | 3 | 10-11 | 4 | 7 |
| | Biomass | 24 | 39-49 | 51 | 52 |
| | Hydro | 81 | 94-98 | 82 | 84 |
| | Total | 177 | 237-252 | 324 | 398 |

Note: SEP= Strategic Energy Plan, Implied= Current Policy Implied Energy Mix (ie, table 1), REI=REI Sustainable Energy Mix (ie, table 2)
Source: REI, 2020 (Author's translation)

ply and relative contributions to the power mix are not estimates but actual results. The main difference between the two tables is the projections for 2030 power generation and percentages of the power mix. Also, the REI data in tables 1 and 2 on 2030 overall power demand, supply, and relative percentages of the power mix are their ideal case (table 1) contrasted to their estimation of where current policy (de facto rather than de jure) is driving the system (table 2). We can see from the table 2 figures for 2030 that the REI believes renewable energy is already on track to achieve 30% of the power mix (cf, the Wood Mackenzie forecast of 27%, noted above), leaving natural gas to decline slightly from 40% in 2017 to between 35 and 39% in 2030. Meanwhile, the REI projects coal to decline to 26% in 2030, from 33% in 2017. And nuclear is viewed as occupying a small share of 3 to 7%, possibly not much up from its 3% share in 2017 (but note that in April, 2020 Japan's nuclear share was 7.6%, according to METI, 2020).

Table 3 (table 3-1 in the original) shows what REI believes to be the difference between the official energy policy, de facto energy development, and aggressive policy for each category of renewables. On the left-hand side, the table shows each type of renewable in terms of capacity (GW) and generation (TWh). The 2018 data for the respective level of capacity and generation are entered in the middle of the table. The right-hand side of the table presents REI 2030's summation of three different scenarios for 2030: 1) the current

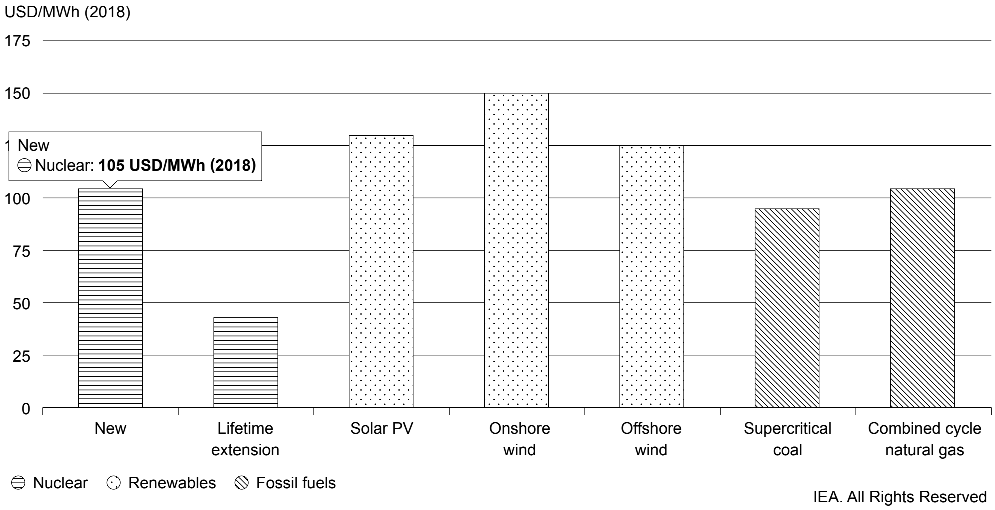
Strategic Energy Plan (in the table, SEP), 2) the Current Policy Implied Energy Mix (Implied), and 3) the REI's Sustainable Energy Mix (REI). The table shows that the REI believe aggressive policy would incentivize a near tripling of solar capacity from 56 GW in 2018 to 145 GW by 2030, far more than the 64 GW aimed at in SEP and the 102 GW the REI deem likely under current policy. In tandem, the REI believes that pro-active policy could raise wind generation capacity (both onshore and offshore) from 4 GW in 2018 to 29 GW in 2030, again much more than SEP and Implied. In the REI scenario, other renewables such as hydro and geothermal would remain largely unchanged relative to how they judge implied policy.

In summary, the REI advocate solar and wind as Japan's crucial decarbonizing combination, a sharp change from the Strategic Energy Plan projection of renewables (in general) and nuclear as key for decarbonization. The REI also raise the role of gas almost 30%, compared to the Strategic Energy Plan projections and what is implied by current policy. In choosing gas over nuclear, the REI have implicitly opted to trade off some element of diversified energy security, decarbonization and economic cost, to back up variable solar and wind with imported, expensive and carbon-intensive liquid natural gas (LNG). The REI justify taking low-carbon nuclear out of the mix on the grounds of negative public opinion and a vision of long-term decarbonization by 100% renewable energy. In their estimation, aggressive policy and their scenario of solar, wind and gas, and reduced power consumption, would lead to more than a 50% cut in emissions from the power sector by 2030, relative to 2018.

### The REI Proposals' Assumptions and Omissions

As noted earlier, there are numerous assumption and omissions in the REI report. Below, we list them in brief before dealing with each in greater detail. We believe that the IEA, IRENA and other data overlooked by the REI study call into question the viability of its proposals.

1) One questionable assumption in REI 2030 is that solar and wind are already the cheapest power options. This assertion is certainly not correct for Japan, where even sympathetic analysts in *PV Magazine* note that the cost of solar remains "among the highest in the world" (Hall, 2020). Figure 2 shows us that Japanese VRE (ie, Solar PV, Onshore wind, Offshore wind) levelized power prices in 2018 were considerably higher than for coal and gas. The figure indeed shows that levelized VRE costs in Japan were even higher than for new nuclear, and that the cheapest option among the displayed costs is



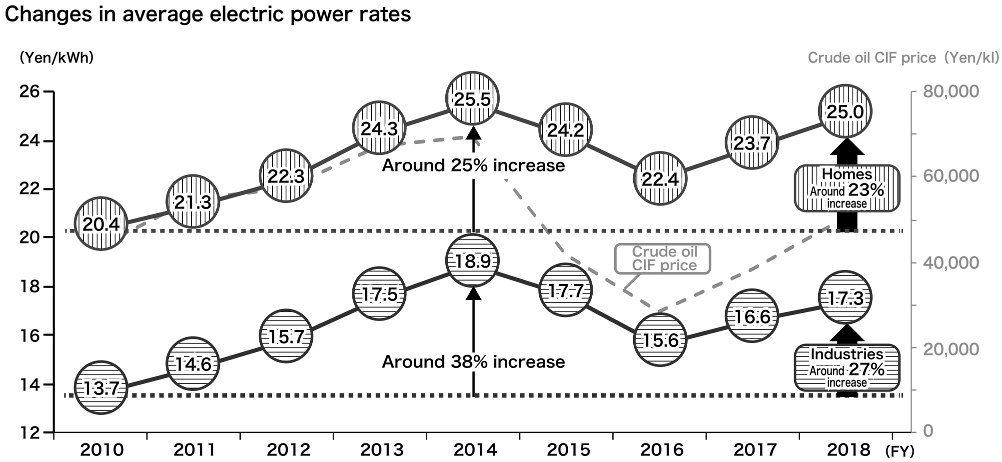

Source: IEA, 2019b

Figure 2 Levelized Cost of Electricity in Japan

for lifetime extensions of nuclear plant[4]. As for Japan's offshore wind, it is so pricey that the Japan Wind Power Association's ambitious scenario is cutting it to JPY 8 /kWh by the early 2030s, compared to the JPY 5 – 6 /kWh that prevails in Europe at present (Obayashi, 2020). The REI 2030, however, base their offshore wind cost projections on much more optimistic assumptions – from Bloomberg New Energy Finance – that Japan's offshore wind will cost just over JPY 5 /kWh by 2030. In short, the Japanese wind power experts (who presumably know their business) and the REI 2030 price projections for 2030 offshore wind differ by 60%. That gap suggests the REI 2030 is opting to use the most favourable assessments to support its arguments, which in fact risks undermining them.

A second problem on costs is that most calculations of solar, wind and other VRE generation costs overlook the larger system costs. These costs are defined as "the total costs above plant-level costs to supply electricity at a given load and given level of security of supply" (World Energy Council, 2020). The elements of these costs include the transmission, frequency regulation, storage, and other facilities required for connecting VRE to the main power grid and backing them up when they cannot generate power. These costs vary by scale of VRE, the project locale, the amount of VRE already on the

4 ) Moreover, since these nuclear plants are already connected to the power system, there are minimal system costs in restarting them. These costs are discussed below, but also taken up in World Energy Council (2020).




Source: ANRE, 2020

Figure 3 Japan's Power Prices, 2010-2018

grid, and other factors. As the World Energy Council 2020 paper on "Renewable Energy System Integration in Asia" puts it, there is "no free lunch." They point out that rising system costs are reflected in rising power prices. They therefore argue for clarity on the costs of integration, leading to a better-informed public debate on who should pay (World Energy Council, 2020). Wood Mackenzie also warned in September of 2020 that VRE investment in Asia generally is encountering grid constraints (in addition to other issues), clouding the outlook for deployment (Wood Mackenzie, 2020b). But in spite of this evidence that system costs are a major issue, the REI 2030 does not address them. The REI 2030 ignores the investments in transmission and storage required to connect distributed solar farms, geographically dispersed onshore wind, and clusters of offshore wind to the grid. It seems misleading to insist that the cost of solar panels and wind turbines is falling without paying attention to whether the transmission, storage and other system costs are declining as well.

Figure 3 indicates that it is especially important to consider costs, as household electricity prices have been rising since 2016. In the context of Covid-19, fuel prices have declined and power prices have accordingly dropped. But OECD data indicate that Japan's relative poverty rates and gendered income inequality are comparatively high. So power proposals need to keep in mind the risk of energy poverty.

2) A second questionable assumption is omission of concerns about critical material supplies and prices. REI 2030 is aimed at Japan's power system, a country that lacks domes-

tic resource endowments[5], so it seems reasonable to assume that Japanese RE advocates would be concerned about critical minerals (also known as rare metals, critical raw materials, energy metals, and various other terms). These materials include copper, lithium, cobalt, nickel, rare earths, and a long list of other metals needed for clean energy. Solar and wind do not burn fuel, in contrast to fossil fuel generation, but they do require massive upfront investments in often exotic materials in order to generate energy. Recent International Energy Agency (IEA, 2020b) and other reports on these critical materials warn that ambitious policies on renewables and electric mobility imply cobalt, lithium, nickel and other critical material demand that exceeds current supply. The IEA and other analyses discuss supply constraints, geostrategic risks, human rights concerns, environmental damage (from harvesting and processing critical materials), and related issues. The IEA's concerns parallel those of the Japanese[6], the European Union[7], and a rapidly growing number of other actors. Indeed, the August 31, 2020 *Financial Times* reported that the EU is sounding the alarm over critical raw materials, as "[s]hortages of elements used to make batteries and renewable energy equipment could also threaten the bloc's target of becoming climate neutral by 2050" (Peel and Sanderson, 2020).

Moreover, Japan's Strategic Energy Plan includes strategies to expand and diversify access to these materials, which the REI experts certainly read. So one would have thought that REI 2030 would offer suggestions on maximizing the efficient use of supply-constrained materials while transforming the power system. This is because many of these critical materials are used at far greater density, per unit of energy consumption or production, in green technologies as compared to conventional power systems, internal combustion automobiles, inefficient air conditioners, and the like. And supplies of these materials have myriad other competing sources of demand, including smart phones, data centres, refrigeration and cooling, health care, and other rapidly expanding areas.

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5) Japan does have undersea reserves in its Exclusive Economic Zone. The need for critical materials is so powerful that Japan has already undertaken seabed mining, announcing the world's first successful excavation in August of 2020. See Yomiuri Shimbun, 2020.

6) Japan's JOGMEC and other agencies publish numerous studies, as do the carmakers (eg, Toyota), battery suppliers (eg, Panasonic), metal firms (eg, Mitsubishi Materials) and other concerns.

7) 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/

The World Bank Group has also been deeply concerned about the supply-demand balance of critical raw materials for several years. Updating earlier work, on May 11, 2020 it released "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition" (World Bank Group, 2020). The report examined scenarios of likely demand for cobalt, copper and other materials, their potential GHG impact, and risks for shortages. One important backdrop to the report was the multiple effects of the Covid-19 pandemic, whose economic fallout led to a drop in prices for materials and reduced investment in new supply. The World Bank Group warns about constrained capacity to satisfy the need for critical materials in light of this context and accelerating moves towards a material-intensive green recovery. Against this backdrop of uncertainty, it would seem imperative that the REI 2030 call for the most materially-efficient deployment of these metals. Resource-poor Japan's renewable advocates should be among the leaders of the global debate in this respect, particularly considering the human rights abuses, environmental destruction, and other costs of critical materials.

3) A third implicit assumption of REI 2030 is that NIMBY and other opposition will not intervene. Yet solar and wind projects already face significant opposition in Japan, due to concerns about environmental damage, disaster resilience, health effects, dominance by big business, and other issues (Choushuu Shimbun, 2020). Community opposition has in fact led to a doubling of local government ordinances, from 30 in 2017 to 60 in 2019 (Nikkei Shimbun, 2020). And this opposition seems unlikely to go away. Indeed, there is significant opposition to new wind, transmission and other assets in Germany, one of the models for REI 2030. This opposition in Germany has led to difficulties in meeting goals, in addition to a very expensive plan to build transmission underground (Chu, 2020, IEA, 2020e).

The likelihood of increased local opposition certainly does not make a significant role for VRE impossible or inadvisable. But it does suggest that REI 2030 gives too much emphasis to solar and wind at the expense of other renewables such as geothermal, hydro, and biomass. These renewables play a large role in many countries, and have the advantage of being 24/7 sources of high-quality power. It pays to recall that REI 2030 aims at removing both nuclear and coal from the power mix by 2030. The massive and rapid power-shift advocated by REI 2030 would allow for little local consultation in planning what must necessarily be very large generation, transmission, storage and other projects.

4 ) Curiously, REI 2030 use Spain (21% nuclear), UK (21% nuclear), and German (12% nuclear) as examples of how to grow VRE. But they fail to note how those countries' increase in wind and solar has been and continues to be facilitated by nuclear and other 24/7 baseload power and massive international power trading networks. In other words, the REI 2030 skips over the question of whether Japan can do without these assets, even as REI 2030 builds its argument on the basis of them.

5 ) We have also seen that REI 2030 implies a massive increase in LNG use. This is a questionable choice for decarbonization. Natural gas is not only a comparatively costly fossil fuel in Japan (cf, the US). Its greenhouse-gas footprint depends on leakages in the production process as well as transmission through pipelines, conversion into LNG, shipment by LNG tanker, reconversion of LNG into natural gas, and then transmission to power-generation plant for combustion. Recent research suggests that these leakages may be higher than thought, leading to questions about the future of gas (Stern, 2019). REI 2030's plans imply huge new investments in the infrastructure to ship, transmit, and burn LNG, in order to drive extant and decarbonizing nuclear assets out of the power mix. This aim does not seem consistent with climate goals.

6 ) A related problem is that the REI 2030 also simply assumes that LNG costs and supply will not be significantly impacted over the next decade. This is a gamble, and should be addressed as such. Certainly Covid-19 flattened LNG demand and thus prices, and may do so again in a second wave of infection and lockdowns. But LNG has become a focus of energy demand growth globally, and particularly within Asia (Iwamoto, 2019; Timera Energy, 2020). Over the next few years, that demand could lead to higher prices, especially because of stalled projects and growing opposition to new development, particularly in the US (Cocklin, 2020).

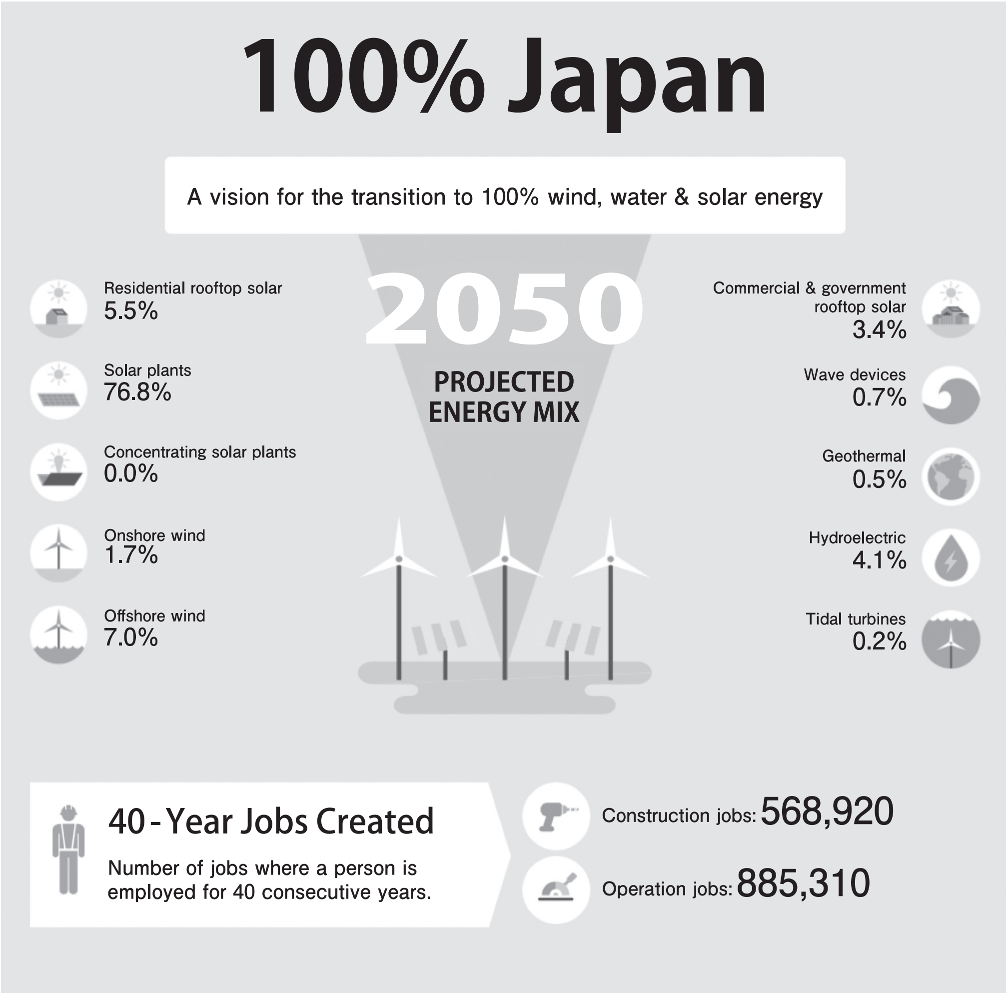
In short, the evidence clearly indicates that the REI 2030 needs a deeper analysis of hurdles and opportunities for decarbonizing Japan's power mix. Perhaps it is possible for Japan to eliminate both coal and nuclear from its power mix in a decade and still have a viable economy. But surely the narrowing of the power mix – to the precarious tripod of LNG, solar and wind – needs to be rethought, in light of critical materials, costs, NIMBY, and other patent risks. A broader portfolio of power sources seems imperative. After all, it was not so long ago when nuclear supplied a quarter of Japan's power and was poised to ramp up. We learned from Japan's 3-11 Fukushima crisis (and now Covid-19) that fat-tail events happen, which is why the key to resilient energy systems is diversity. Were Japan to pursue the REI 2030 "sustainable scenario," it could soon find itself in a severe crisis brought on by NIMBY, escalating costs, and other challenges. The REI 2030 overlooks far too many risks in aiming to get 54% of Japan's power mix from costly LNG in order to back up a 45% renewable share composed almost entirely of intermittent solar and wind.

### Previous 100% RE Visions for Japan

But the REI 2030 approach, discussed earlier, is generally consistent with previous 100% RE visions in Japan. These studies generally rely heavily on VRE and ignore myriad material, governance, NIMBY, and other issues. The advocates want Japan to exit both nuclear and coal as soon as possible, and to eliminate all fossil fuels in a few decades. Some of their proposals are dated, such as Greenpeace's September 12, 2011 "Renewable Energy Revolution for Japan." This scenario addressed only the power sector, and allowed natural gas to remain part of the power mix in 2050 (Greenpeace Japan, 2011). But most of the analysts now offer ambitious scenarios in which Japan could achieve 100% reliance on renewable energy by 2050. And in contrast to REI 2030, which aimed at the power mix only, whose output is roughly 46% of Japan's total energy as of 2018 (FEPC, nd). The proposals below do not restrict themselves to electricity alone, but rather address all energy, including heating/cooling, transport and such energy-intensive industrial processes as making steel and aluminum.

One example is "The Solutions Project" (2017), outlined in **figure 4**. The Project's main scientific advisors are Stanford University's Mark Jacobson and other experts (Hanley, 2018). Their Project scenarios and previous works are frequently cited in Japanese and international arguments that a 100% renewable energy economy is achievable in the medium term, with reduced costs (eg, EIC, 2018; Tsuchiya, 2017). Jacobson and his colleagues are perhaps the world's foremost exponents of a 100% RE transition. For example, American Senator and 2020 Democratic Presidential primary candidate Bernie Sanders (who co-authored an op-ed with Jacobson in the April 29, 2017 edition of *The Guardian*[8]), former US Vice-President Al Gore, and other have relied on their work. The Solutions Project has also informed energy policymaking in such US states as California and New York (Spector, 2017).

8) See Bernie Sanders and Mark Jacobson, "The American people – not Big Oil – must decide our climate future," *The Guardian*, April 29: https://www.theguardian.com/commentisfree/2017/apr/29/bernie-sanders-climate-change-big-oil

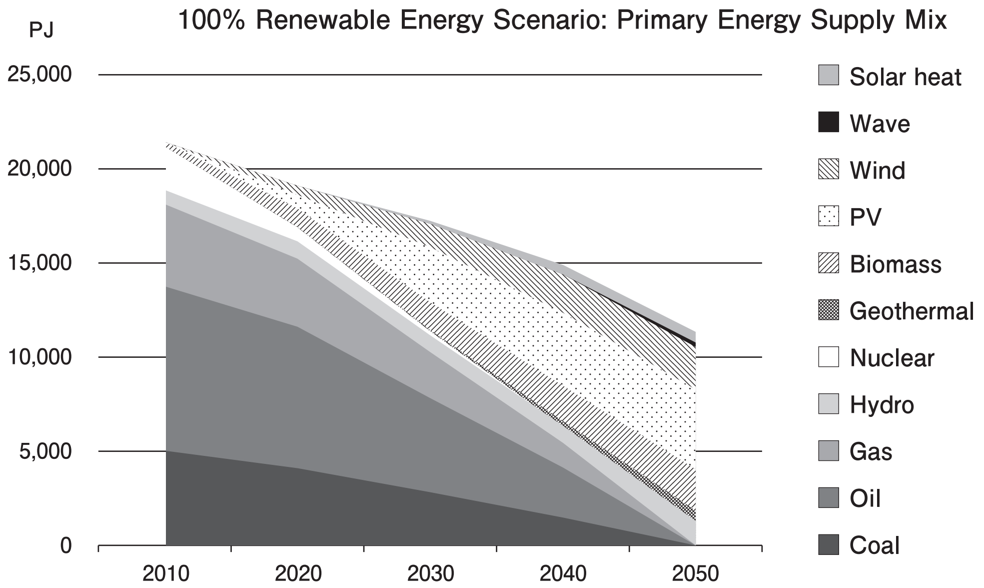



Source: The Solutions Project, 2017

Figure 4 The Solutions Project 100% Renewable Proposal for Japan

As figure 4 shows, this initiative's vision for Japan posits that solar arrays could provide over 85% of all energy needs by 2050. That number is the sum of the various categories of solar, including residential rooftops, commercial and government rooftops, and solar plants. The Solutions Project further argues that supplementing this solar with some wind and hydro could allow Japan to displace all fossil fuels and nuclear while reducing energy costs by about 35%. It also calculates that the transition would create 568,920 construction jobs and 885,310 operational jobs (The Solutions Project, 2017).

The Solutions Project is only one example of several 100% renewable proposals for Japan. Another 100% renewable proposal is offered by the World Wildlife Federation Japan




Source: WWF Japan, 2017b

Figure 5 WWF Japan Long-Term Scenario for a Decarbonized Society

(WWF Japan, 2017a). On February 16 of 2017, the WWF Japan published a “Long-Term Scenario for a Decarbonized Society,” together with a brief executive summary in English. As seen in figure 5 and table 4 borrowed directly from the executive summary, this scenario also seeks to substitute all fossil fuels and nuclear energy with renewables.

Interestingly, the WWF’s projected energy mix is considerably less reliant on solar than the Solutions Project. We saw that the Solutions Project foresaw Japan’s energy being over 85% solar. By contrast, the WWF scenario projects solar’s share of all primary energy to be only 38% by 2050. While less ambitious in this respect that the Solutions vision, the WWF scenario still involves some fairly bracing numbers. It foresees solar energy rising from providing 20 petajoules (PJ) of primary energy in 2010 to 4,316 PJ in 2050, an increase of 215.8 times. The next highest shares of primary energy are the 19% represented by wind and biomass respectively. Following that, hydro is estimated to be 11%, with geothermal contributing 5%, solar thermal 5%, and marine energy 2%. The projected costs of the deployment are JPY 191 trillion for efficiency and JPY 174 trillion for renewable capacity, with these expenses calculated to result in a net saving of JPY 84 trillion. The WWF scenario sees primary energy supply dropping by nearly 50%, from 22,157 PJ in 2010 to 11,287 in 2050 (WWF Japan, 2017a; WWF Japan, 2017b).

Table 4 WWF Japan Long-Term Scenario for a Decarbonized Society

| | Primary energy supply (PJ) | | | | | Share | |
|---|---|---|---|---|---|---|---|
| | 2010 | 2020 | 2030 | 2040 | 2050 | 2030 | 2050 |
| Coal | 4,981 | 4,076 | 2,814 | 1,443 | 0 | 16% | 0% |
| Oil | 8,819 | 7,474 | 5,009 | 2,657 | 0 | 29% | 0% |
| Gas | 4,243 | 3,682 | 2,380 | 1,278 | 0 | 14% | 0% |
| Hydro | 747 | 810 | 873 | 949 | 1,215 | 5% | 11% |
| Nuclear | 2,322 | 801 | 207 | 0 | 0 | 1% | 0% |
| Geothermal | 28 | 33 | 66 | 331 | 552 | 0% | 5% |
| Biomass | 153 | 938 | 1,500 | 1,778 | 2,200 | 9% | 19% |
| PV | 20 | 794 | 2,890 | 3,900 | 4,316 | 17% | 38% |
| Wind | 29 | 397 | 1,260 | 1,946 | 2,167 | 7% | 19% |
| Wave | 0 | 0 | 2 | 118 | 237 | 0% | 2% |
| Solar heat | 0 | 20 | 120 | 444 | 600 | 1% | 5% |
| Total | 22,157 | 19,025 | 17,122 | 14,844 | 11,287 | | |
| Total renewables | 976 | 2,992 | 6,711 | 9,466 | 11,287 | 39% | 100% |

Source: WWF Japan, 2017b

## Some Problems with the 100% Scenarios

Critiquing the Solutions Project is a risky endeavor, as its principal author, Mark Jacobson, took previous critics to court on September 29, 2017. These 21 critics, under lead author Christopher Clack (a PhD in solar physics and specialist in wind and solar forecasts), argued that 100% RE was likely not possible and that many aspects of the scenario were questionable. They are all strong advocates of renewables, and of aggressive decarbonization, so they were not denying that very high levels of renewable energy could be attained. But they also insisted that Jacobson's own modeling issues showed that nuclear or carbon-capture fossil energy (or some combination of the two) would be needed to fill the gap and, as it were, keep the lights on with a very high level of certainty and at an acceptable cost.

Quite germane to our purposes here, one of the most glaring problems that Clack et al highlighted was the Jacobson et al assumption (for the US case) that massive hydroelectric capacity, about 600 Hoover Dams worth (1,300 gigawatts) could be used as back-up. The Jacobson et al work apparently made a signal error in assuming 15 times hydro capacity was readily available (Porter, 2017). Clack and his coauthors published their work (Clack, 2017) in the *Proceedings of the National Academy of Sciences* (PNAS), and Jacobson was given space for rebuttal. However, he angrily took Clack and the National Academy of

Sciences (NAS) to court, targeting them with a USD 10 million defamation suit. The suit was eventually dropped, on February 22, 2018, but burdens on the lead author were about USD 500,000 and the NAS costs might have been even higher.

In addition, the suit clearly had an inhibiting effect on the climate-energy debate. Climate scientist Ken Caldeira, one of the world's most respected experts and a co-author of the Clack paper, has publicly described how an article rebutting Jacobson was passed on to him anonymously "because the author worried about it being sued" (Caldeira, 2018).

Quite rightly, the suit was derided as "ridiculous" by Pulitzer Prize-winning journalist Michael Hiltzik, who (like others) argued convincingly that Jacobson withdrew the suit because the judge in the case was about to dismiss it on the basis of a SLAPP ("Strategic Lawsuit Against Public Participation") charged levelled by Clack and the NAS (Hiltzik, 2018). The SLAPP-related laws were specifically designed "to provide for early dismissal of meritless lawsuits filed against people for the exercise of First Amendment rights" (Media Law, nd).

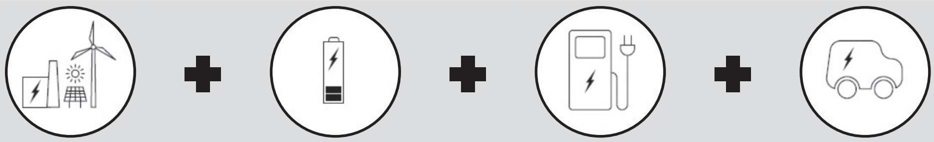
Adding to the oddity of the Jacobson et al suit against Cohen et al, Jacobson employed the law firm Cohen Seglias Pallas Greenhall & Furman PC. Yet the same law firm is prominent in defending fossil fuel interests. Indeed, their "Energy and Utilities" website declares this explicitly, stating that the firm is a "proud member of the Marcellus Shale Coalition" (Cohen Seglias, nd.).

In the event, even though Jacobson withdrew the suit, the court was not sympathetic. On April 20, 2020, the presiding judge ruled that Jacobson must pay the defendants' (ie, Clack and the NAS) legal fees. On June 25, 2020 the judge also summarily dismissed Jacobson's appeal of the initial ruling (Retraction Watch, 2020). Moreover, Jacobson et al appear to have suffered reputationally due to Jacobson's action: their most recent work (Jacobson et al, 2019), an update of the Solutions Project, is published in a far less prestigious journal than PNAS.

More importantly, this paper argues that the Solutions Project, at least its application to Japan, suffers from serious inattention to infrastructure, governance and energy security. These problems are similar to the REI 2030, discussed above. For example, it seems quite risky for Japan to secure nearly all its energy needs from solar. These risks relate to material supplies, infrastructure, governance and energy security.

First, Japan would have to deploy enormous amounts of silicon, steel, concrete, copper, cobalt and other materials in building out a vast solar capacity together with greatly expanded storage, transmission and distribution networks. Yet copper alone is a significant challenge for resource-poor Japan, not to mention the global economy in general. Copper requirements for renewables are generally 5 times that of conventional energy. Hence, even in the mid-2010s, there was already considerable concern that global supply can meet increasing demand for solar, wind, electric cars in the short and medium term, let alone the 100% RE energy transition scenarios. Similar problems confront cobalt, whose supply is constrained but which is crucial to batteries and renewable power systems (Sanderson, 2018). The other materials, such as steel and silicone are less constrained in terms of absolute supply. But the quantity required for a rapid build-out of solar, wind and other renewables, to displace a significant share of fossil fuels, would be prodigious. That fact does not make the initiative impossible or unwise, as decarbonization is an urgent imperative. But the most practical, least-cost route to decarbonization is essential, as there are multiple other demands on fiscal, material, human, and other resources. Decarbonization via renewables alone would almost certainly require a coordinated, intensively planned approach that rationed scarce commodities. In other words, finite supplies of critical materials would have to be allocated by planners rather than left to decisions by firms and consumers. In concrete terms, individual consumers would be required to forego many common goods (such as electronic devices and automobiles) so as to permit a focused use of scarce materials.

Figure 6 offers one example of how much demand would increase for critical raw materials (CRM) even under conservative assumptions. The figure represents the increased demand for copper (Cu), nickel (Ni) and cobalt (Co) between 2020 and 2030 for a scenario in which 30% of new vehicle sales are electric, non internal-combustion (ICE) vehicles. As



**Generation and grid infrastructure (kt)**

| | 2020 | 2025 | 2030 |
|---|---|---|---|
| Cu | 40 | 170 | 536 |

**Grid storage (kt)**

| | 2020 | 2025 | 2030 |
|---|---|---|---|
| Cu | 24 | 86 | 180 |
| Ni | 20 | 71 | 150 |
| Co | 7 | 26 | 55 |

**Charging infrastructure (kt)**

| | 2020 | 2025 | 2030 |
|---|---|---|---|
| Cu | 23 | 115 | 392 |

**Non - ICE vehicles (kt)**

| | 2020 | 2025 | 2030 |
|---|---|---|---|
| Cu | 304 | 1,068 | 2,972 |
| Ni | 66 | 299 | 985 |
| Co | 17 | 80 | 259 |

**Leading to additional metal demand by 2030**

**Copper 4.1 Mtpa**
18% of 2017 global supply

**Nickel c.1.1 Mtpa**
55% of 2017 global supply

**Cobalt 314ktpa**
332% of 2017 global supply

Source: Glencore, 2018

Figure 6 Critical Material Demand for 30% Electric Vehicles by 2030 the figure shows, there would be a considerable increase in copper demand for the generation and transmission infrastructure to cope with the electrification of transport. Indeed, copper demand in this sphere alone is calculated to increase from 40 kilotonnes (kt) in 2020 to 536 kt in 2030. Other areas include grid storage, charging infrastructure, and the vehicles themselves, where required volumes of copper, nickel and cobalt increase many times in the decade 2020–2030. The bottom section of the figure shows what this new demand represents as a fraction of 2017 global supply. Copper demand for EVs in 2030 is seen to reach 18% of 2017 global supply. Without massive increases in copper production, that share would necessarily restrict the amount of copper available for other goods. The challenge is even more bracing for nickel and cobalt, whose respective demand in 2030 becomes, respectively, 55% and 332% of 2017 global supply.

These concerns are hype from the mining industry, in search of investment capital. In March 2018 Japan's JOGMEC grew concerned enough to release a detailed report (in Japanese) on "Changes in the Copper Business Since 2000." JOGMEC investigates the lessons learned from the material-intensity of China's development (about half of global copper consumption) and what it implies for other low and middle-income countries with large populations and massive latent infrastructure demand. It also examines the copper-intensiveness of projected urbanization, mobility and power generation, while outlining the supply problems due to declining ore grades, under-investment in new projects, political instability, environmental damage, and related factors (JOGMEC, 2018).

Infrastructure is another problem area. Japan's current power grid, a network exceeding 4.22 million kilometers (ANRE, nd), would have to drastically reconfigured. Like other power systems, its major transmission cables were built for centralized, stable, large-scale generation (especially nuclear and fossil fuels), a clear hurdle in undertaking an energy transition towards distributed energy. But in addition, Japan's national power grid is split (for historical reasons) into two zones of different frequencies. In Japan, shifting from highly centralized generation to more of its polar opposite – solar on a multitude of roofs and open spaces – implies a massive, resource-intensive investment in cables, frequency converters, batteries, heat pipes and other infrastructure to generate, transmit, store and distribute the energy. Construction costs are notoriously high in Japan, due to land scarcity and other factors. Hence, the Solutions Project's vision would perhaps be more persuasive if it provided even a rough estimate of the costs of this large-scale and complicated network.

As to governance, the Solutions Project does not address the critical question of whether price incentives are sufficient to mobilize the required scale of investment. Though its scenario indicates that energy costs would decline by shifting to renewables, that may not happen as we saw in earlier our review of REI 2030. Moreover, even if VRE and ancillary costs (eg, system costs) eventually do decline, the direct pecuniary benefits come after quite large upfront investments. That fact requires that investors possess relatively long time-horizons and a high degree of certainty that their investments will remain viable. But as we shall see later concerning critical raw material per se, long-time horizons are not favoured by stock markets or by civil society. Rather, short-term incentives and a myriad distractions overwhelm the capacity to plan. Only very close collaboration among the public and private sectors, together with civil society, seems likely to lead to the extensive planning, or industrial policy, required to shift the energy economy. That collaborative approach is required in order to capture the non-monetizable health and other benefits (positive externalities) that accrue to society as a whole as opposed to individual firms, investors and other economic agents. Moreover, collaborative planning would seem essential to keep the energy transition's deployment of power and thermal energy systems consistent with Japan's rapidly changing demography, the effects of climate change on insolation and wind speeds, and other pertinent factors.

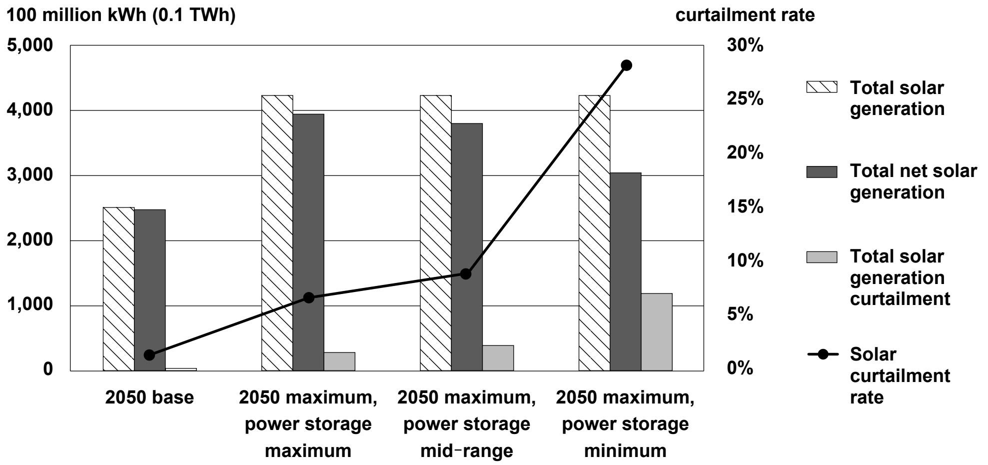
Another problem is energy security. Nowhere in Solutions Project is there any concern expressed that relying so heavily on solar may present significant risks in an archipelago subject to increasingly severe weather extremes. For example, some of Japan's solar arrays have suffered damage by high winds and typhoons (Kaneko, 2019; KGS, 2017), and they have significant challenges generating power in snow-bound regions (Nikkei Shimbun, 2017). It is also perhaps unwise, as solar expert (and one co-author of the Clack paper) Varun Sivaram argues, to overcommit to solar. It may be more cost-effective and secure to make it part of a portfolio, integrating it with other energy sources and infrastructures. Sivaram makes this argument on the basis of lessons learned from past decade's undue confidence in nuclear energy (Sivaram, 2018).

Much the same could be said for the WWF vision, though it is far less reliant on solar than the Solutions Project. But like the Solutions Project, the WWF vision does not concern itself with transmission costs and other ancillary issues. In fact, it even ignores capital costs (Shiozu, 2017).

### The Japanese Photovoltaic Energy Association Vision for 2050

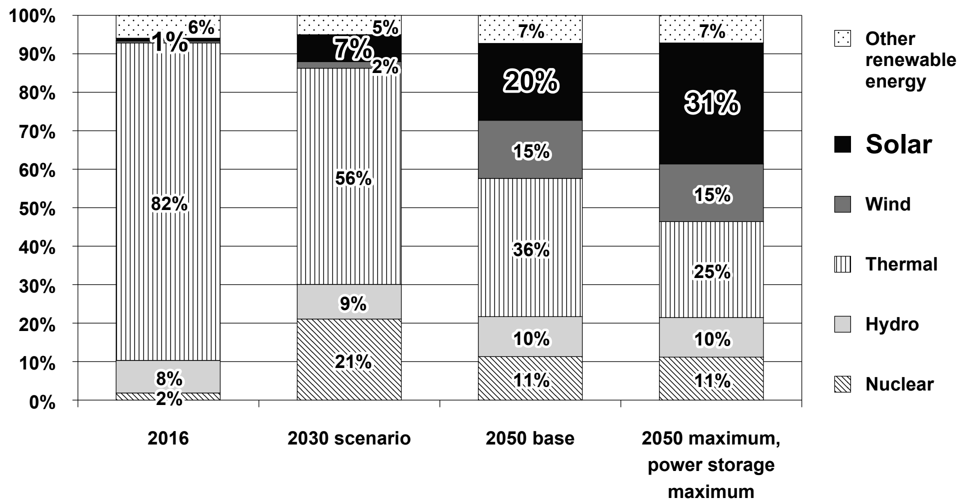
We next turn to consider a May 18, 2020 study by the Japanese Photovoltaic Energy Association (JPEA). The JPEA title their assessment a "Vision for 2050" for overcoming the pandemic and building a new society. In other words, they are aimed at one aspect of a green recovery. It will be useful to review the details of the JPEA assessment and compare them with REI 2030 in addition to the Solution Project and others.

The Japanese data from the JPEA give additional cause to question the argument that VRE is the cheapest and only choice for decarbonization, as implied by REI 2030 and other arguments. The JPEA naturally wants to maximize solar, and thus sketches a scenario in figure 7. The JPEA scenarios for 2050 suggests that storage solutions (such as pumped hydro




Source: JPEA, 2020

Figure 7 JPEA Solar and Storage Scenarios for Japan

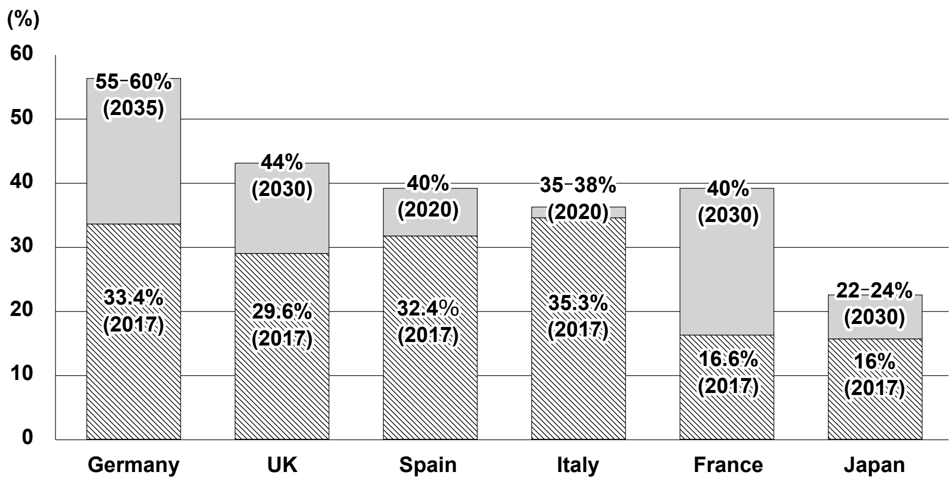



Source: JPEA, 2020

Figure 8 JPEA Power-Mix Scenarios for Japan and batteries) greatly reduce the need for overbuild. The JPEA's best case foresees ample storage, leading to just under 400 TWh of net generation from solar. They show that storage solutions dramatically reduce rates of curtailment and thus lost output. Their base scenario is for about 250 TWh in 2050.

As we see in figure 8, the JPEA scenario builds on the maximized solar outlook, projecting a future which solar moves from 1% of total power generation in 2016 to 7% in 2030, and then – depending on the storage availability – to either 20% or 31% in 2050. Over the same period, wind increases from about 1% to 15% in 2050. Interestingly, thermal power does not disappear, but rather declines from 82% in 2016 to 25% in 2050. Presumably, the JPEA outlook is for a switch from coal to natural gas (LNG). Over the same period, hydro rises from 8% of power generation to 10%. This increase is modest relative to assertions that the Dam Revival Vision policy could double or triple hydro's role in Japanese power generation (MLIT, 2017).

Even more interesting, considering Japan's anti-nuclear domestic politics and the REI 2030 vision, the JPEA 2050 Vision forecasts nuclear to rise from 2% in 2016 to 11% in 2050. And this overall scenario is based on the assumption that solar is backed up by maximum storage capacity. In the JPEA 2050 Vision base case, solar achieves only 20%, and none of the other RE and nuclear shares change. This fact leaves thermal power to fill the gap by increasing from 25% (in far-right column portraying solar storage as maximized) to 36% (in 2050 base case).



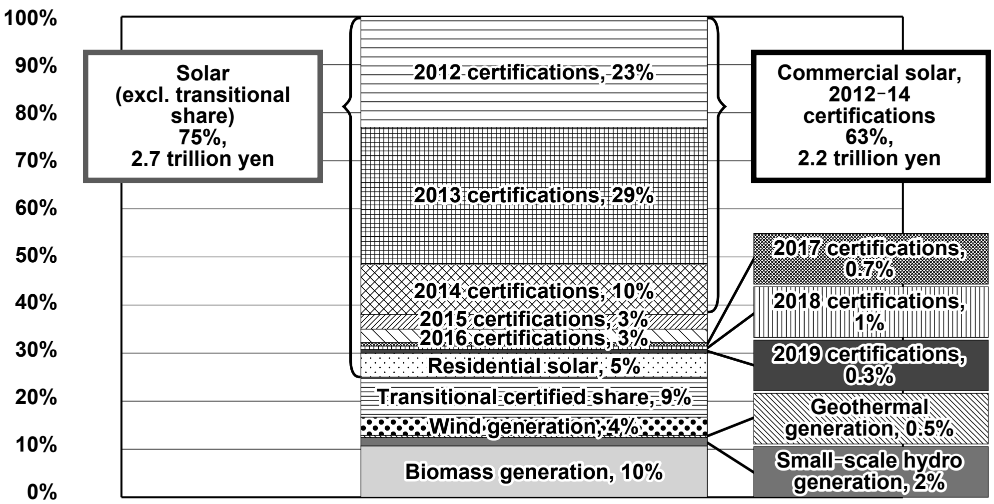

Source: JPEA, 2020

Figure 9 JPEA Comparative Power-Mixes and Targets

As we see in figure 9, the JPEA scenario includes a snapshot of comparative RE profiles by major country for 2017 and commitments (for between 2020 and 2035). Hence, the data for Germany show an undifferentiated RE of 33.4% in 2017 and a commitment to raise that to 55-60% by 2035. The Japanese case reflects the numbers in the 5th Strategic Energy Plan. This kind of comparison is frequent in Japanese and other RE studies. But it might be more realistic to compare Japan with Asian-region neighbours and with large islands and peninsulas. It would also be more useful to show the role of hydro and geothermal, which tends to be very large in Iceland, New Zealand, and other island cases with significant renewable penetration in the power mix.

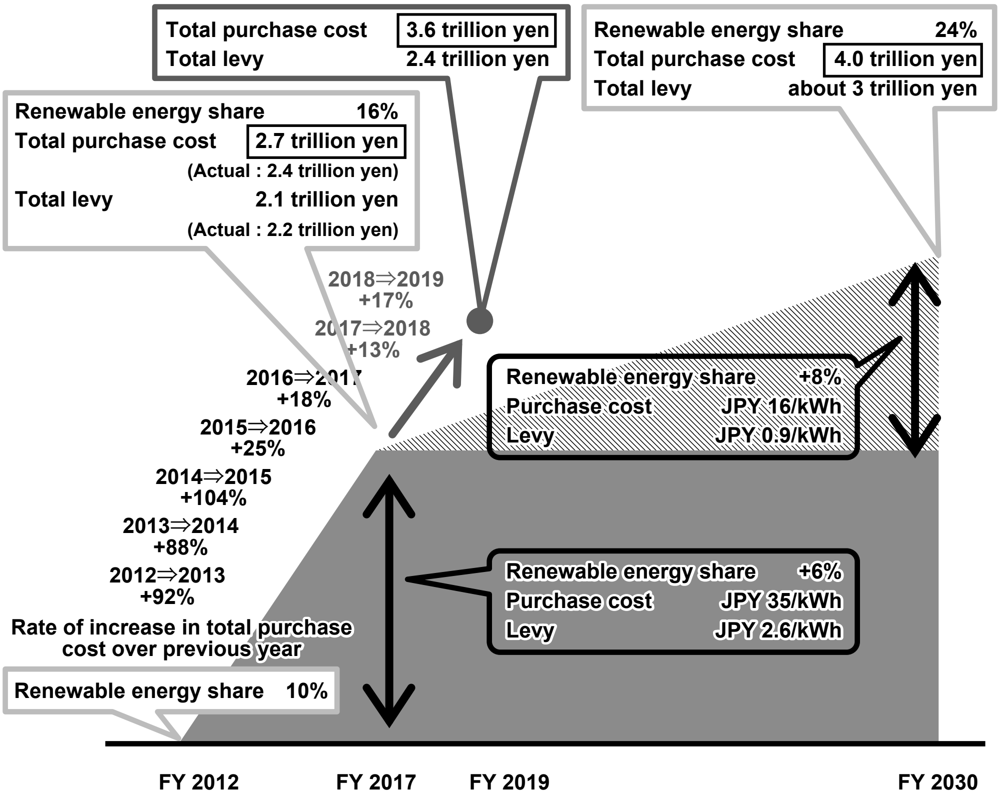
The JPEA data, in figure 10, show that Japan's RE after 3-11 was almost entirely composed of expensive solar. The column shows that fully 84% of Japan's new RE in the wake of the 2011 disaster was solar (including transitional certified share, meaning projects given regulatory asset but still under construction). The remaining 16% was composed of biomass (10%), wind (4%), small-scale hydro (2%), and geothermal (0.5%). The figure also provides a breakdown of costs, at least for operating solar from 2012-2019, which totals JPY 2.7 trillion in FIT tariff support. Installation and system costs are separate from this figure.

The JPEA figure 11 analysis is based on a METI projection of FIT support costs, adjusted according to changing rates of support (METI, 2019). We see from the lower-left




Source: JPEA, 2020

Figure 10 JPEA FIT Costs for RE in Japan, 2012-2019

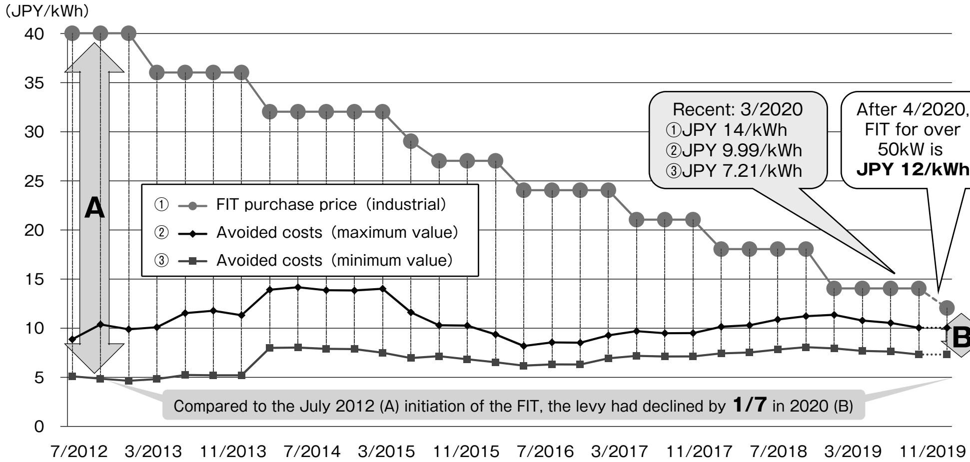



Source: JPEA, 2020

Figure 11 JPEA FIT/FIP Costs for RE in Japan, 2012-2030

corner of the figure that the RE share in power in 2012 was 10% and that between 2012-13 the total purchase cost via the FIT rose 92%. Over the following years to 2017, the cost of raising the RE share by 6 % was an average FIT of JPY 35/kWh and levy (or system costs) of JPY 2.6/kWh. This cost is projected to decline to JPY 16/kWh and JPY 0.9/kWh respectively between 2017 and 2030. The data for 2017 show that the RE share had risen to 16%, while the FIT support increased to JPY 2.7 (JPY 2.4 actual) and the levy to JPY 2.1 (JPY 2.2 actual). In 2019, these totals had risen yet again to JPY 3.6 trillion and JPY 2.4 trillion respectively. The levy is system-cost calculation done by subtracting the avoided cost of fossil fuels from the total FIT support purchase cost and then adding an administrative charge for adjusting the costs. The FIT supports portrayed in the figure are for solar. As for other power generation, including offshore wind (since 2018), it receives higher support in order to incentivize more investment and reduce the over-reliance on solar.

The METI (METI, 2019) calculations also show that Japan's cost of raising RE from




Source: JPEA, 2020

Figure 12 JPEA FIT Support for Solar in Japan, 2012-2020

10% to 15% was an average of JPY 2.25/kWh, much higher than Germany's average of JPY 0.63/kWh and the UK's JPY 0.28/kWh. The reasons are several, and include Japan's excessive focus on expensive solar, the too-generous FIT supports, constrained land and other resources.

The JPEA figure 12 shows that Japan's FIT supports for solar declined between 2012 and 2020. The 2012 JPY 40/kWh had dropped to under JPY 15/kWh for all types by March of 2020. Avoided costs remained relatively flat at about JPY 10/kWh for most of the period (or between JPY 5 - 7 /kWh by a more conservative estimate). This resulted in a 1 / 7 decline in the levy in 2020 versus what it was in July 2012, when the FIT was started.

JPEA builds on the data reviewed above to present – in Table 5 – its scenario for a large build-out of solar for 2030 and 2050. The scenario projects solar rising from 3.4% of power output in 2015 to 11.6% in 2030 and then 31.4% by 2050. To achieve this level of power output, the scenario envisages 300 GW of solar capacity by 2050. It makes a set of assumptions about how much that capacity would cost, how much imported fossil fuel it would displace, what level of final energy consumption would be provided, and the amount of GHG that would be reduced. We can see from Table 5 that JPY 2.7 trillion in fossil fuels is projected to be displaced by 2050, via the solar generation.

Figure 13 is a summary visualization of the data in Table 5. The scenario does not apparently assess the lifecycle material and fossil-fuel costs of building out the solar capacity (which is very CRM-intensive) and maintaining it. Solar panels and their associated infrastructure have an average lifetime of roughly 20-25 years, after which they have to be re-

Table 5 JPEA Cost-Benefit Assessment of Solar in Japan, 2015-2050

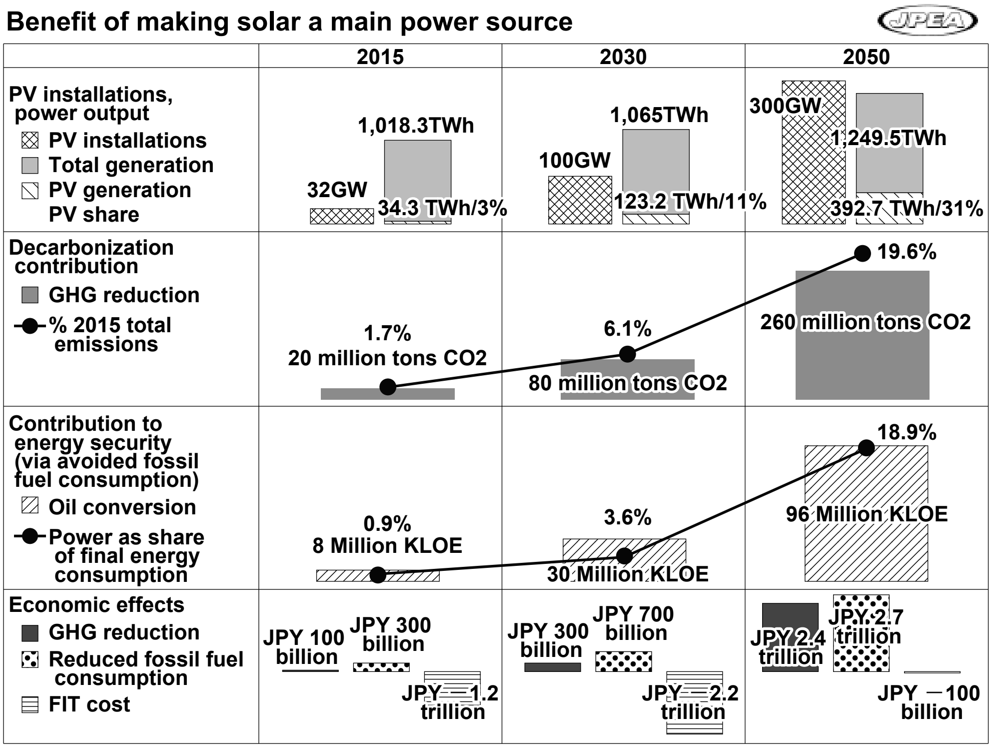
| Importance/goal | | Benefit/expected effect | | |
|---|---|---|---|---|
| | | Base (2015) | 2030 | 2050 |
| National solar power installation | Cumulative operating capacity | 32 GW | 100 GW | 300 GW |
| | Power output | 34.3 TWh | 123.2 TWh | 392.7 TWh |
| | Share of total national power generation | 3.4 % | 11.6 % | 31.4 % |
| Total national electricity generation | incl. in-house generation, transmission & distribution losses | 1,018.3 TWh | 1,065 TWh | 1,249.5 TWh |
| Decarbonization contribution (via reduced GHGs) | GHG reduction | 23 million tons $CO_2$ | 81 million tons $CO_2$, approx. | 259 million tons $CO_2$ |
| | % 2015 total emissions | 1.7 % | 6.1 % | 19.6 % |
| | Carbon price conversion | — | JPY 700 billion | JPY 2.4 trillion |
| Contribution to energy security and reduced costs (via avoided fossil fuel consumption) | Oil conversion | 8 Million KLOE | 30 Million KLOE | 96 Million KLOE |
| | Fossil-fuel cost reduction | JPY 300 billion | JPY 700 billion | JPY 2.7 trillion |
| | Power as share of final energy consumption | 0.9 % | 3.6 % | 18.9 % |
| FIT cost | | JPY 1.18 trillion | JPY 2.2 trillion | JPY 0~100 billion |

Source: JPEA, 2020

placed and (one hopes) recycled. Apart from base metals such as steel and aluminum, which solar requires in surprising abundance, solar has a large CRM footprint. The CRMs (copper, silicon, and others) used in solar weigh about 8,000 kg/MW of capacity, and this capacity should be assessed on a 20-year lifecycle. As a result, it is difficult to determine whether the JPEA assessment is reasonably accurate. And this is apart from the impossibility of verifying its assertions about future fossil-fuel costs.

Though the fuel and CRM numbers are uncertain, the JPEA does do a good job of seeking to assess the cost-benefit of solar in Japan's power mix. We see the data for power output and other items presented as blocks corresponding to their changing scale. The power output data are significant. Less credible are the emissions-reduction data, as there is no assessment of Japanese solar's lifecycle emissions.

The JPEA data include a cost-benefit assessment of solar installed between 2020-2030



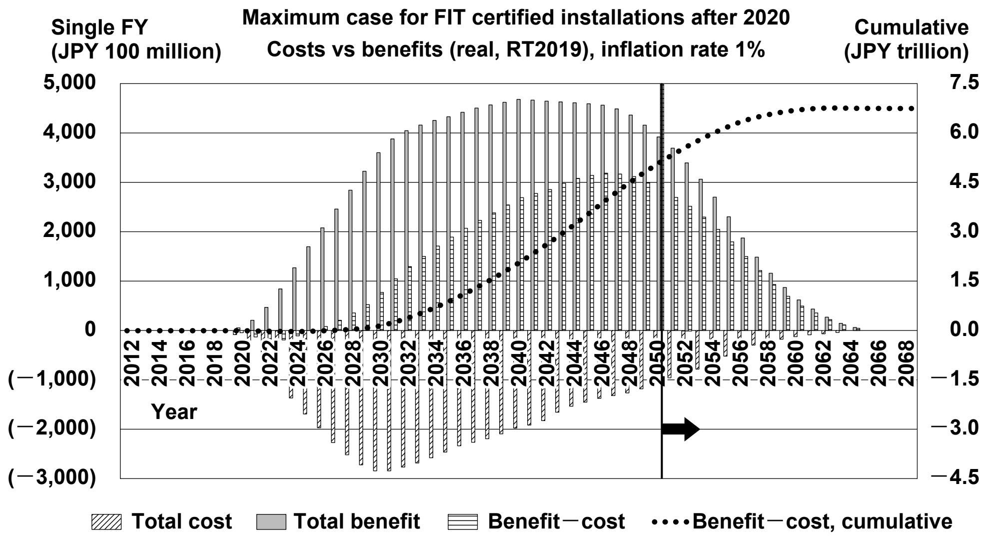

Source: JPEA, 2020

Figure 13 JPEA Visualizing the Cost and Benefits of Solar in Japan, 2015-2050

in light of the FIT and FIP (feed-in premium, another version of tariff-support)[9]. Figure 14 therefore shows that the solar deployed between 2020 and 2030 is expected to become net-positive in its cost-benefit assessment by 2025. The cost for the FIT/FIP is expected to peak out in about 2030, and then decline to zero in about 2064. Meanwhile, the overall benefit (avoided costs, GHG reduction) peaks at about 2038. The JPEA then subtracts the projected FIT/FIP costs from the benefits to arrive at a summary of net benefit. Their numbers suggest that on an annualized basis, benefits exceed costs in 2025, and on a cumulative basis by 2028. Their projection of benefits indicates that the benefits decline rapidly from 2051. This is because they are examining solar deployed between 2020 and 2030, and are assuming that the systems will start being dismantled.

In short, the data from the JPEA are a sharp contrast with the 100%RE studies exam-

9) The main difference between the FIT and the FIP is that the former's tariff is decided administratively whereas the latter is determined with reference to market costs. The FIP is a premium tariff over market costs, and is aimed at driving down the price of solar.




Source: JPEA, 2020

Figure 14 JPEA Visualizing the Cost and Benefits of FIT/FIP Support for Solar in Japan, 2020-2030 Installations

ined earlier. The JPEA certainly have ambitious goals for solar. But they include solar as part of a larger portfolio of energy generation. They have a more credible assessment of costs, even though they do not include a focused survey of system costs or CRM issues. In the next section, we turn to examine some of the impending challenges on power systems, via cooling and climate change.

## Section 2:

### Cooling and its Implications

Since 2017, the demand for cooling has emerged as one of the blind spots in the climate and energy debate. Much research time and money were focused on electrifying mobility via 100%RE vs competing power-generation portfolios (especially the question of nuclear). Too little attention and resources were invested in the implications of urbanizing populations in the context of climate change. Since 2018, an increasing number of specialized studies have turned to examine the current and future scale of demand for cooling.

For example, the diffusion of air conditioning is already being partly modeled. Air conditioning is especially crucial to human health in the midst of rising heat and humidity and increasingly frequent heat waves. The Rocky Mountain Institute (RMI) suggest that current (2016) global average is use of air conditioning is 720 hours/yr. 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).

In 2018, the RMI and other partners, 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 point out that the global number of room air conditioners (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.

The RMI data are not definite, however, as in 2019 the Economist Intelligence Unit (EIU) forecast that 4.8 billion new units of cooling equipment would be sold between 2019 and 2030. The EIU study differs from the RMI survey in including refrigeration and highlighting the growing role of business demand. It concedes that 62% of global cooling demand in 2018 is via domestic refrigeration and residential air conditioning. But its analysis revealed that the industrial and transport refrigeration sectors are likely to show the strongest forward growth. The report includes a plethora of recommendations for minimizing demand and GHG implications (EIU, 2019).

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.

In India alone, where RAC penetration is only 7% (2016 data) but sales are already increasing at 15%/yr, the RMI and IEA estimates indicate a more than 20-fold increase in 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 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 magnitude of growth by adding renewables alone." It points out that 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 (Campbell et al, 2018).

The IEA is the best single source of comprehensive data on the diffusion of air conditioning and implications for power consumption. The IEA work consists of past data plus scenarios of the future. Its "baseline scenario" projects future demand and other items on the ais of current policies and targets. This baseline scenario suggests that power demand will triple by 2050, driven in particular by emerging economies. Cooling will be the second-strongest driver of power demand, just behind industrial motors. To ameliorate this, the IEA provides an "efficient cooling scenario" that focuses on improved efficiency. This latter scenario would – if its assumptions are accurate – reduce future demand by 45%, an energy saving equivalent to the EU's power consumption in 2016. Unfortunately, the IEA does not model the CRM footprint of cooling technologies. But in this section, we examine the IEA data and supplement it with the EIU study plus other evidence of the material implications.

The IEA assesses global air conditioning stock in 2016 as 1.6 billion, and predicts an increase to 5.6 billion by 2050. These numbers are larger than the RMI and EIU assessments, but roughly in the same ballbark. Based on its data, the IEA warns that global energy demand from cooling alone in 2018 totaled 2075 TWh (IEA, 2020g). That massive number is about 10% lower than the earlier RMI/IEA estimate of 2,300 TWh. But it is still larger than the total 2018 electricity consumption of India (1,201 TWh), Japan (946 TWH), and every other country on the planet except the United States (3,901 TWh) and China (6,011 TWh) (IEA, 2020h). And because of ongoing urbanization and accelerating climate change, the IEA adds that access to cooling is a major social issue. Its research shows that 2.8 billion people live in the world's hottest areas, such as the Middle East, parts of Africa, regions in Southeast Asia (particularly India), and elsewhere. Of this 2.8 billion people, whose health and productivity are already being degraded, only 8 % have access to cooling. That compares to over 90% ownership in the United States and Japan.

The EIU is rather more concerned. It warns that "[l]ed by countries such as Indonesia, it is estimated that 2.3bn lower/middle-income people are at an income level near which they will begin buying cheap but inefficient cooling devices. Buildings to accommodate this expanding urban 'carbon captive' population are also installing AC of variable quality. In India, notes the EIU's Eric Gibbs, '70% of building stock is not yet built, and we've seen a massive construction boom nationwide, with high rises from Mumbai to Delhi to Calcutta.

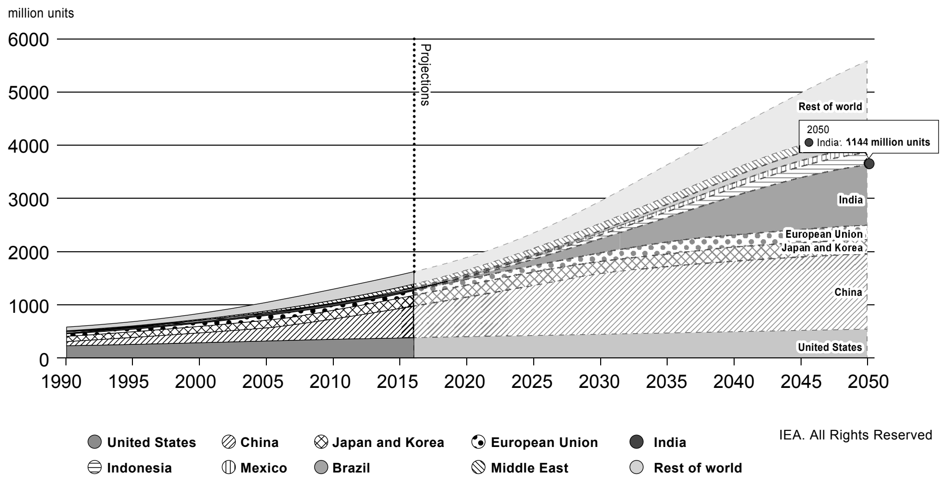
Cooling units in these buildings are often lower cost and less efficient.' As a result, cooling is forecast to almost double its energy consumption by 2050, to ~ 7,500 TWh annually, compared with 3,900 TWh in 2018" (EIU, 2019: 29). That figure of approximately 7,500 TWh would be considerable higher than China's 2018 power consumption of 6,011 TWh.

As shown in figure 15, the IEA data show that the earlier estimates by the RMI and its partners were too conservative. Compared to the RMI assessment of China's air conditioners (at least its RACs) of about 400 million, the IEA data indicate that China's total in 2016 was in fact 569 million units. Further, the IEA expects China's numbers to rise to 1.419 billion by 2050.

India's data are even more impressive. The IEA assesses India's air conditioner stock in 2016 as 27 million units. The IEA expects that number to balloon to 1.144 billion by 2050, a startling 4,237% increase. India's rate of diffusion of air conditioning thus increases from roughly 10% in 2018 to 45% in 2050.

The IEA therefore forecasts that in air-conditioning alone, energy demand is likely to increase to 3,400 TWh in 2050. In absolute terms, this means cooling growth would require adding the equivalent of all electricity demand today in the United States and Germany.

Table 6 shows the main countries/regions' data for 2016 in more detail. The stock data are in the left-hand side of the table, whereas the flow (ie, sales) are in the right-hand side. The items of particular note are the relationships between stock, new sales, and overall output capacity. We see that the Chinese account for 39% of new sales in 2016, on a unit basis, but less than 32% on an output basis. That means their air-conditioners are smaller, on




Source: IEA, 2019

Figure 15 Global Air Conditioner Stock 1990-2050 average, than in the United States. In the United States, sales were 17.8% of the global unit total, but 36.7% of the global output capacity total. As for Japan, it accounts for 8.15% of global unit sales, but 5.05% of global output capacity. And India's 27 million units are only 1.7% of global stock, but its 4 million units of sales in 2016 were just under 3 % of global sales and 2.17% of added total global output capacity.

By way of comparison, the EIU survey assesses sales in India at 27.2 million in 2018 and forecasts that number to reach 52.6 million by 2030 (EIU, 2019). Again, this EIU survey includes refrigeration units, not just air conditioning per se.

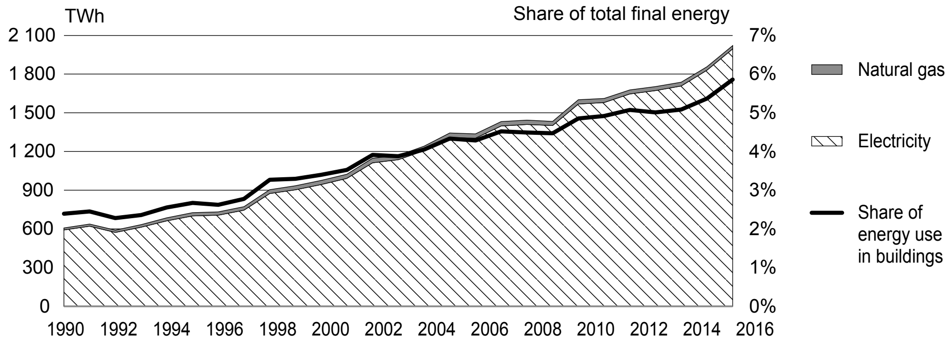
**Figure 16** tells us that the vast majority of cooling systems have been powered by electricity since 1990 and remain almost entirely electric. Natural gas is used in some applications, such as thermally driven chillers, but that accounts for just over 1 % of the total energy use in 2016. What is particularly concerning is the rise in the cooling's share of energy

**Table 6 Air-conditioning Units, 2016**

| | Installed stock | | | | | | Annual sales | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Million units | | | GW output capacity | | | Million units | | | GW output capacity | | |
| | Res | Com | Total | Res | Com | Total | Res | Com | Total | Res | Com | Total |
| United States | 241 | 132 | 374 | 2 295 | 2 430 | 4 726 | 16 | 8 | 24 | 314 | 129 | 443 |
| European Union | 43 | 53 | 97 | 192 | 654 | 847 | 9 | 3 | 12 | 34 | 41 | 75 |
| Japan | 116 | 33 | 148 | 407 | 352 | 759 | 9 | 2 | 11 | 47 | 14 | 61 |
| Korea | 30 | 29 | 59 | 129 | 220 | 348 | 2 | 2 | 4 | 19 | 15 | 34 |
| Mexico | 7 | 9 | 16 | 40 | 65 | 105 | 1 | 1 | 2 | 5 | 6 | 10 |
| China | 432 | 138 | 569 | 2 092 | 807 | 2 899 | 41 | 12 | 53 | 305 | 81 | 386 |
| India | 14 | 13 | 27 | 77 | 72 | 149 | 3 | 2 | 4 | 14 | 12 | 25 |
| Indonesia | 7 | 5 | 12 | 32 | 27 | 59 | 1 | 1 | 2 | 5 | 4 | 9 |
| Brazil | 14 | 14 | 27 | 59 | 68 | 127 | 1 | 0.3 | 1 | 5 | 1.4 | 6 |
| South Africa | 1 | 1 | 3 | 6 | 15 | 22 | 0.1 | 0.1 | 0.3 | 0.9 | 1.1 | 2.1 |
| Middle East | 30 | 18 | 47 | 147 | 153 | 299 | 4 | 2 | 6 | 29 | 16 | 45 |
| World | 1 093 | 529 | 1 622 | 6 181 | 5 491 | 11 673 | 94 | 40 | 135 | 848 | 359 | 1 207 |

Notes: Res = residential; Com = commercial; the data on air-conditioning capacity and units shown in this report, unless otherwise noted, include residential and commercial systems, including packaged and split units, chillers and other large space-cooling systems; district cooling and solar cooling applications are not included in these estimates; "China" = the People's Republic of China.

Source: IEA, 2018




Source: IEA, 2018

Figure 16 World Energy Consumption for Cooling, 1990–2016

use in buildings. That figure was just over 2% in 1990, but by 2016 had roughly trebled to 6%.

Table 7 shows that the US power consumption for cooling – though immense – increased by only 182% between 1990 and 2016. In other words, the increase over 26 years was less than double. Over the same period, South Korea's consumption went up by over 10 times, or 1,025%. China's numbers are even more startling, at over 60 times, or 6,428.6%. Globally, the increase was more constrained, at roughly triple, or 332.4%.

The table also tells us that the IEA assesses total global electricity demand for cooling in 2016 to be 2,000 TWh, or about 10% of the global total power consumption (for all sectors) of 21,000 TWh in 2016. In terms of primary energy, the IEA calculates power demand for space cooling to be roughly 400 million tonnes of oil equivalent, or 3% of world total primary energy use. It adds that a lot of this energy is lost as heat in transforming primary energy sources into electricity. To portray the scale of this amount of oil equivalent, the IEA notes that it is on par with that year's global fuel use for international aviation and shipping.

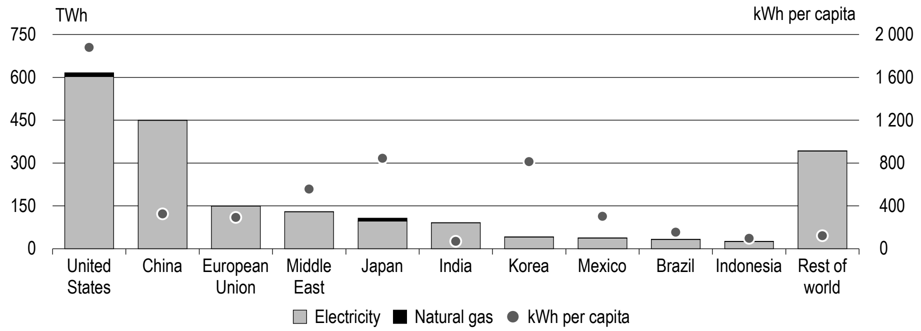
Figure 17 is also instructive in showing the total power usage for cooling per country (TWh) and per-capita (kWh per capita). It shows how low both TWh and KWh per capita are in India, Brazil, Indonesia, and other countries. Even China's per-capita consumption for cooling is low compared to its regional peers, Japan and South Korea, not to mention the United States. One reading of the data might be that the US uses too much cooling per capita. That is likely true. But even if so, it does not mean that simply reducing demand in the US will solve the global problem. The other countries contain about 20 times the US population. And many of them are increasingly requiring cooling, in order to cope with the impact of climate change.

Figure 18 shows these 1990–2016 comparative rates of increase in power demand in

Table 7 World Final Energy Consumption for Cooling, 1990-2016, and 2016 Share in Building Use

| | TWh | | | | % of total building final energy use in 2016 |
|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2016 | |
| United States | 339 | 448 | 588 | 616 | 10.6% |
| European Union | 63 | 100 | 149 | 152 | 1.2% |
| Japan | 48 | 100 | 119 | 107 | 9.5% |
| Korea | 4 | 17 | 34 | 41 | 8.5% |
| Mexico | 7 | 16 | 23 | 37 | 9.8% |
| China | 7 | 45 | 243 | 450 | 9.3% |
| India | 6 | 22 | 49 | 91 | 3.4% |
| Indonesia | 2 | 6 | 14 | 25 | 3.0% |
| Brazil | 10 | 19 | 26 | 32 | 7.7% |
| South Africa | 4 | 6 | 6 | 8 | 2.8% |
| Middle East | 26 | 49 | 97 | 129 | 9.3% |
| World | 608 | 976 | 1 602 | 2 021 | 5.9% |

Source: IEA, 2018

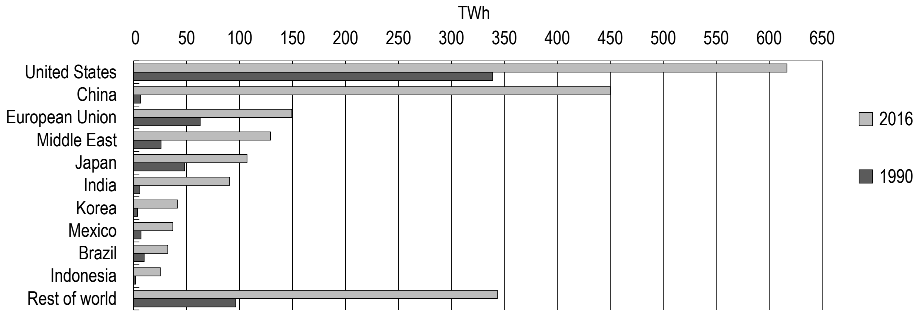



Source: IEA, 2018

Figure 17 Final Energy Use for Space Cooling, 2016

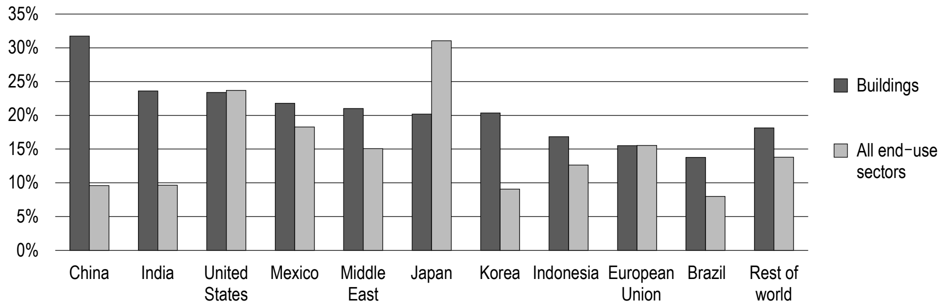
visual terms. The Chinese increase is quite striking. But under business as usual (below, the "baseline scenario"), India's could be equally startling.

Figure 19 shows the share of space cooling in overall increases in electricity demand, between 1990 and 2016. The share of cooling in all end-use sectors was 13% and 22% of the increase in electricity use in buildings alone. China recorded the highest share for building, at one-third.




Source: IEA, 2018

Figure 18 Final Energy Use for Space Cooling, 1990 and 2016



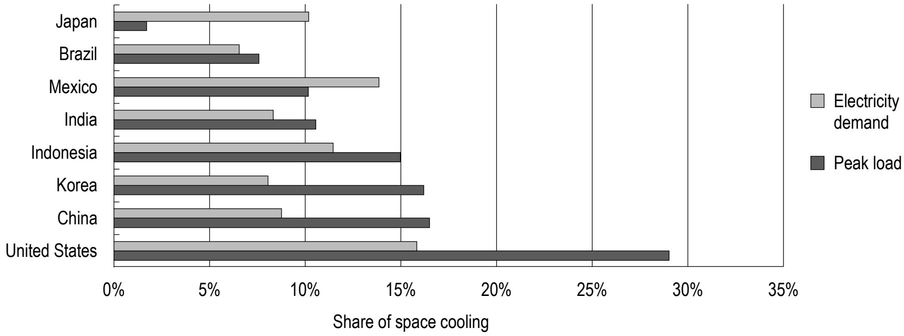

Source: IEA, 2018

Figure 19 Share of Cooling in Increased Electricity Demand,1990-2016

Figure 20 shows another reason cooling is a particularly challenging item. Demand for cooling is not constant, but rather peaks when the ambient temperature and humidity are high. Hence, during a heat wave, demand for cooling skyrockets, and the power system has to meet that demand or fail in a black-out. And during heatwaves, as the IEA underscores, the power system itself – from generation through to transmission and distribution equipment – is under heavy thermal stress. Solar panels lose output in high heat, power lines sag and their transmission capabilities decline, and transformers' performance is reduced (see also Allen-Dumas et al, 2019). As a result, the spiking cooling demand confronts a power system whose capacity to provide power is lessened, shaving the ever-important margin of output over demand, and further exacerbating the risk of blackouts.

In mid-August of 2020, for example, the US state of California endured its first rolling blackout in 19 years precisely when spiking demand from a heat wave overloaded a power system weakened by multiple structural and governance problems (Gilbert and Bazilian, 2020).

And worse seems yet to come. Cooling demand in some areas, including the United




Source: IEA, 2018

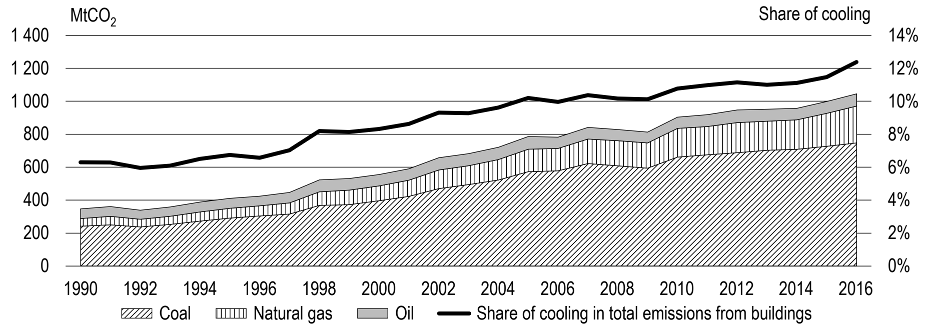
Figure 20 Share of Cooling in Peak Load, 2016

States, can drive in excess of 70% of peak residential electricity demand on very hot days. Cooling demand averages (in 2016) about 10% of total electricity demand globally, but the peaks are what the system has to be prepared for. That peak load is represented in figure 20, and is high in the US as well as many Asian countries. The IEA adds that the "share of cooling in national peak load has been calculated for the moment in the year at which the overall peak in total electricity demand occurs; the contribution of cooling to local peak load in towns and cities can be much higher."

Another issue is the GHG emissions from cooling. Air conditioners and related equipment often contain very impactful GHGs, such as HFC and other gases. They emit these GHGs when they leak or when they are not properly disposed of, allowing the gases to escape from the apparatus. Also, generating the electricity needed for cooling generally results in significant GHG emissions. Figure 21 shows that rising global $CO_2$ emissions for cooling from 1990 to 2016.The share of cooling in total global emissions more than doubles between 1990 and 2016, with coal-fired power being the single main cause.

Figure 22 highlights the role of China's coal-centred power system in GHG emissions for cooling. Natural gas is also involved, particularly in the US and the Middle East. The IEA's data indicate that the 2016 2,000 TWh of global electricity demand for cooling was responsible for 1.130 billion tonnes of $CO_2$, derived from the carbon-intensities of power systems in addition to losses in transmission and distribution.

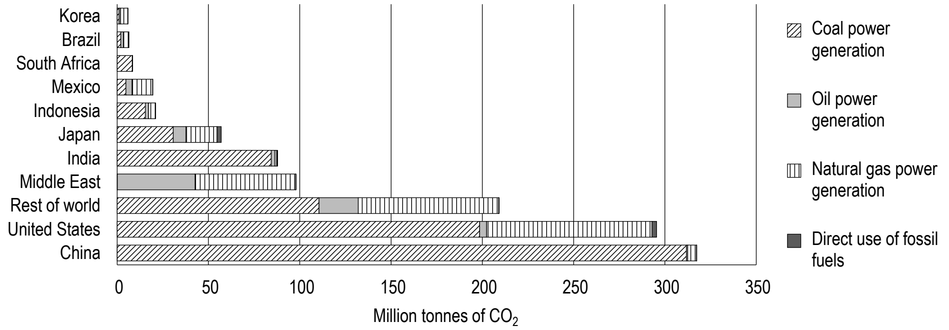
Table 8 presents the 2016 and 2050 data on Cooling Degree Days (CDDs). Those numbers are a measure of how much the mean temperature exceeds the standard temperature each day over a given period (eg, a week in the summer or the entire year). For example, a day with a high temperature of 30℃ and a low of 20℃, and thus a mean temperature of 25℃, has 7 CDDs (25-18). The CDDs evident in 2016 in India, Indonesia, and the




Notes: Emissions take account of losses in transmission and distribution; they include indirect emissions from power generation and direct emissions from the use of gas in chillers; up to 2015, annual average $CO_2$ intensities have been used, while for 2016 and in the scenario analysis for future years, the $CO_2$ intensities at times of air-conditioning demand have been used; for 2016, this results in a global average annual $CO_2$ intensity for cooling of 578 $gCO_2$/kWh, including transmission and distribution losses (derived from the modelling analysis in this report – see Chapter 3).

Source: IEA, 2018

Figure 21　Global $CO_2$ Emissions from Cooling, by Energy Source, 1990-2016




Source: IEA, 2018

Figure 22　Cooling and $CO_2$ Emissions, 2016

Middle East imply a massive latent demand for cooling, as those countries' CDDs are many times higher than seen in the US, Europe, South Africa, and Mexico. At the same time, projected increases in CDDs are most striking in Mexico, the US, and Brazil. And those countries' increases in CDDs should be seen in the context of the world per se, where CDDs in 2016 are expected to rise by 25.4% by 2050.

It is especially important to note here that the IEA also analyzed the relationship between CDDs, average per-capita income, and ownership of air conditioners. The study covered "68 countries across more than 500 country data points according to their climate, using CDDs adjusted for relative humidity (ie, a heat index). The climate-wealth relationship is strong – especially for the countries with the hottest climates... In countries with average CDDs under 500, such as in Scandinavia, [air conditioner] ownership is extremely low as it is

Table 8 Cooling Degree Days (CDDs), 2016 and 2050

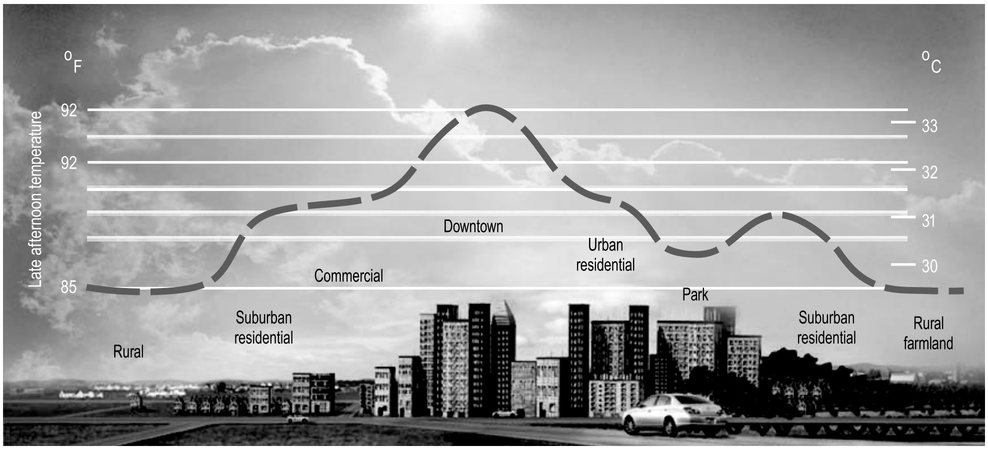
| | 2016 | | 2050 | | |
|---|---|---|---|---|---|
| | CDDs | Million persons | CDDs | Million persons | Change in CDDs over 2016 |
| United States | 764 | 328 | 973 | 392 | 27.4% |
| European Union | 292 | 511 | 343 | 505 | 17.5% |
| Japan | 909 | 127 | 1 040 | 108 | 14.4% |
| Korea | 762 | 51 | 844 | 51 | 10.7% |
| Mexico | 868 | 123 | 1 188 | 156 | 36.8% |
| China | 1 051 | 1 384 | 1 169 | 1 351 | 11.3% |
| India | 3 084 | 1 327 | 3 486 | 1 705 | 13.0% |
| Indonesia | 3 390 | 261 | 4 051 | 322 | 19.5% |
| Brazil | 1 846 | 210 | 2 314 | 238 | 25.4% |
| South Africa | 714 | 55 | 746 | 66 | 4.6% |
| Middle East | 2 337 | 232 | 2 516 | 354 | 7.6% |
| World | 1 905 | 7 422 | 2 388 | 9 714 | 25.4% |

Notes: CDDs shown here are calculated on the basis of a temperature of 18℃ ; historical population distributions were used to calculate the weighted CDDs in 2016 and expected population growth rates (without taking into account potential shifts in population distribution from migration patterns) were used to calculate future trends. “China” = the People’s Republic of China.

Source: IEA, 2018

rarely hot enough to warrant it, though ownership is slightly higher among the richest countries. At the other extreme, in countries with CDDs over 3,000, including Brazil, Egypt, India, Thailand, Indonesia and Venezuela, [air conditioner] ownership rises very steeply with income as cooling is virtually essential for people to live and work in comfort” (IEA, 2018). Concerning these relationships, note that table 8 also shows no country will be below 300 CDDs in 2050.

Figure 23 provides a generalized depiction of the urban heat island, wherein the urban core (“Downtown” in the chart) is a few degrees centigrade higher than rural areas. The heat island effect is a product of density, in terms of inhabitants, buildings, paved surfaces, and other aspects of cities. The urban built environment absorbs solar radiation during the daytime while also being a source of significant heat through the city high spatial density of traffic, air-conditioning (which dumps heat outside), and other activities. That is why the urban core is hotter than urban and suburban residential areas. The heat island effect can be ameliorated, by green space (as is evident in the “Park” area of the chart) and reflective sur-



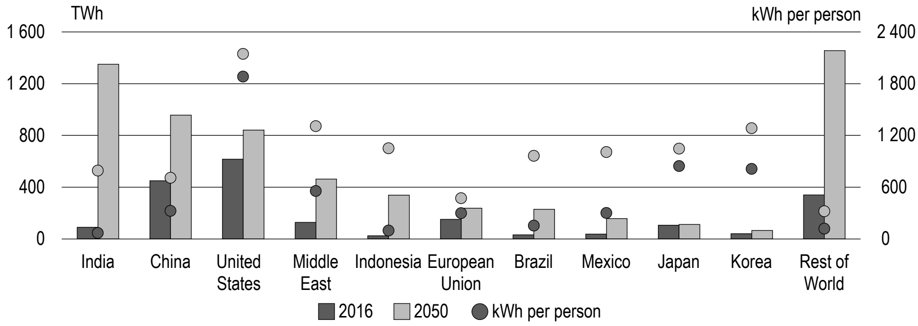

Source: IEA, 2018

Figure 23　Heat Island Effect

faces, but not entirely eliminated. Moreover, over half the human population lives in cities, and the rate of urbanization is increasing. The increasing number and size of cities is virtually certain to increase heat island effects and thus the demand for cooling. Indeed, one important finding of a 2020 EU-funded research project on air conditioning was that "[l]iving in an urban area increases the probability of having air conditioning by 9 percentage points, a sizeable effect compared to the role of income and climate, probably due to the heat island effect in cities" (Cooling Post, 2020).

The IEA also points out that ageing populations (a signal feature of East Asian and several other populous countries) is likely to accelerate the increase in demand for cooling. The United Nations Department of Economic and Social Affairs (UNDESA) publishes an annual report on World Population Ageing. In its 2019 report the UNDESA argues that "[p]opulation ageing is a global phenomenon. Virtually every country in the world is experiencing growth in both the size and the proportion of older persons in the population. In 2019, there were 703 million persons aged 65 years or over in the global population. This number is projected to double to 1.5 billion in 2050" (UNDESA, 2019). Elderly people living in cities are especially susceptible to heat-stress, and climate change is expected to dramatically increase their mortality during heat waves (Varquez et al, 2020). We saw the projected increase to 2050 in CDDs for the world and several countries above. Those data are average, and likely the CDDs for megacities are even higher. These facts all suggest an increasing demand for cooling, especially in order to achieve SDG and related goals of equitable climate adaptation.

As noted, the IEA work provides a baseline scenario and an efficiency scenario. No




Source: IEA, 2018

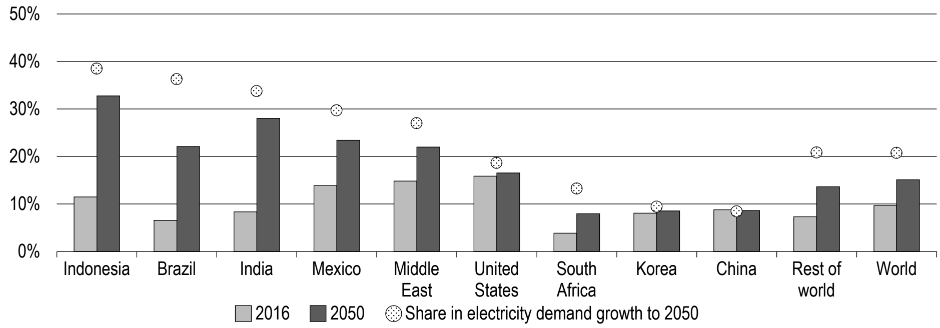
Figure 24 Baseline Scenario for Space Cooling, 2050

doubt actual developments will be quite different from both, as 2050 is 3 decades hence. Few observers in 1990 would have predicted that in 2020 a pandemic would disrupt the global economy simultaneous with dramatic changes in energy, CRMs, climate change, and other phenomena. So it is wise to be humble about building forecasts on the basis of current trends in technology, resources, and related variables. In any event, in this paper we have opted to use the IEA's baseline scenario as a guide to what the future might look like. Thus figure 24 portrays the total energy use (TWh) and per-capita energy use (kWh) for cooling for the major countries and the rest of the world. In no case does per-capita energy use for cooling decline between 2016 and 2050. In many cases, particularly India and Indonesia, it increases dramatically. And the corresponding volume of energy demand is also striking in these cases, as is it for the rest of the world. The human population is so large that per-capita (kWh) energy demand for cooling in the rest of the world shows only a comparatively small increase, but a massive overall rise (TWh).

Similarly, figure 25 reveals a strong and generalized 2016-2050 increase in demand for space cooling and correspondingly striking share of increase as a share of overall electricity demand. The global total alone is just over a 20% share of overall increased demand for power.

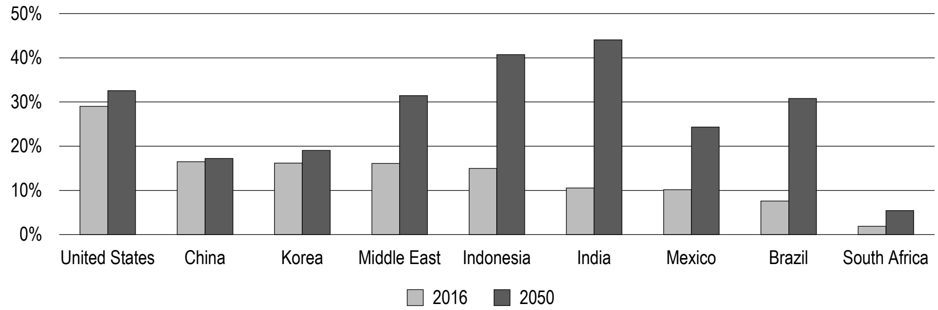
Figure 26 reveals another disturbing trend. We saw earlier that the US power system is most challenged by peak loads from cooling demand on hot days. But the IEA calculations indicate that India and Indonesia are likely to be especially challenged in 2050.

Figure 27 builds on the previous data and estimates. India's requisite increase in power generation capacity to meet cooling demand is simply enormous. But so too are the data for China, the US, and everywhere except the EU. And the data may be an underestimate, as one trend in Africa is the purchase of used and inefficient, energy-intensive air condition-



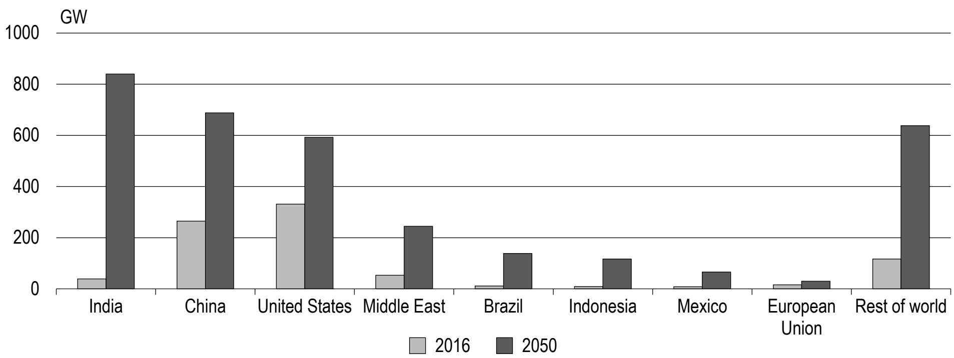

Source: IEA, 2018

Figure 25　Baseline Scenario for Cooling Demand Growth




Note: The shares have been calculated for the time within the year at which the peak load of overall electricity demand occurs.
Source: IEA, 2018

Figure 26　Baseline Scenario for Peak Load in 2050

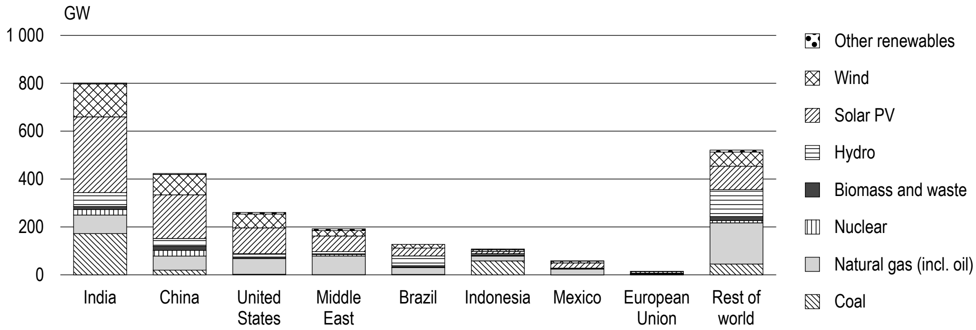



Source: IEA, 2018

Figure 27　Baseline Scenario for 2050 Power Generation Required for Cooling

ers from Europe and other areas (Fleming, 2020).

Figure 28 displays the baseline scenario projects for future power demand in addition



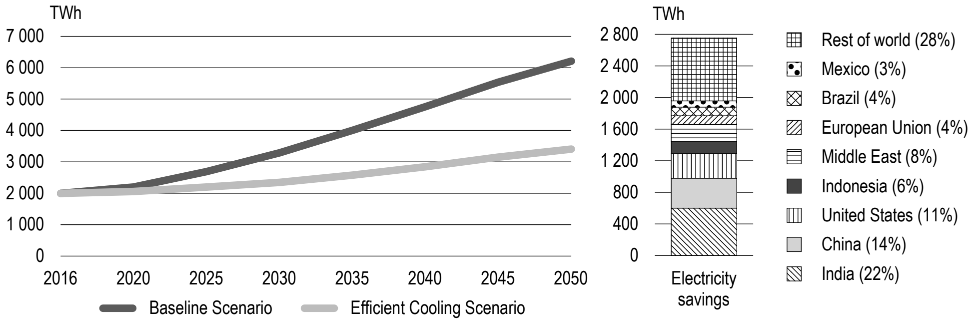

Source: IEA, 2018

Figure 28 Baseline Scenario for 2050 Power Generation Capacity Additions

to how the various countries are likely to generate the power for cooling. We can see that even with impressive assumptions about solar and wind, a lot of the power demand is likely to be met by fossil fuels. The IEA estimates that China will use considerably less coal as a share of power generation than in 2018, with a broader portfolio composed of solar, wind, hydro, natural gas, nuclear, and other generation. India is also expected to add a lot of solar, wind, hydro, nuclear, and others, but choose a higher share of coal than China. In countries/regions such as Indonesia, Mexico, the Middle East, and the rest of the world, the choice is largely more natural gas or coal.

Figure 29 shows that the signal difference between the IEA's "baseline scenario" and the "efficient cooling scenario" is 1,300 TWh. That is a lot of power. The IEA describes this amount of electricity as equivalent to the EU's power consumption in 2016 and, alternatively, equal to all the power that China and India generated with coal in 2016. Moreover, the IEA projects a massive drop in emissions through its efficiency scenario. Emissions from cooling in 2050 are estimated to be just 150 million tonnes in the efficient cooling scenario, only 7% of the baseline scenario and 13% of the actual 2016 emissions. That forecast is derived half from greater efficiency for cooling and half from less GHG-intensive power generation. The efficiency scenario is also assumed to result in reduced investment, fuel and operating costs totaling USD 2.9 trillion between 2017-2050.

The IEA and other work thus indicate pathways through which gargantuan increases in electricity demand might be reduced. One problem, however, is that the measures for an efficient outcome rely on robust and integrated governance, nationally and internationally. The dramatic worsening of relations between China and the US would seem to impair the prospect for climate agreements per se, let alone a stronger international regime to finance efficient cooling in addition to police the transfer of inefficient, GHG-intensive equipment.




Source: IEA, 2018

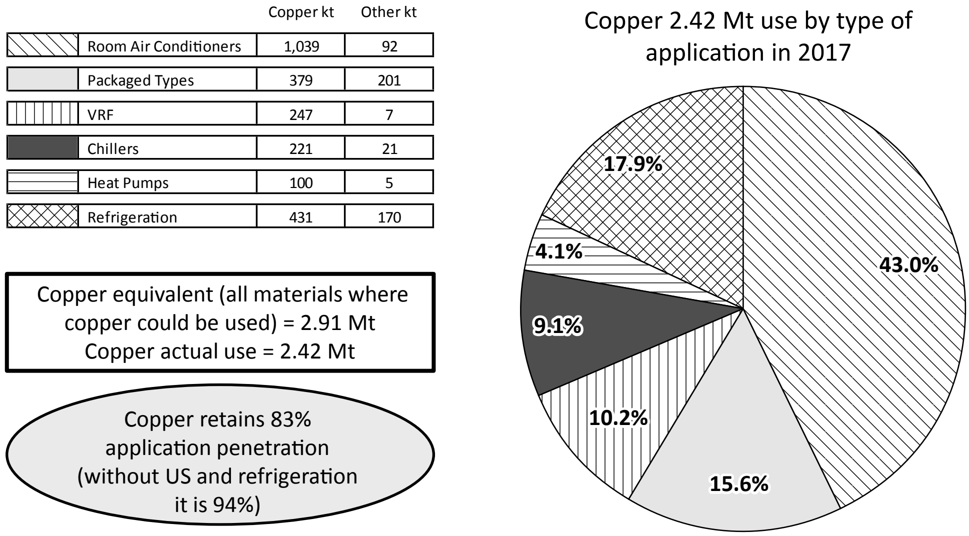
Figure 29 Comparing the Baseline and Efficient Scenarios

And much of the global cooling trend will depend on what Chinese manufacturers do in co-operation with their public sector. After all, Chinese manufacturers produce about 70% of global room air conditioners (IEA, 2018). And the evidence on Chinese financing of energy projects in the Belt and Road Initiative suggest it may not prioritize climate in cooling initiatives (Saha, 2020).

In the midst of this uncertainty, an additional factor must be considered: CMR-density in cooling. None of the studies discussed above examine the implications that cooling has for CRMs. Yet even conventional cooling equipment contains significant amounts of copper, one of the CRMs, as we see in figure 30.

Figure 30 shows that in 2017 copper use in refrigeration was 2.42 million tonnes (Mt in the figure). That amount of demand is more than 10% of the same year's total global production of 19.1 million tonnes (ICSG, 2018). Copper resources are not going to be depleted, but there is not an infinite capacity for mining. Similar to other CRMs, the demand pull on copper production increases with increasing efficiency of the cooling equipment. And the more RE (and especially VRE) used to power the cooling, the greater the CRM density of the overall system.

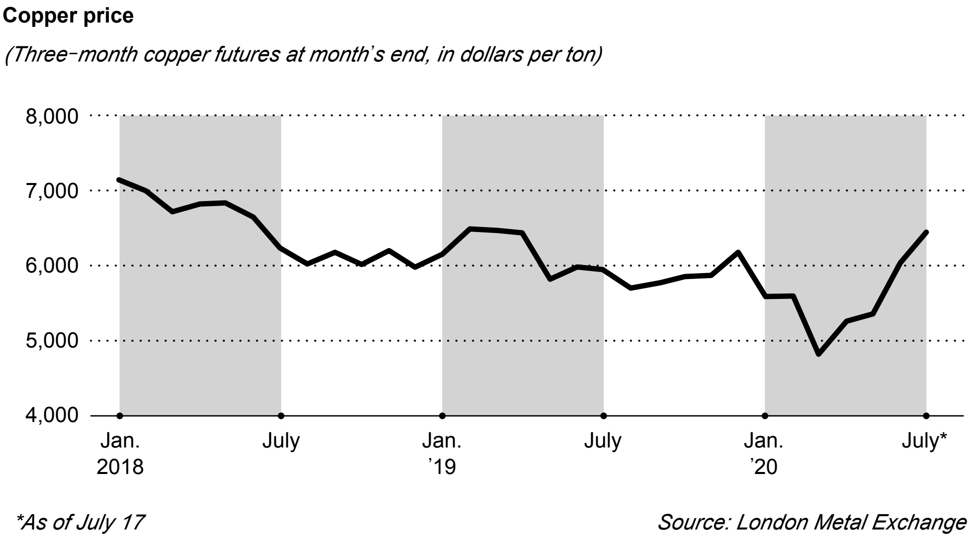
Yet as we see in figure 31, the prices of copper have been too uncertain in recent years to incentivize a lot of new mining activity. This kind of uneven price trend is evident among most of the CRM needed for a “green recovery.” It impacts the most essential part of the supply chain, mining. The is because investors have little certainty that the massive volumes of capital and effort required to develop new mining capacity will be profitable. Indeed, battery and other clean-energy related manufacturers worsen the problem by applying pressure for lower CRM prices. We return to these issues further below, in the industrial policy section.




Note: “All Material” includes all items that may be made of copper

Source: Kalman-Schueler et al, 2017

Figure 30 Copper and Copper Equivalent Use in 2017




Source: Shida, 2020

Figure 31 Global Copper Prices, 2018-2020

With respect to cooling, per se, these material facts would seem to make it imperative that the CRM density of cooling solutions be added to the list of variables to assess. Indeed, we are beginning to get a powerful sense of the need for comprehensive and integrated industrial policy.

## Section 3:

In the next section, we turn to examine why coordinated "national resilience" planning appears to be especially important in Japan. We begin with a survey of global energy and CRM trends, and then turn to examine what Japan is doing.

### Global Power Developments

The past decade of deployment and declining costs make it clear that non-hydro renewable energy has a major contribution to power systems. By 2019 solar power generation capacity had become the fourth largest source of power globally, according the BNEF's Power Transition Trends 2020 report. "The report highlights the enormous strides solar has made in a decade, rising from just 43.7GW of total capacity installed in 2010 to 651GW as of year-end 2019. Solar in 2019 also moved past wind (644GW) to become the fourth largest source of power on a capacity basis, behind coal (2,089GW), gas (1,812GW), and hydro (1,160GW)" (BloombergNEF, 2020).

These numbers generally conform to the IEA's projection in their "Renewables 2019" report. As we see in table 9, in 2019 the IEA's "main case" (more conservative than its accelerated case) forecast 609 GW of solar and 595 GW of onshore (622 GW with offshore included) wind for 2019. The IEA's numbers are lower than the BNEF survey, but the BNEF survey is for year-end of 2019. Since the IEA also forecast significant increases into 2020, their data seem quite credible. The IEA's data are also better quality, as they include the full slate of renewable electricity generation capacity.

Capacity does not, however, equate with actual generation. This is because neither renewable, fossil or nuclear plants run all the time at their theoretical maximum. They often do not operate due to maintenance, market conditions that do not require their output (common with gas-fired power), lack of fuel (or sunshine/wind) and less frequently due to blackout. As a result, power technologies differ by capacity factor, defined as "[t]he ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period (USNRC, 2020). The IEA data tracking – last updated on March 6, 2020 – tells us that, as of 2018, the average annual capacity factors (globally) of solar were between 10-21%, onshore wind 23-44%, and offshore wind 29-52% (IEA, 2020c). In Japan, the power actually generated by intermittent

Table 9 Renewable Power Outlook by Capacity, 2018-2024

**Total renewable electricity capacity by technology (GW)**

| | Main case | | | | | | | Acc. case |
|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2024 |
| **Hydropower** | 1,290 | 1,308 | 1,337 | 1,357 | 1,373 | 1,394 | 1,411 | 1,447 |
| Pumped storage | 155 | 158 | 163 | 167 | 171 | 176 | 181 | 202 |
| **Bioenergy** | 130 | 138 | 146 | 152 | 159 | 165 | 171 | 187 |
| **Wind** | 565 | 622 | 686 | 744 | 799 | 857 | 917 | 996 |
| Onshore wind | 543 | 595 | 654 | 704 | 753 | 802 | 851 | 920 |
| Offshore wind | 22 | 27 | 32 | 39 | 46 | 55 | 66 | 77 |
| **Solar PV** | 496 | 609 | 716 | 823 | 939 | 1,064 | 1,195 | 1,374 |
| PV-Utility | 283 | 352 | 411 | 469 | 532 | 598 | 665 | 754 |
| PV-Distributed | 213 | 258 | 305 | 354 | 407 | 466 | 530 | 619 |
| **CSP** | 6 | 6 | 7 | 8 | 9 | 9 | 9 | 12 |
| **Geothermal** | 14 | 15 | 15 | 16 | 17 | 18 | 18 | 20 |
| **Marine** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Total** | 2,501 | 2,699 | 2,907 | 3,101 | 3,296 | 3,508 | 3,721 | 4,036 |

Source: IEA, 2019a

VRE projects was only 12% (solar) or 20% (wind) of their total capacity in 2015[10]. These factors vary according to the amount of sunlight, consistency of wind patterns, and other parameters. By contrast, capacity factors for nuclear plant are generally far higher, often close to or above 90%. Thus in the US, the nuclear share of total power generation capacity is 9 %, but the nuclear share of total power generated in 2019 was 20% (USDoE, 2020). The result of comparatively low capacity factors for VRE (solar and wind) is that achieving a desired output target requires more generation assets than conventional power and that some form of back-up has to be provided for when the sun is down, weather conditions are adverse, and etc. That back-up can be in the form of fossil-fuel generation (often gas-fired plant), power imports from elsewhere, or battery back-up (generally pumped-hydro storage, but sometimes actual batteries).

One consequence of low capacity factors is to increase the amount of materials needed

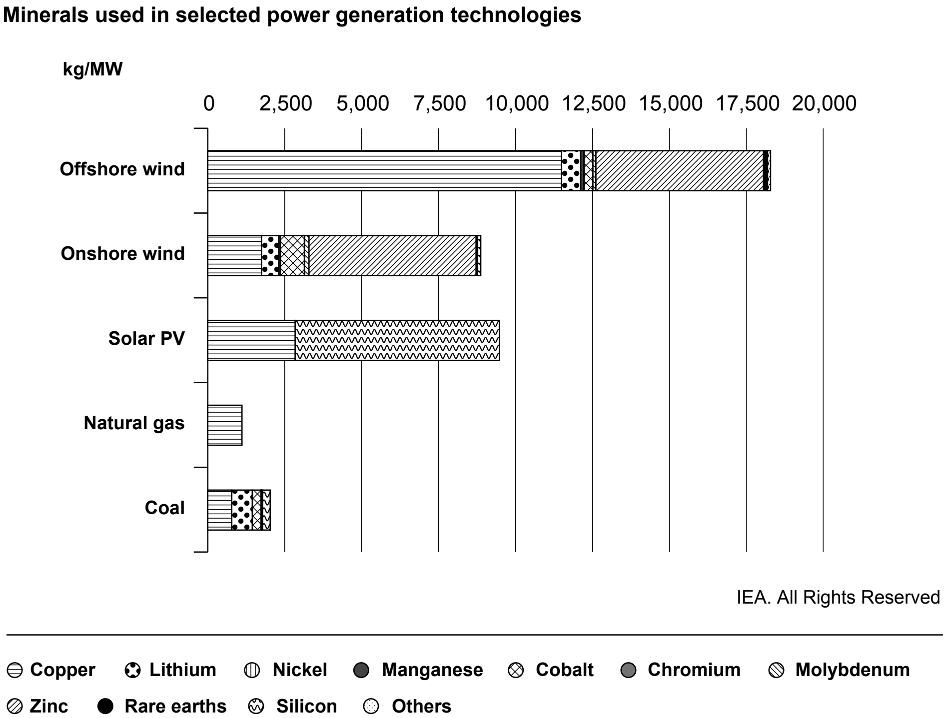
10) The US EIA undertakes comparative studies on average generation capacity factors (meaning the percentage of energy output versus rated capacity). Its survey of output between 2008-2012 indicates that Japan's aggregate figure for both solar and wind is 15 percent, far less than the 27 percent recorded for the United States, the 26 percent seen in Canada, and the 18 percent figure for China (EIA, 2015).

to construct the VRE plant to reach a desired power output target or share of overall power demand. Some of these materials are such conventional building materials as steel, aluminum, concrete and plastics (or fiberglass). Prodigious quantities are required for VRE installations, especially for offshore wind, but securing the required volumes does not require new mining, plant and other upstream preparation. Quite different is the demand for what are referred to as critical minerals, critical raw material (or rare metals in Japanese parlance). As we noted earlier, these substances differ according to country, but almost always include the rare earths along with cobalt, lithium, manganese, silicon, and other minerals[11]. VRE generation does not require fuel to generate electricity, and EVs do not burn fuel to provide mobility. But they do need a significant upfront investment in CRM.

Figure 32 provides a different perspective on comparative material demand for power generation. The figure is from a May 2020 IEA report titled "Clean energy progress after the Covid-19 crisis will need reliable supplies of critical minerals" (IEA, 2020a). The IEA figure ranks the material density of the various power generation technologies in kilogram per megawatt (kg/MW) of generating capacity. Its data show that copper, lithium, silicon, and other critical raw materials are used in very high amounts for a given generating capacity, especially when compared with natural gas and coal-fired capacity.

That fact does not mean that fossil-fuel generation assets are cleaner, as they burn vast quantities of fuel and release enormous volumes of GHGs. For example, a conventional 1 GW coal plant burns about 9,000 tonnes of coal per day (Hanania et al, 2019). In addition, a US National Renewable Energy Lab (NREL) meta-study of GHG emissions data from 1970 to 2010 determined that renewables and nuclear are generally quite decarbonizing compared to fossil fuels. The NREL harmonized the disparate data on lifecycle GHG emission assessments for fossil fuel generation, renewable generation, and nuclear generation. The NREL reported that "renewable technologies are between 400 and 1,000 g $CO_2$eq/kWh lower than their fossil-fueled counterparts without carbon capture and sequestration (CCS)." The NREL results for nuclear also show that its lifecycle GHS are roughly between wind and solar (NREL, 2012). The NREL data are somewhat dated, of course, and do not measure the full system impacts of adding massive battery back-up. Moreover, the European Commission (EC) experts on emissions point out that "[f]or an accurate depiction of real-life emission

11) Critical raw materials are composed of rare earths in addition to cobalt, copper, nickel and other minerals and metals. The list of critical raw materials varies by country/region and over time. A summary of the European Commission's work on critical raw materials and announcement of its expanded 2020 list is at EC (2020).




Source: IEA, 2020a

Figure 32 Comparative Assessment of Mineral Demand for Power Generation (units: kg/MW)

savings of a RES project, boundaries of the calculations should be broadened to expose potentially hidden environmental impacts from clean technologies, such as emissions for the extraction of rare earth minerals to produce photovoltaic panels for solar projects." The EC experts are quick to add that this approach needs to be standardized, otherwise each site would have to be sampled. But they do emphasize the need for "default factors" so as to account for the majority of "cradle-to-grave" emissions (Edwards et al, 2020). One indicator of the need for clear assessments is seen in the Institute for European Studies (IES) report on "Metals for a Climate Neutral Europe: A 2050 Blueprint," released on December 15, 2019. Among the IES report's findings, the carbon footprint for nickel produced in China was 678% higher than that produced in the EU. For silicon, essential for solar panels, the Chinese produced material had a 241% higher carbon footprint than the material refined in the EU (IES, 2019: 70). The NREL study was undertaken long before any of these detailed CRM assessments had started, so those emissions are missing from the lifecycle assessments. But the NREL's work continues to be cited as a general standard of inclusive emissions assessment. And coal is at present about 50% of the global mining market, vastly overshadowing CRM flows (Delevingne et al, 2020).

At the same time, the critical minerals used in significant densities (relative to power output/storage capacity) in VRE and related applications impose environmental and other costs. Their accelerated use could dramatically increase mining threats to biodiversity (Sonter et al, 2020) as well as zoonotic disease risk (Vidal, 2020). So surely one extremely important issue is finding the most materially efficient uses of CRMs in order to achieve the most rapid and least costly decarbonization.

The IEA is quite literate on these CRM issues, and is rapidly integrating them into their assessments. They are not yet comprehensive enough, however, as we saw earlier in their work on cooling. In that section, we saw that the IEA neither addresses the CRM implications of accelerate cooling diffusion or the power required. Let us turn to the BNEF's Power Transition Trends 2020 report, and examine its assumptions and omissions in addition to whether it addresses CRM requirements.

The report on "Global Trends in Renewable Energy Investment 2020" (hereafter, GTR 2020) was released by the Frankfurt School-UNEP Collaborating Centre for Climate and Sustainable Energy Finance on June 10, 2020 (Frankfurt School-UNEP Centre/BNEF, 2020). The report is authoritative, having been commissioned by the UN Environment Programme in cooperation with Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and produced in collaboration with BloombergNEF. The report is also supported by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety. The report shows that 2019 investment in renewable energy brought the share of renewables, excluding large hydro, in global electricity generation to 13.4%, up from 12.4% in 2018. Over a 10-year time-span, renewables went from 5.9 per cent of generation in 2009 to 13.4% in 2019. GTR 2020 argues that in 2019, renewable power plants prevented the emission of an estimated 2.1 gigatonnes (GT) of carbon dioxide, a substantial saving given global power sector emissions of approximately 13.5 GT in 2019. However, they do not measure GHG emissions and other impacts to produce the critical metals and other materials required to build out renewables.

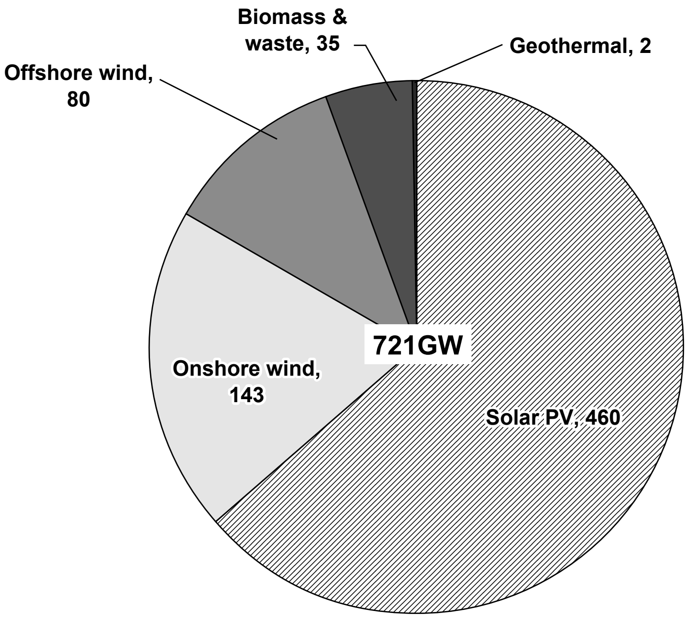
The GTR 2020 also highlights forward commitment by governments businesses, and other actors. These data provide a reasonably accurate image of how much VRE and other renewable investment is likely over the ensuing few years. The data indicate governments and businesses globally have expressed the intent to add approximately 826 GW of new non-hydro renewable power capacity in the decade to 2030. The GTR 2020 estimates that this RE deployment will cost about USD 1 trillion, compared to USD 2.7 trillion invested during

2010-2019. The GTR 2020 also points out that the total of government and business commitments have an estimated decarbonizing effect that is much less than the IPCC and other estimates of what would be required to keep global warming below 2 degrees Celsius.

The GTR 2020 adds that its analysis of targets is not based on the Nationally Determined Contributions, or NDCs, as prepared by countries in the context of the Paris Climate Agreement of December 2015. Some of those aspirations have been translated into government policy statements or laws, but others have not. This chapter concentrates on what is written into official policy so far, and therefore has the clearest momentum behind it (this clearly inspired REI 2030).

GTR 2020 points out that the RE 2030 targets already written into official policy by 87 governments globally imply about 721 GW of new capacity in wind, solar and other non-hydro renewable power technologies between 2020 and 2030.

Also, GTR 2020 note that governments have official targets to install 488 GW of hydro-electric capacity, large and small, by 2030. But GTR 2020 also show their bias towards wind and solar by confessing that "large hydro-electric dams of more than 50 megawatts are outside the main scope of this report" (cf, IRENA reports on need for hydro and pumped storage). They argue that "[l]arge hydro is not included in the main investment figures in this




Source: Frankfurt School-UNEP Centre/BNEF, 2020

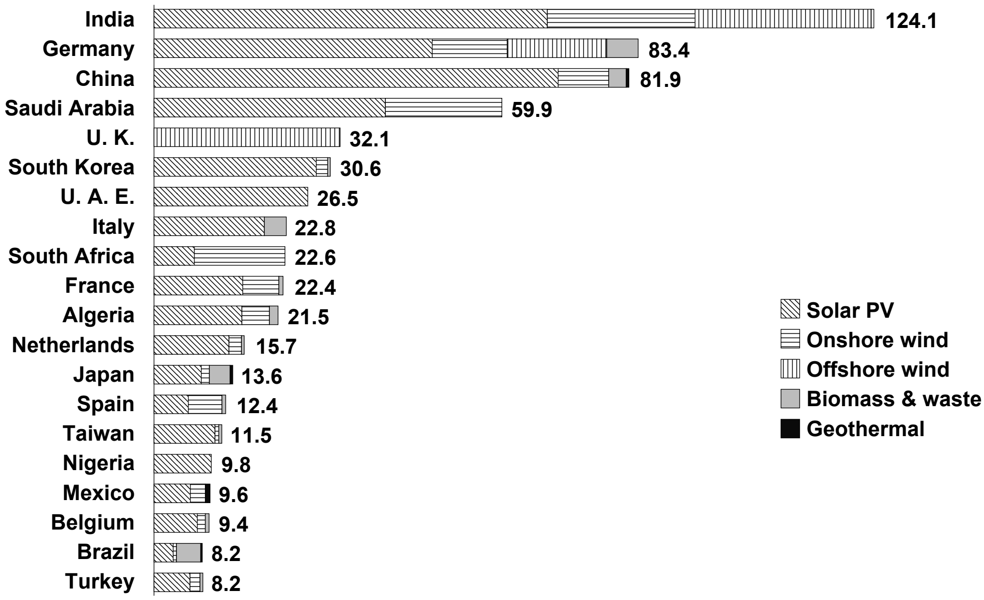
Figure 33 Aggregate Renewable Power Needed to Meet Government Targets, 2020-2030 (in GW) report, for two main reasons. One is that it is a long-established technology, dating back a century or so, and therefore does not share the same dynamics as 'new renewable' technologies such as wind, solar and biomass. The other is that investment is hard to estimate with any precision, since big projects tend to unfold over many years, even a decade or more, will often stop and start, and may be part-financed at different times." The GTR 2020 argument seems reasonable on the surface. But on the other hand, there clearly is a massive amount of hydro being deployed, and it plays a large role in backing up intermittent renewables as well as (in some cases) alleviating flood risks. In addition, it is misleading to describe VRE as new, since solar and wind both have decades of history. Moreover, their investment cycles are not as even as the GTR 2020 suggest in their contrast with hydro.

Indeed, given the scale of the "climate change emergency," as GTR 2020 refer to it, it seems unwise to omit hydro: we need a portfolio of decarbonizing solutions. Even GTR 2020 point out that current VRE and other RE commitments are quite inadequate to decarbonize power, let alone cope with new demand due to cooling needs. Either the technology has got so good and cheap that hydro and pumped storage is no longer needed, or there are strong political biases (ie, anti-nuclear, anti-hydro) underlying the analysis. If the latter, this seems unwise. As we saw earlier concerning REI 2030, various issues are omitted. Similar to the REI 2030 scenario, the GTR 2020 focus on VRE needs to confront the patent risks of NIMBY, geopolitical issues over CRM, the risk that system costs have been underestimated, inadequate analysis of CRM demand in light of competing uses (eg, air conditioning), and climate risks posed for VRE (as evident in California and other areas during the summer of 2020).

In any event, the GTR 2020 show in figure 33 that there is massive need for RE, especially VRE, to meet government commitments for the 2020-2030 period. The GTR 2020 data are in GW, and we see that of 721 GW in total, 460 GW are solar, 143 GW are onshore wind, and 80 GW are offshore wind. These targets imply significant CRM demand, but we cannot be certain whether the generation is sufficient to keep up with increasing demand for cooling (as seen earlier) and mobility. Nor camn we feel confident that industrial and other power needs are adequately forecast.

Figure 34 provides a detailed breakdown of these targets by country and by generation type. India is at the top, with about half of its implied commitment from solar. But even these targets, which GTR 2020 argues are insufficient, are in 2020 being undermined by supply chain problems, lack of land, and inadequate grid capacity[12] (Chatterjee, 2020).

12) The grid problems are an example of the system-cost issues noted repeatedly in this paper.



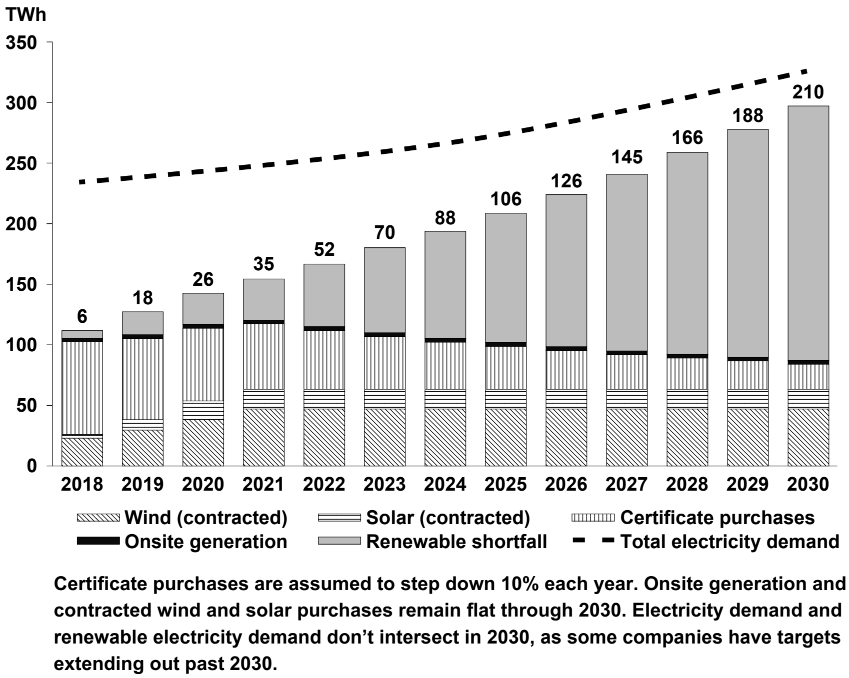

**For targets based on electricity consumption or generation, the equivalent volume of capacity was devised, based on BloombergNEF's New Energy Outlook 2019 estimates for future demand and capacity factors for the relevant technologies.**

Source: Frankfurt School-UNEP Centre/BNEF, 2020

Figure 34 Renewable Power Needed to Meet Government Targets, 2020-2030, by Country (in GW)

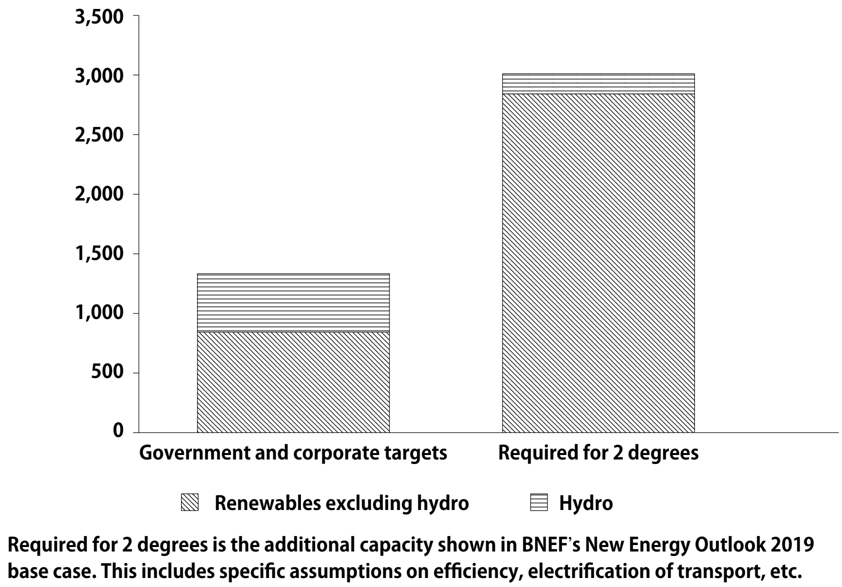
Figure 35 is GTR 2020's summary of demand (in TWh) from private firms' commitment, via the RE100 initiative. We see here also that there is a shortfall from 2018, one that becomes increasingly large with each year. The GTR 2020 use the data to indicate massive demand for more RE, especially VRE. But in light of NIMBY, CRM, and other issues, the figure might just as easily be read as an estimation of massive and steadily increasing.

Figure 36 is a summary of the GTR 2020 estimates of government and corporate commitments compared to the decarbonization effect (from diffusing RE) climate science indicates is necessary to keep global warming below 2 degrees C. The GTR 2020 note that 1.5 degrees is preferred, but that "[e]ven limiting the increase to 2 degrees would require the gross addition of some 2,836GW of new non-hydro renewable energy capacity by 2030 according to the base-case scenario in BloombergNEF's New Energy Outlook 2019. The latter's projection of the technology mix based on the evolution of relative costs is for this to consist of 1,646GW of solar 1,156GW of wind and 34GW of other non-hydro renewables at an estimated cost of [USD] 3.1 trillion over the decade" (Frankfurt School-UNEP Centre/BNEF, 2020).




Source: Frankfurt School-UNEP Centre/BNEF, 2020

Figure 35　Projected Renewable Power Shortfall for RE100 (in TWh)

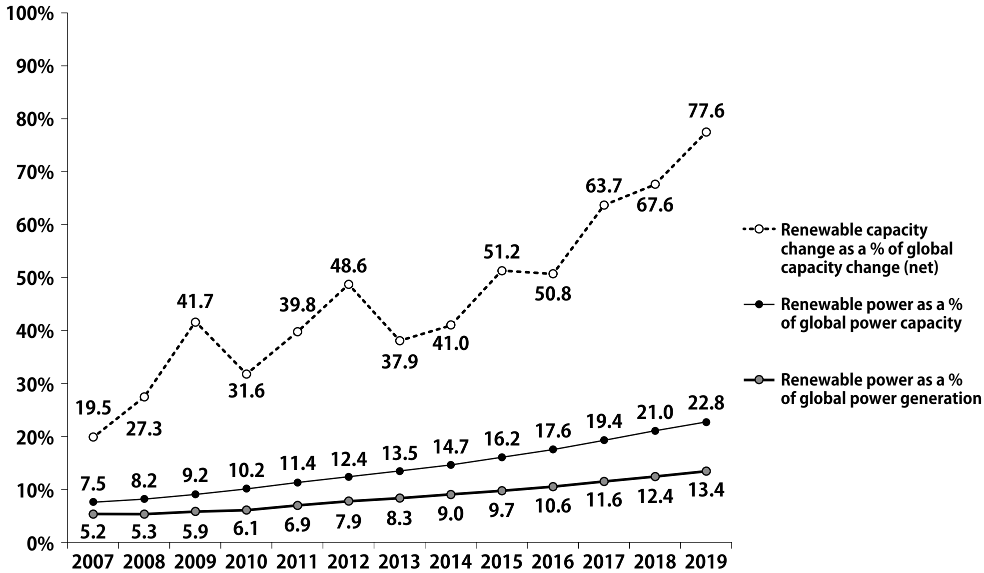



Source: Frankfurt School-UNEP Centre/BNEF, 2020

Figure 36　Projected Renewable Capacity for Targets Compared to 2 Degrees C Target, by Country (in GW)

Figure 37 shows why the GTR 2020 is bullish on the capacity of non-hydro RE to grow exponentially. The contribution on non-hydro RE in actual power generation (vs capacity addition) has indeed increased at an accelerating pace. Between 2007 and 2008, RE capacity increases were about 20% of global capacity additions, and overall RE capacity rose 0.7%. But power output rose only by 0.1% of total global power (from 5.2% to 5.3%). Yet in 2018-2019, RE capacity was roughly 70% of global added capacity, and RE capacity per se increased from 21% to 22.8%. The RE share of total global power generation rose from 12.4% to 13.4%.

One could argue that this RE diffusion is about to go exponential, driven by the virtuous cycle of cheapening costs, technological advances, and other factors argued by 100% RE advocates. And that may turn out to be true. Yet it is also true that they overlook NIMBY and other issues that are clearly worsening. Such realities may slow down the rate of increase in deployment and price declines, making RE more expensive and undermining its attractiveness. These risks make it imperative to have comprehensive analyses of RE alongside other decarbonizing technologies. Again, the GTR 2020 only allude to these issues, as (on




**Renewables figure excludes large hydro. Capacity and generation based on BloombergNEF totals.**

Source: Frankfurt School-UNEP Centre/BNEF, 2020

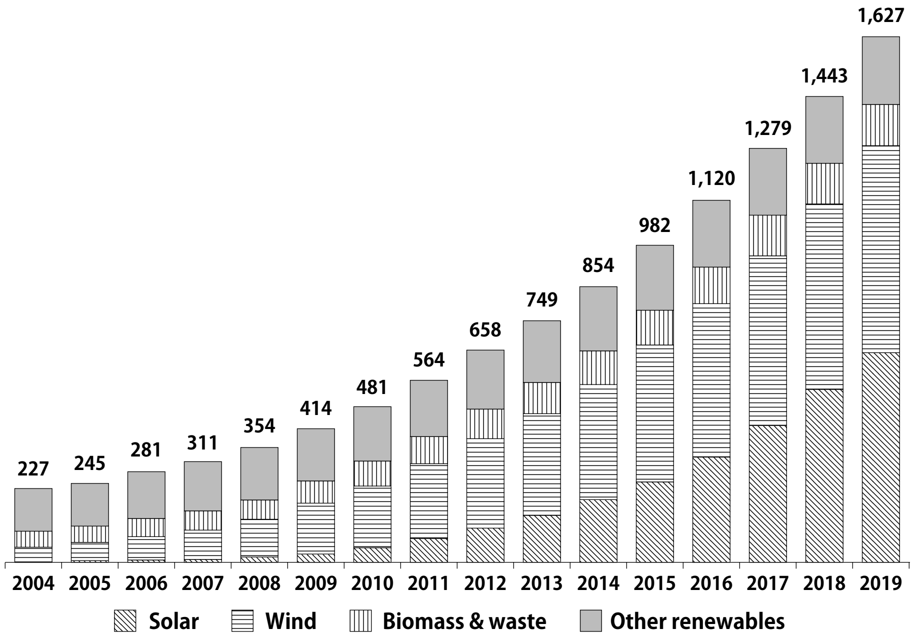
Figure 37 Projected Renewable Generation and Capacity as a Share of Global Power, 2007-2019 (%)

p 57) where they confess that RE investment in Japan declined in part because of the country's "continued grid and land constraints that held back developer activity and auction bidding." This is an indirect admission of the significance of system costs, material constraints, and NIMBY (which restricts the availability of land for VRE and other RE).

At 2019 global benchmark capital costs per megawatt 826GW of new capacity might have an upfront capital cost of some $900 billion – if the technology split was 75:25 between utility-scale PV and onshore wind. Or $1.1 trillion if it was 70:20:10 between utility-scale PV onshore wind and offshore wind.

Figure 38 also shows why the GTR 2020 is bullish on the capacity of non-hydro RE to grow exponentially. These data are for capacity only, which is far less than actual generation. But the presentation of the data certainly has a powerful effect on what seems possible.

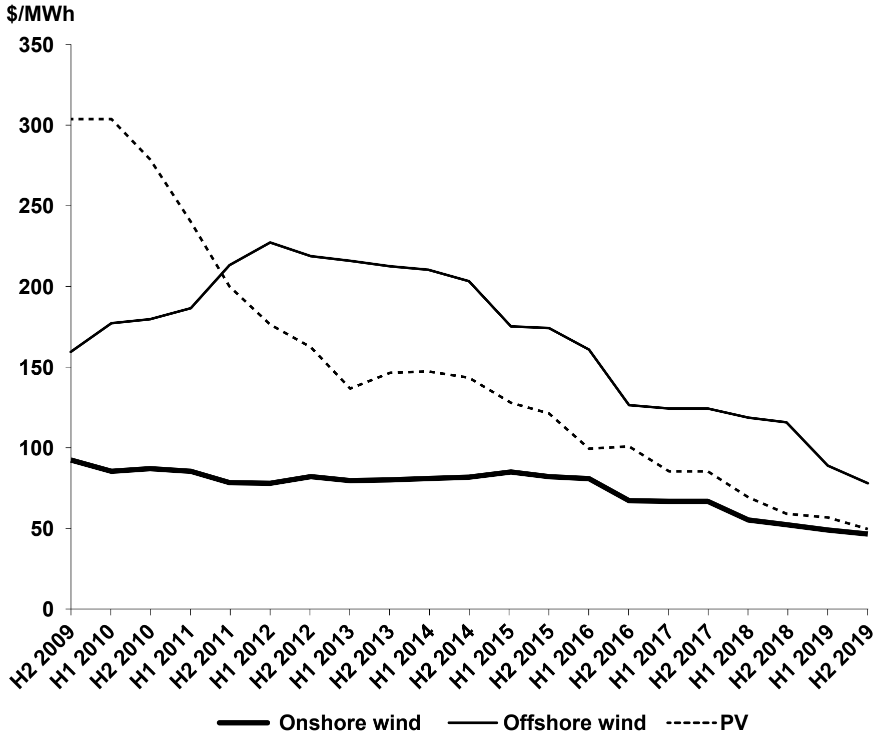
Similar to the previous item on capacity increases, cost-decline data can also makes trends seem inevitable. Figure 39 is GTR 2020's chart on the levelized cost of wind and solar. The data certainly indicate a rapid cheapening of generation costs, at least on-site. By 2019, solar (in the figure, PV) had dropped below a third of what it cost in 2009. The costs for on-




**"Other renewables" does not include large hydro-electric projects of more than 50MW.**

Source: Frankfurt School-UNEP Centre/BNEF, 2020

Figure 38 Global Renewable Capacity, 2004-2019 (in GW)



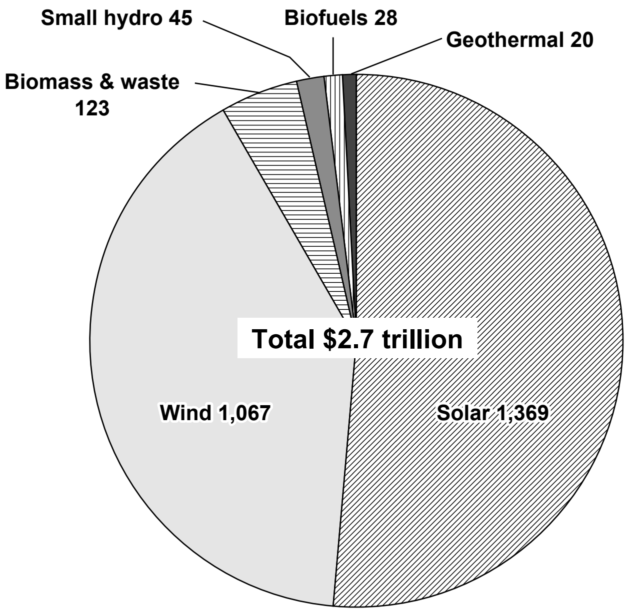

**PV is crystalline silicon with no tracking.**

Source: Frankfurt School-UNEP Centre/BNEF, 2020

Figure 39 Levelized Costs for Electricity Generation, 2009-2019 (USD/MWH)

shore and offshore wind had also declined, albeit not as spectacularly as solar. The IRENA also point out that "[e]lectricity costs from utility-scale solar PV fell 13% in 2019, reaching a global average of 6.8 cents (USD 0.068) per kilowatt-hour (kWh). Onshore and offshore wind both declined about 9%, reaching USD 0.053/kWh and USD 0.115/kWh, respectively." These price declines are assumed to continue and to be an accurate accounting of all-in costs (IRENA, 2020a). Yet CRM prices and other factors may impede further price declines. And it certainly not the case that system costs are reflected in the levelized cost of generating equipment. For example, the German energy transition is expected to include 1,600 kilometers of new transmission lines and bolstering of 2,900 kilometers of extant lines. This new transmission equipment is required to integrate renewables into the power system, at a cost of EURO 52 billion (Appunn, 2019).

Figure 40 also underpins this sense of escalating momentum in the GTR 2020 report. The data portray RE investment from 2010-2019 in USD billions. The total investment of USD 2.7 trillion for the decade makes the GTR 2020 assertions seem, at first glance, quite




Source: Frankfurt School-UNEP Centre/BNEF, 2020

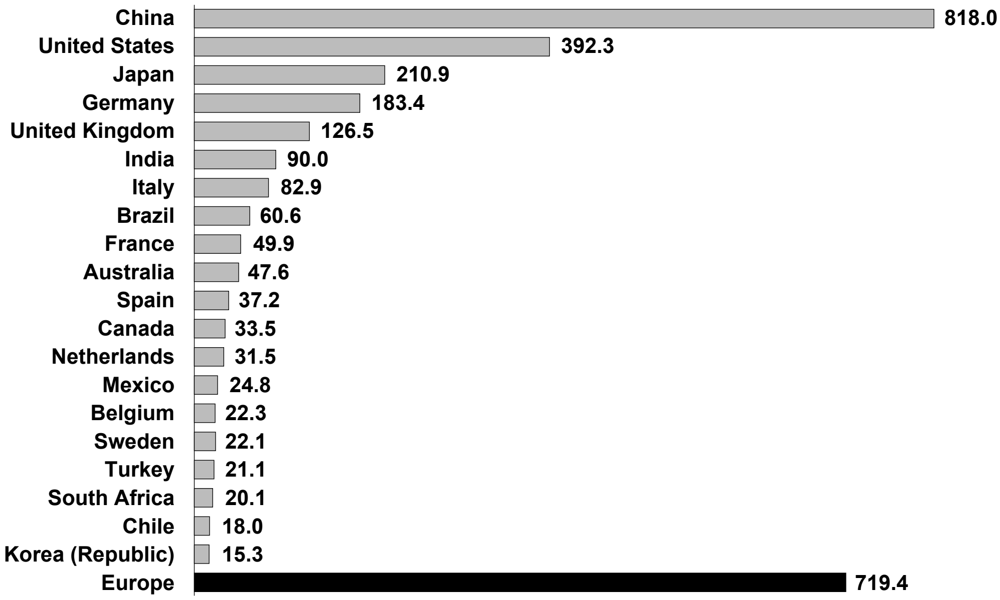
Figure 40 Global Renewable Capacity Investment Volume, by Generation, 2010-2019 (USD Billion)

reasonable.

Figure 41 presents the previous figure's summary data by country. We see that China is the leader, with USD 818 billion invested, followed by the US (USD 392.3 billion), and Japan (USD 210.9 billion). The EU as a region is in fact just behind China, at USD 719.4 billion. These data reinforce the impression that GTR 2020 forecast exponential diffusion is unstoppable, in tandem with decreasing prices.

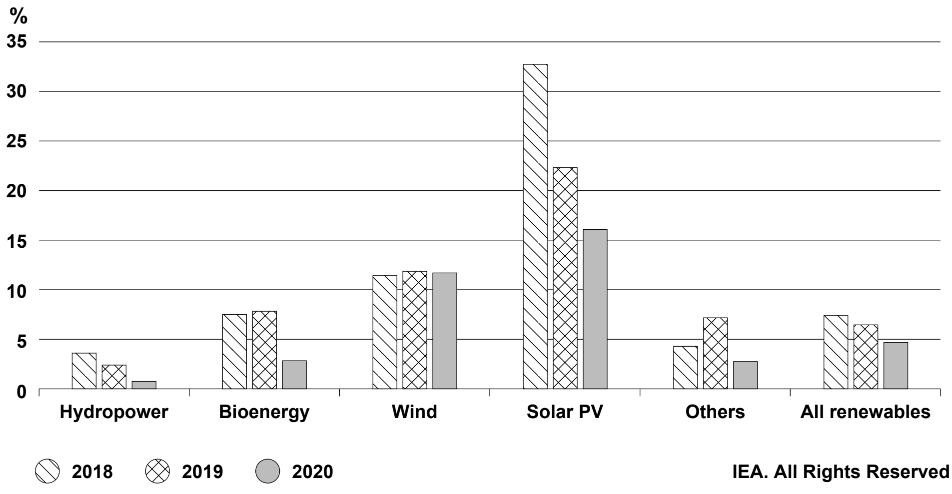
Yet the IEA data in figure 42 suggest that matters may be less certain. As we see from the chart, in the period 2018-2020 solar PV dropped from 33% to 16%. Since most 100%RE and other VRE-intensive scenarios rely on exponential growth, this fact seems problematic. It would appear that a broader portfolio of decarbonizing energy options is essential, in addition to changes in land use, dietary shifts, accelerated weathering, and other means of decarbonization (or even negative carbon emissions, via capture of existing atmospheric stock).

Figure 43 is also from the IEA. It shows the average for non-OECD Asia growth in total energy supply (ie, not just electricity) from 1971-2018. Non-hydro RE certainly has a large role in 2017-2018 (seen in the dot within the chart boundaries). But even more impressive is the data for nuclear, which outpaces non-hydro RE by 16% to 14%. Non-OECD Asia may be an important forward indicator, as its "main energy-consuming sector was in-




Source: Frankfurt School-UNEP Centre/BNEF, 2020

Figure 41 Renewable Capacity Investment Volume, by Country, 2010-2019 (USD Billion)

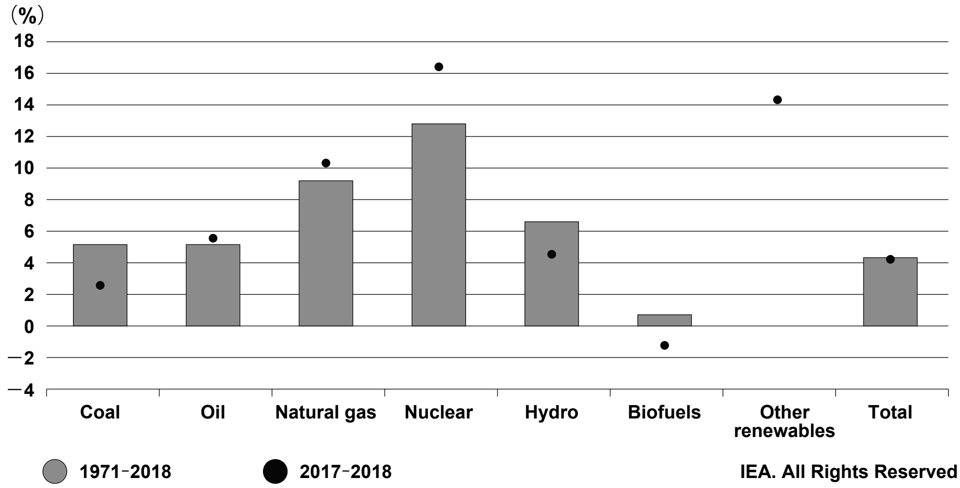



Source: IEA, 2020k

Figure 42 Annual Growth of Renewable Electricity Generation, by Source 2018-2020

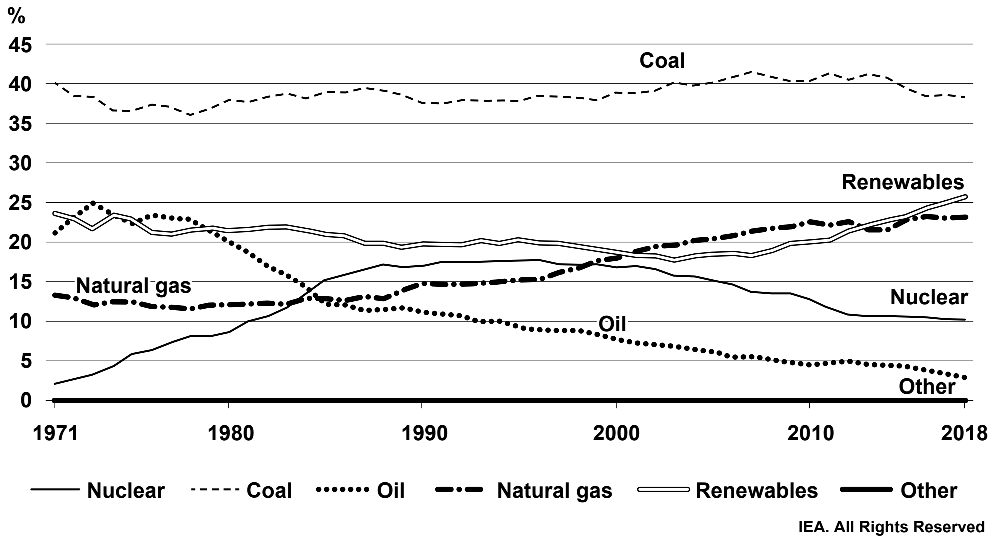
dustry, which represents 51% of the region's total final consumption" (IEA, 2020l). Cooling, mobility, CRM and other demand projections certainly suggest there will be a lot of industrial activity over the coming decades.

In the below, we drill down on the power numbers. We examine surveys and projec-




Source: IEA, 2020l

Figure 43　Annual Growth in Total Energy Supply in Non-OECD Asia, 1971-2018




Source: IEA, 2020i

Figure 44　World Electricity Generation Mix by Fuel 1971-2018

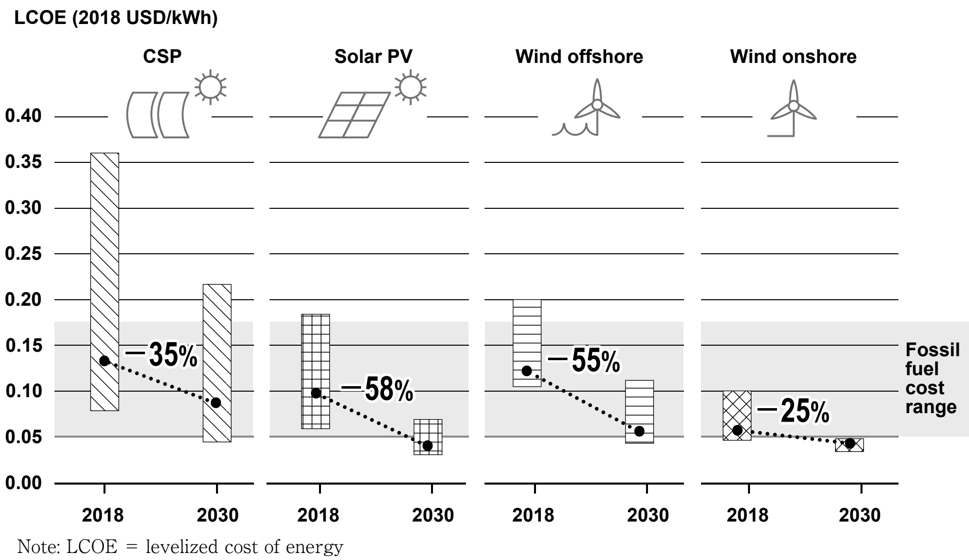
tions, mixing them with studies of CRM demand and supply issues.

First, as we see in figure 44, the global power mix has changed significantly between 1971 and 2018. At 38.2% of global power generation in 2018, GHG-intensive coal remains the principal source of power generation. This fact is a major impediment to decarbonization. Indeed, in many places (especially the US), reduced use of coal in favour of natural gas has been the main route of emissions reduction for the past decade. Hence, we see that natural gas has risen from 13.2% in 1971 to 23.1% in 2018. Natural gas emits lower GHG than coal (in general), but it is still a fossil fuel. Increasing reliance on natural gas is almost certainly not a wise means of pursuing rapid decarbonization.

We also see that renewable energy and nuclear energy are the main low-carbon sources of power, but the nuclear share has been declining since reaching a peak of 17.7% in 1996. Renewables (principally hydro) were 23.6% of power in 1971, when the overall volume of global power generation was much smaller. In 2018, renewables became 25.6% of global power, with hydro remaining the principal source supplemented by massive growth in solar, wind, and other forms of renewable energy.

Whether variable renewables (VRE) can continue their rapid diffusion and cost reduction is a major concern in this section. One main reason for concern is the NIMBY discussed earlier. Another issue area is the system costs that are often overlooked in claims about dramatic declines in VRE costs.

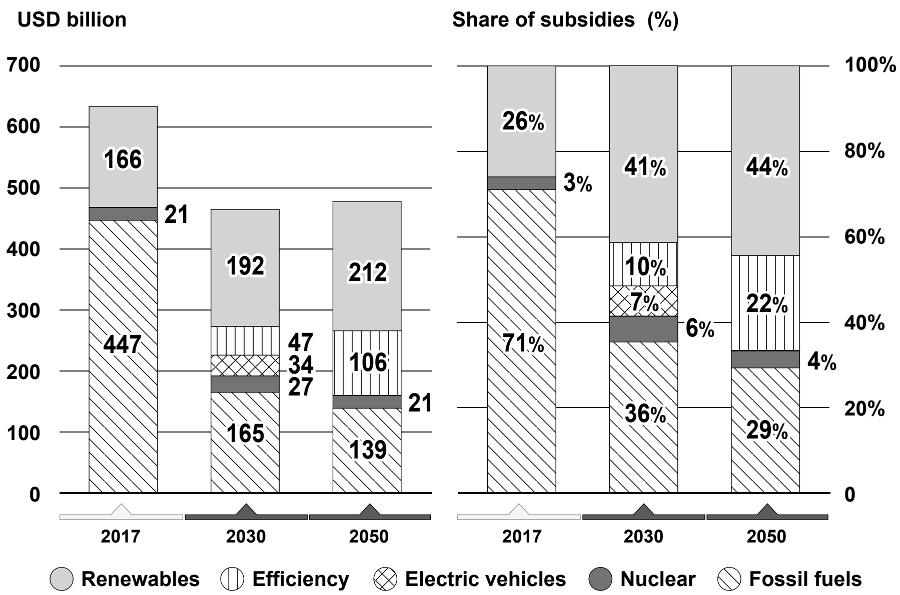
The expected cost reductions are displayed in figure 45 from the International Renewable Energy Association's (IRENA) 2020 report on the Global Renewable Outlook. The figure shows that the IRENA experts forecast dramatic price declines to continue. Solar is expected to drop an additional 58% between 2018 and 2030, while offshore wind is projected to decline just a little less at 55% over the same period. Unlike earler reports by IRENA,




Note: LCOE = levelized cost of energy
Source: IRENA, 2020b

Figure 45 Expected Cost Reductions of VRE, 2018-2030 which mentioned the role of CRM, this report does not take up the issue of whether material supplies are sufficient or could become a bottleneck for future price reductions.

As we see in figure 46, the IRENA call for the shift of energy subsidies from carbon-intensive fossil fuels to decarbonizing renewables, nuclear, and energy efficiency. This emphasis is to be lauded, as in 2017 fossil fuels received 71％ (USD 447 billion) in subsidies, whereas renewables received 26% (USD 166 billion) and nuclear a mere 3％ (USD 21 billion). The IRENA wants a dramatic cut in subsidies overall by 2030 along with a shift of support towards renewables, nuclear, electric vehicles, and energy efficiency. And for 2050, the IRENA urges that these changes be further accelerated. The 2050 target is for an increase in subsidies relative to 2030, but with only 29% (USD 139 billion) going to fossil fuels, while 44% (USD 212 billion) would be for renewables, 22% (USD 106 billion) for efficiency, and 4％ (USD 21 billion) for nuclear. It is interesting that the IRENA recognizes several pertinent factors, one of which is that abandoning fossil fuels immediately is not an option. Hence, the IRENA would maintain support for them, albeit at reduced levels. A second factor is that immediately cutting all subsidies would have massive deleterious impacts on lower-income households. That kind of shock would likely greatly diminish support for any kind of energy transition. A third factor is that nuclear energy is required, at least as a baseload supply of decarbonizing energy in areas where hydro, geothermal and other such 24/7




Source: IRENA, 2020b

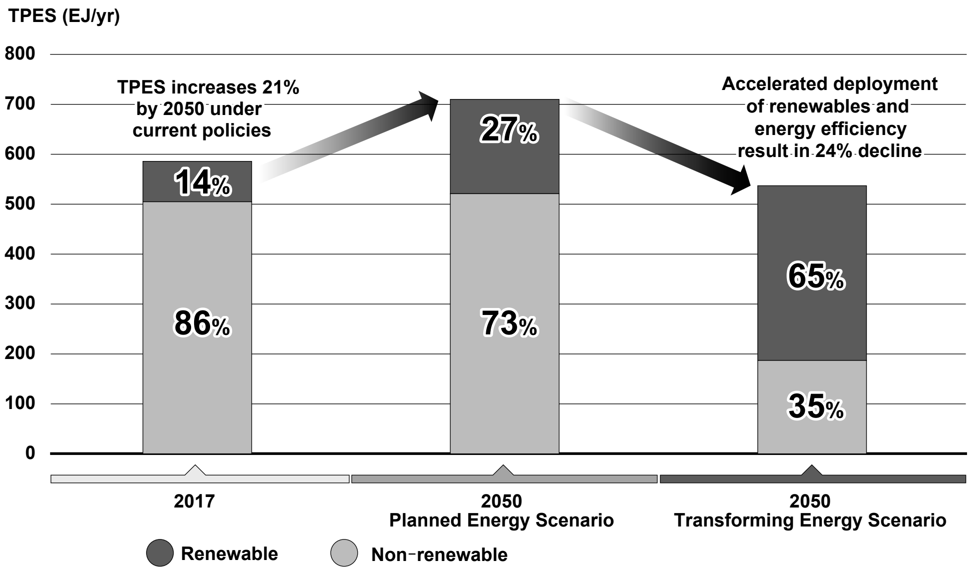
Figure 46　Energy Subsidies

sources are minimal.

But what the IRENA misses is the need for massive R&D and supply-chain investment in CRMs. One would have thought that the IRENA would have examined its earlier reports that include data on CRMs, compared that to current under-investment in CRM supply chains (especially at the very upstream of mining), and called for coordinated investment. If the IRENA and related environmentally oriented institutions were to champion sustainable CRM development, then a great deal of geopolitical, environmental, and other risks could be minimized.

Note that in figure 47 the IRENA argue that meeting climate goals requires that 65% of all the world's energy be supplied through renewables by 2050. The IRENA do not mean power alone, but all energy. They stress that a lot of energy currently lost as waste heat (such as in gasoline-powered cars) would not be necessary. Hence, they project a 24% savings in energy. Even so, the IRENA is arguing for a massive increase in the diffusion of VRE and other forms of renewables. That fact has enormous CRM implications. In addition, they are presumably supportive of sustainable cooling and other solutions for increasingly heat-stressed areas. Yet as we saw in the previous section, cooling solutions necessarily entail increased CRM footprints, particularly if those solutions are smart and efficient.

Figure 48 shows that the IRENA are calling for 8,519 GW in solar PV generation alone by 2050, together with 6,044 GW of onshore and offshore wind. These VRE would be the

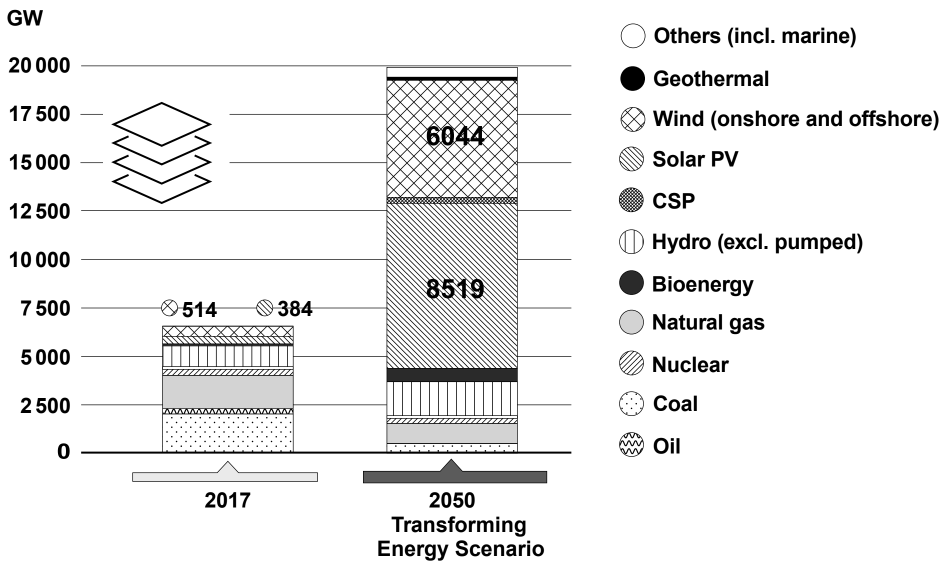



Source: IRENA, 2020b

Figure 47 IRENA's Scenario for Transforming Energy mainstay of the global energy system, an aim which implies overcoming a great deal of NIMBY and other issues. But for our purposes here, the required volumes of CRM are of immediate interest.

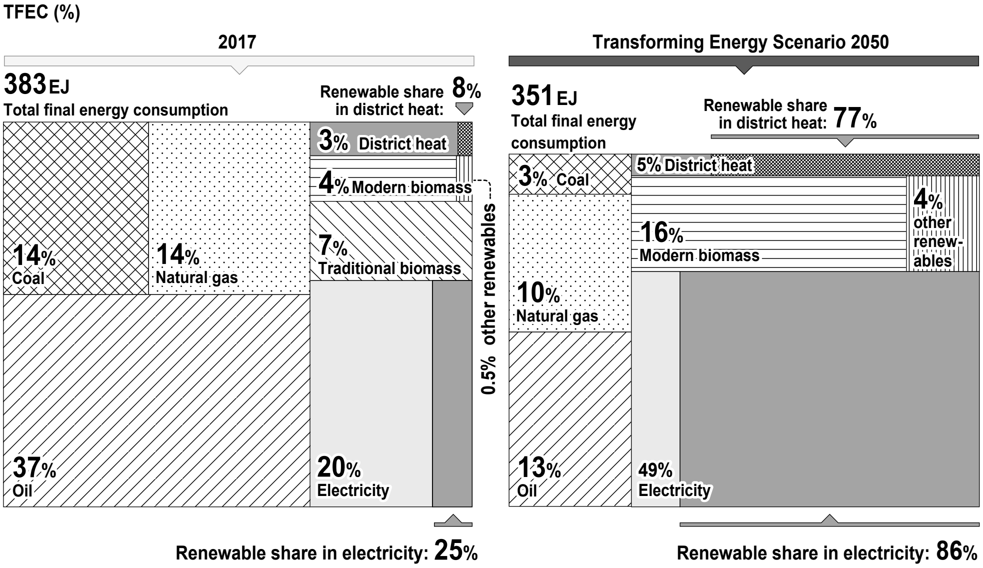
Figure 49 shows the IENA's proposal in sectoral detail. The IRENA plan for final energy consumption would raise the global share of electricity from 20% in 2017 to 49% by 2050. This increased role for electricity would be seen in EVs in place of gasoline (and other fuel, such as diesel) in mobility. Power would also replace a lot of fossil-fuel use in industry and other areas. These ambitious goals mean that CRM-density would be even greater across the entirety of the energy economy and ancillary areas.

Figure 50 confirms that the CRM-density of IRENA's proposal is enormous. They envision a rapid rollout of electric cars. They project the 2018/2019 global total of 7.9 million EVs to rise to 379 million by 2030, 744 million, in 2040, and then 1.109 billion in 2050. This aim would require an allied deployment of millions of electric chargers and other infrastructure, all of which require CRM. And the IRENA target of 379 EVs by 2030 is more ambitious than the IEA Sustainable Development Scenario target of 250 million EVs by 2030, yet the IRENA expresses no concerns about CRM. By contrast , the IEA observes that "[t]he estimated material demand for the batteries of the electric vehicles sold in 2019 was about 19 kt for cobalt, 17 kt for lithium, 22 kt for manganese and 65 kt for nickel. For battery needs in the Stated Policies Scenario, cobalt demand expands to about 180 kt/year in 2030, lithium to around 185



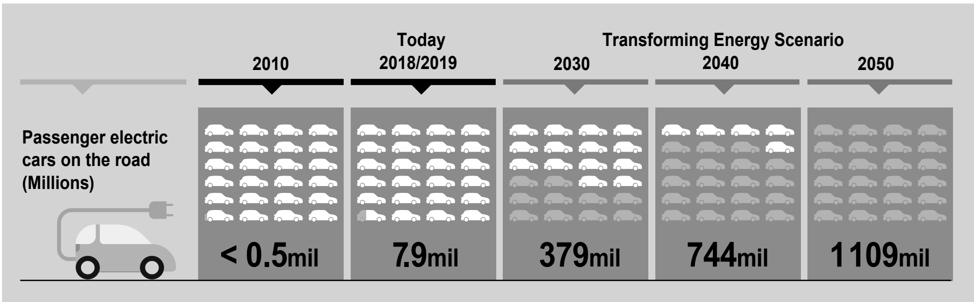

Source: IRENA, 2020b

Figure 48 IRENA's Scenario for Transforming Energy, in Detail




Source: IRENA, 2020b

Figure 49 IRENA's Scenario for Transforming Energy, Electrification



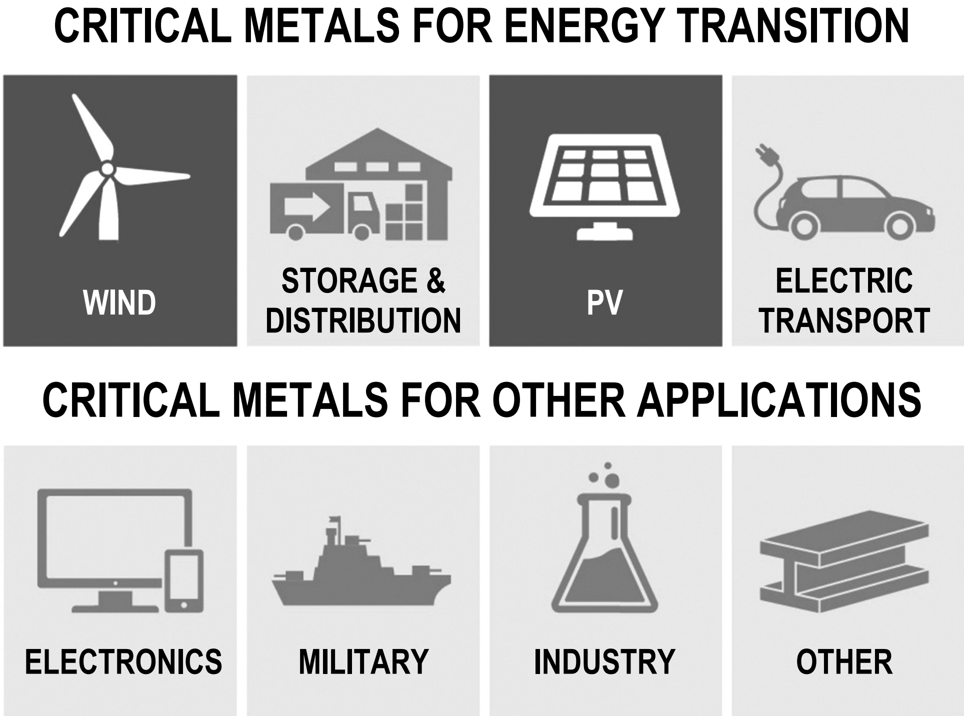

Source: IRENA, 2020b

Figure 50 IRENA's Scenario for Transforming Transport

kt/year, manganese to 177 kt/year and class I nickel to 925 kt/year. In the Sustainable Development Scenario, higher electric vehicle uptake leads to 2030 material demand values more than twice as high as the Stated Policies Scenario (IEA, 2020j).

Hence, we want to focus on the question of whether sufficient supplies of CRMs are available for an accelerated diffusion of VRE and other CRM-dependent technologies. So first we need to scope the issue. Fortunately, a great deal of high-quality research has already been done. We consider the best of it below.

Figure 51 shows us some of the complexity of the CRM challenge. The figure was prepared by Dutch researchers at Metabolic, Copper 8, and other cutting-edge consultancies.



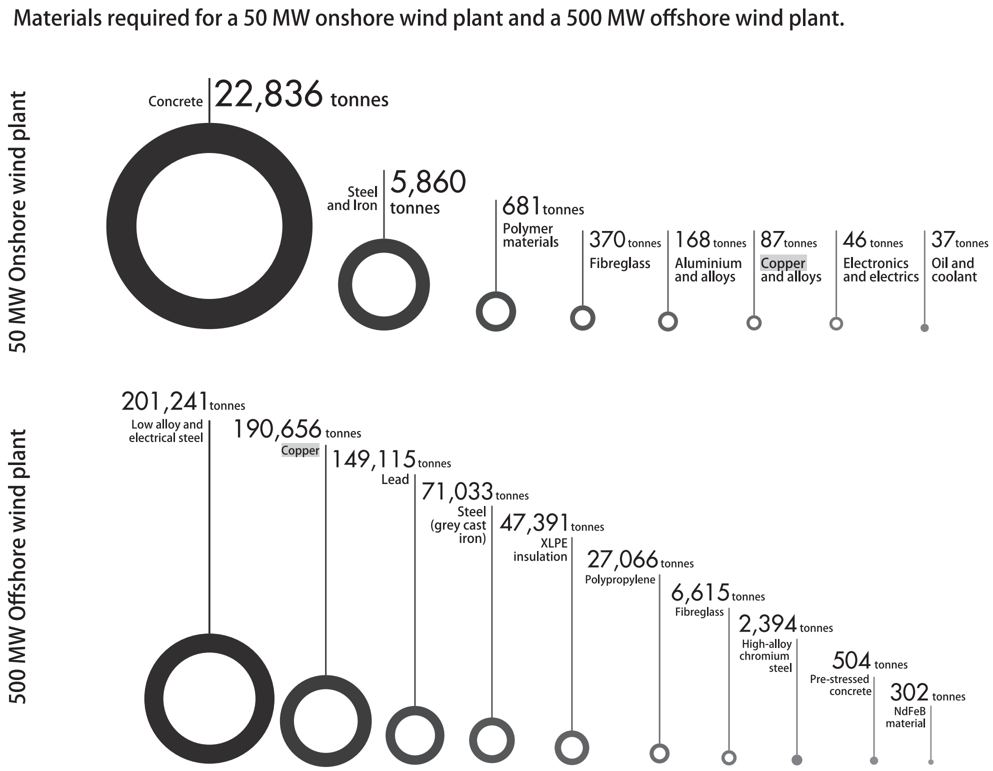

Source: van Exter et al, 2018

Figure 51 CRMs and the Energy Transition

Their collaborative work is supported by the Dutch Ministry of Infrastructure and Water Management in addition to other stakeholders. The reason we are suing their work in this paper is that it among the best of globally available surveys. Unlike most work, the researchers did not only compile CRM requirements for one particular area, such as EV batteries, solar power, wind generation, and the like. And also unlike most work, the researchers did not restrict their demand assessments to one country or one region. Rather, they assessed the demand for CRM for a range of technologies and for the entire globe. As we see in the figure, they begin by outlining the range of uses for CRM, which include energy, mobility, power systems (ie, transmission and storage), electronics, military, and other uses. Much work on CRM demand in mobility, for example, forgets that there are competing areas of demand, rendering their conclusions practically useless.

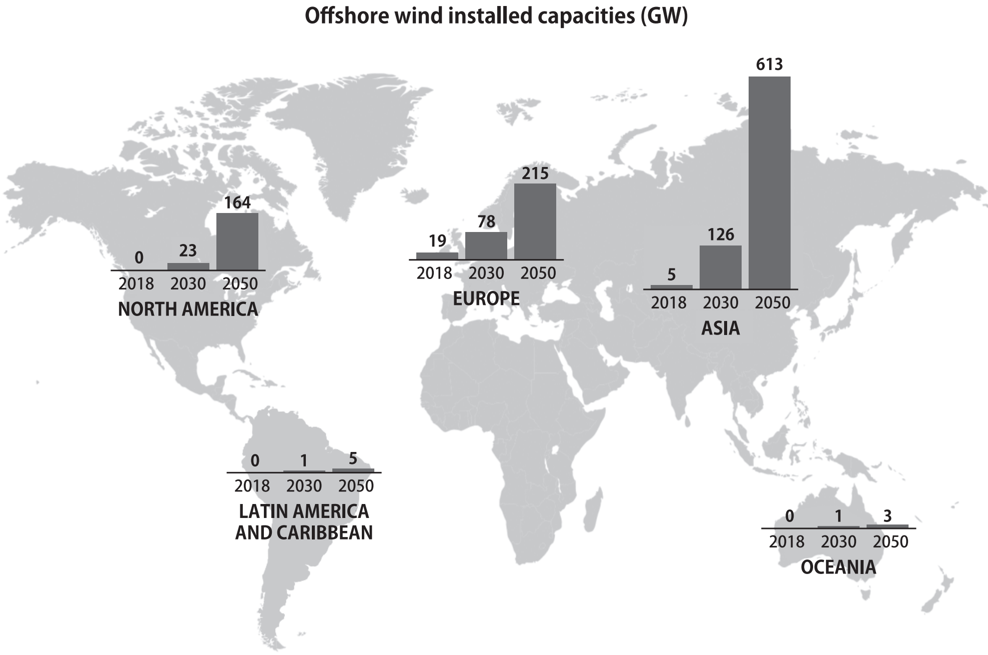
For example, figure 52 derives from an IRENA assessment of material requirements for large-scale wind arrays. The IRENA portrays the concrete, steel, copper and other materials required to construct a plant composed of 20-2.5 MW onshore turbines, or alternatively a plant composed of 200-2.5 MW offshore turbines. The material requirements of the two types differ, in large part because the length of power cables and other aspects do. The figure shows that the material requirements are prodigious for both onshore and offshore wind, but especially for the latter and particularly concerning copper and other metals. Is it a mystery why the IRENA left these CRM requirements out of its 2020 reports, which we reviewed earlier.

One of the key variables in calculating the increased call on critical materials is the rate of deployment of wind and other renewable generation. Figure 53 is drawn from the same 2019 IRENA assessment, and portrays the diffusion of offshore wind. It shows that the 2018 total of offshore wind, assessed at 23 gigawatts (GW), may grow to a global total of just under 1,000 GW by 2050. The IRENA does not assume that material requirement will remain the same over time, and in fact recognizes that significant changes will be required. All the same, their own data indicate increased distances (from the shore) and depths of offshore deployment. These parameters suggest higher requirements for copper and other ma-




Source: IRENA, 2019

Figure 52 Wind Turbines and Materials




*The designations employed and the presentation of material herein do not imply the expression of any opinion on the part of IRENA concerning the legal status of any region,country,territory,city or area or of its authorities,or concerning the delimitation of frontiers of boundaries.*

Source: IRENA, 2019

Figure 53 Offshore Wind, 2018-2050

terials needed to connect the generation assets with power grids. Hence the data in figure 52 may be an under-assessment.

It is unclear whether the IRENA wind projections can be realized. Table 10 reproduces table 8 used earlier, and presents the IEA's more short-range and conservative assessment of the likely increase in deployment of various renewable generation. The IEA data offer both a main case and an accelerated case. In both cases, the increase in wind is considerably less than a doubling for onshore and well beneath a quadrupling for offshore assets. And the increased deployment of renewables overall, including hydro, is a fairly modest growth from 2018's 2,501 GW of capacity to 3,721 GW in 2024 (or 4,036 GW in the accelerated case). In both cases, the very large share of hydro in the total renewable portfolio declines. That decline in the share of hydro is important. Hydro is comparatively low in CRM-intensity and high in terms of actual power output versus nameplate capacity. Based on current and conceivable technologies, the implied shift to a much greater role for wind and solar means higher CRM-intensity and lower output as compared to rated capacity.

Table 10 Renewable Power Outlook by Capacity, 2018-2024

**Total renewable electricity capacity by technology (GW)**

| | Main case | | | | | | | Acc. case |
|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2024 |
| **Hydropower** | 1,290 | 1,308 | 1,337 | 1,357 | 1,373 | 1,394 | 1,411 | 1,447 |
| Pumped storage | 155 | 158 | 163 | 167 | 171 | 176 | 181 | 202 |
| **Bioenergy** | 130 | 138 | 146 | 152 | 159 | 165 | 171 | 187 |
| **Wind** | 565 | 622 | 686 | 744 | 799 | 857 | 917 | 996 |
| Onshore wind | 543 | 595 | 654 | 704 | 753 | 802 | 851 | 920 |
| Offshore wind | 22 | 27 | 32 | 39 | 46 | 55 | 66 | 77 |
| **Solar PV** | 496 | 609 | 716 | 823 | 939 | 1,064 | 1,195 | 1,374 |
| PV-Utility | 283 | 352 | 411 | 469 | 532 | 598 | 665 | 754 |
| PV-Distributed | 213 | 258 | 305 | 354 | 407 | 466 | 530 | 619 |
| **CSP** | 6 | 6 | 7 | 8 | 9 | 9 | 9 | 12 |
| **Geothermal** | 14 | 15 | 15 | 16 | 17 | 18 | 18 | 20 |
| **Marine** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Total** | 2,501 | 2,699 | 2,907 | 3,101 | 3,296 | 3,508 | 3,721 | 4,036 |

Source: IEA, 2019a

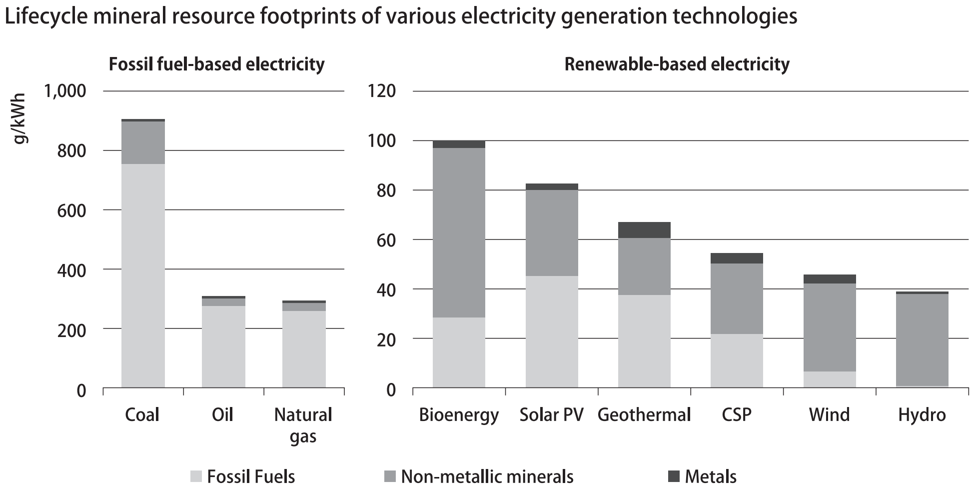
Table 11 Renewable Power Outlook by Output, 2018-2024

**Total renewable electricity generation by technology (TWh)**

| | 2018e | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | CAAGR |
|---|---|---|---|---|---|---|---|---|
| **Hydropower** | 4,203 | 4,258 | 4,385 | 4,483 | 4,537 | 4,591 | 4,648 | 2% |
| Pumped storage | 115 | 125 | 129 | 134 | 139 | 144 | 149 | 4% |
| **Bioenergy** | 546 | 599 | 640 | 683 | 715 | 746 | 761 | 6% |
| **Wind** | 1,268 | 1,389 | 1,534 | 1,698 | 1,852 | 1,998 | 2,135 | 9% |
| Onshore wind | 1,202 | 1,307 | 1,433 | 1,571 | 1,697 | 1,808 | 1,921 | 8% |
| Offshore wind | 66 | 82 | 101 | 126 | 155 | 190 | 214 | 22% |
| **Solar PV** | 585 | 720 | 864 | 1,005 | 1,151 | 1,309 | 1,480 | 17% |
| **CSP** | 13 | 16 | 18 | 20 | 25 | 26 | 26 | 12% |
| **Geothermal** | 90 | 94 | 98 | 101 | 106 | 111 | 116 | 4% |
| **Marine** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3% |
| **Total** | 6,707 | 7,076 | 7,542 | 7,991 | 8,387 | 8,783 | 9,168 | 5% |

Source: IEA, 2019a

We see the output aspect of the above in table 11. The table reflects the IEA's calculations of the power derived from the different renewable technologies, 2018-2024. The IEA data indicate that the wind and solar capacity increases in table 3 are not matched with corresponding levels of output. This result reflects the fact that solar and wind are inherent-




Source: IEA, 2019a

Figure 54　Lifecycle Mineral Footprints

ly variable, because of changes in insolation and wind speed.

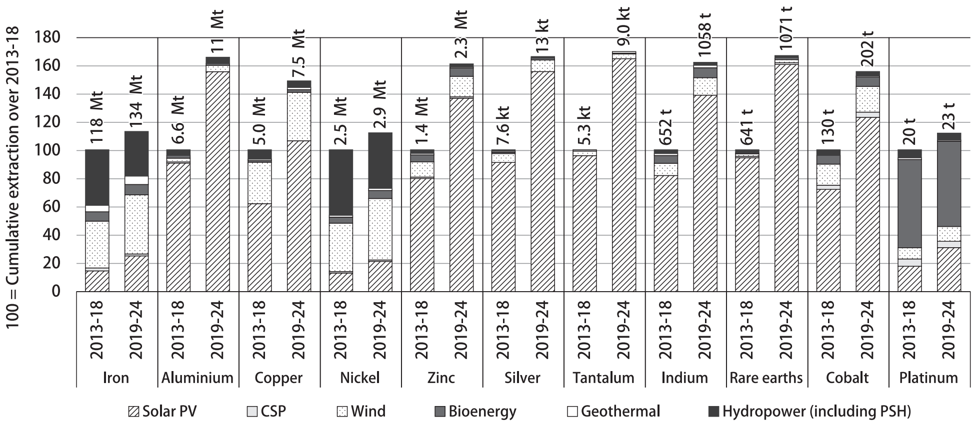
Figure 54 is drawn from the same IEA 2019 report on renewables, and provides more perspective on material costs. The fossil fuel costs involved in various power generation are seen as prodigious for conventional thermal power, but also significant for renewables. This is because significant quantities of fossil fuels are required to produce the steel, concrete and other materials used in building the generation assets. The figure also shows that the non-metallic materials and metals footprint of variable renewables are significant, particularly when compared with hydro.

Figure 55 follows up the above with a calculation of metal demand for several key renewable power technologies. The data are separated into actual demand between 2013-2018 and projected demand for 2019-2024. The latter calculation reflects comparatively conservative assessments for deployment. Even so, it is clear that the diffusion of solar has a major impact on demand for copper, tantalum, rare earths, cobalt, and other critical materials.

Figure 55 did not include data on the role of lithium, another critical material. Thus figure 56 supplements the figure 55 data with a calculation of how much lithium is used, per unit, in Tesla Model S electric cars, laptop batteries and other devices. The figure makes it clear that lithium demand is another significant parameter in the diffusion of clean-energy technology[13].

13) The Tesla Model S battery may contain 63 kg of lithium, in a 70 kWh battery pack.

**Cumulative extraction of selected metals for the renewable electricity sector over 2013-18 and 2019-24**





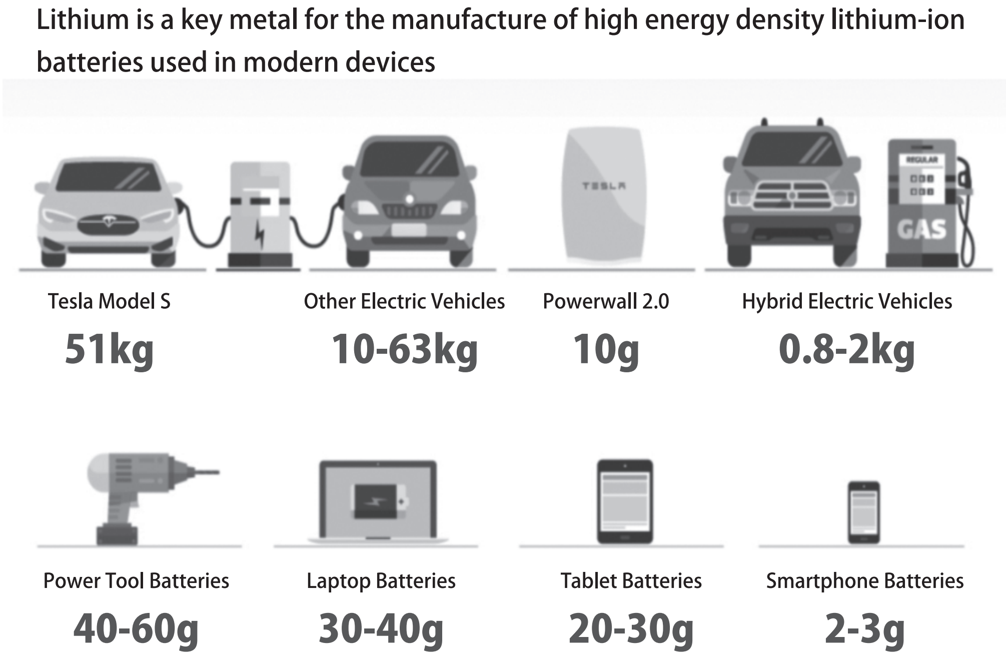

Source: IEA, 2019a

Figure 55 Actual and Projected Metals Demand for Renewables, 2013-2024

Figure 57 further enlarges the picture by presenting one calculation of what reaching 100% electric vehicles would require. The assessment is, of course, based on current technologies, which can be presumed to change. But it is instructive to note that just in the one area of electric vehicles, the required amounts of lithium, cobalt, and other materials are many multiples of current demand. And those materials are also used in myriad other devices, as figure 56 demonstrated is also true of lithium.

Yet another important variable is vehicle size. Figure 57 was assessed on the basis of CRM demand for current electric vehicles, but figure 58 reveals that heavy SUVs have become a major portion of car markets between 2010 and 2018. In the United States, SUVs seem likely to become more than half of all new-vehicle sales in 2019. SUVs make up a lower share of sales in China, India and other markets. But the figure shows that in all cases, the share of SUVs has increased dramatically over the period 2010-2018. This trend continued into 2019, when the share of SUVs in overall vehicle sales exceeded 40%, and accounted for 60% of the expansion of the global car fleet since 2010 (IEA, 2020f). Global auto sales dropped in 2020, due to the pandemic, declining from just over 90 million in 2019 to perhaps 75 million in 2020 according to LMC Automotive (Reuters, 2020). As we saw earlier concerning RACs and variable renewables, the data on SUVs are only just beginning to factor into analyses of material requirement and other issues related to decarbonization.

Figure 59 also reveals that overall vehicle sizes have increased globally, between 2010




Source: FE Limited, 2019[14)]

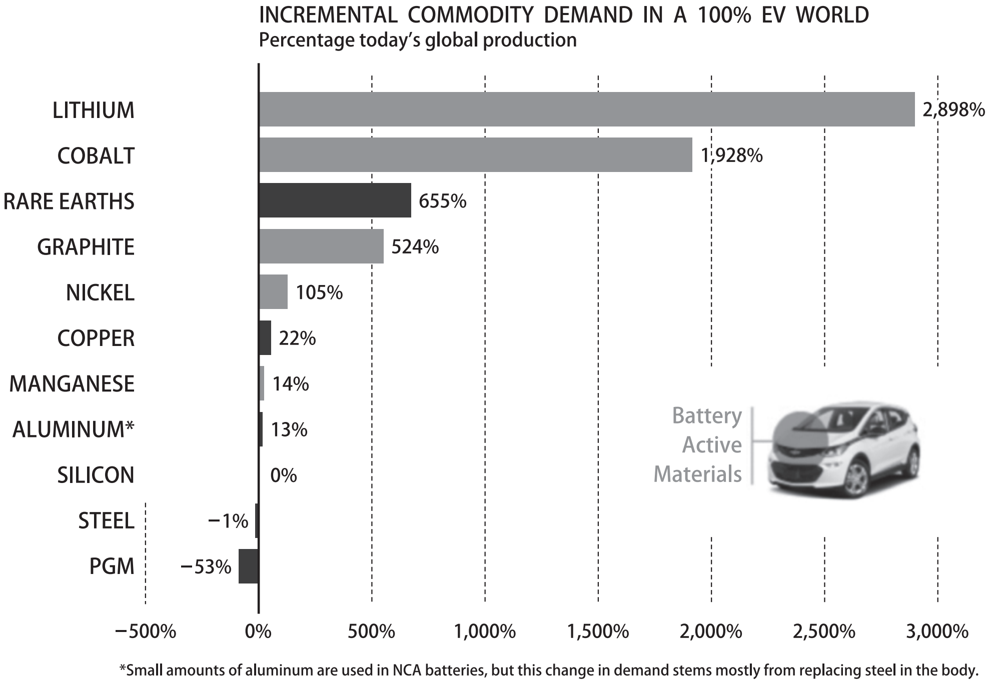
Figure 56 Lithium's Role in Various Applications

and 2018. It is not just that SUVs have proliferated. The data show that small and medium-sized vehicles were nearly 60% of all vehicle sales in 2010, but in 2018 that share had dropped to just over 40%. The significance of the data, for our purposes here, is that the heavier weight of vehicles implies even higher per-capita and per-unit demand for critical materials to electrify mobility. And as noted earlier, assessments of overall critical material demand for decarbonization are yet to analyze this trend in light of the evidence from solar, wind and other relevant areas. Materials research remains largely siloed by area of demand, type of material, and other fragmentation.

With the above key facts on CRM-density in power and mobility in mind, let us return to the Metabolic report. The Metabolic and partners' report was only one in a series. One of their reports examined EVs, which we have seen the IRENA and IEA emphasize.

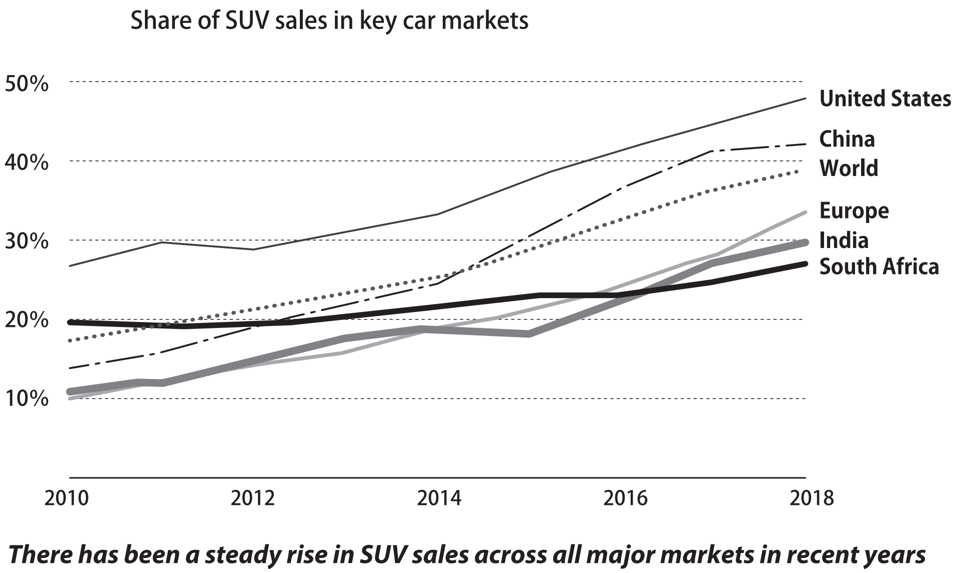
Figure 60 shows the same group of researchers' collaboration on CRM for EVs in the Netherlands, the EU, and the entire world. First, they calculated the impact of stated goals for the Netherlands relative to global CRM production. As we see in the figure, even the

14) The figure is from "Why Battery Metals?" FE Limited, 2019: https://www.felimited.com.au/why-energy-metals/



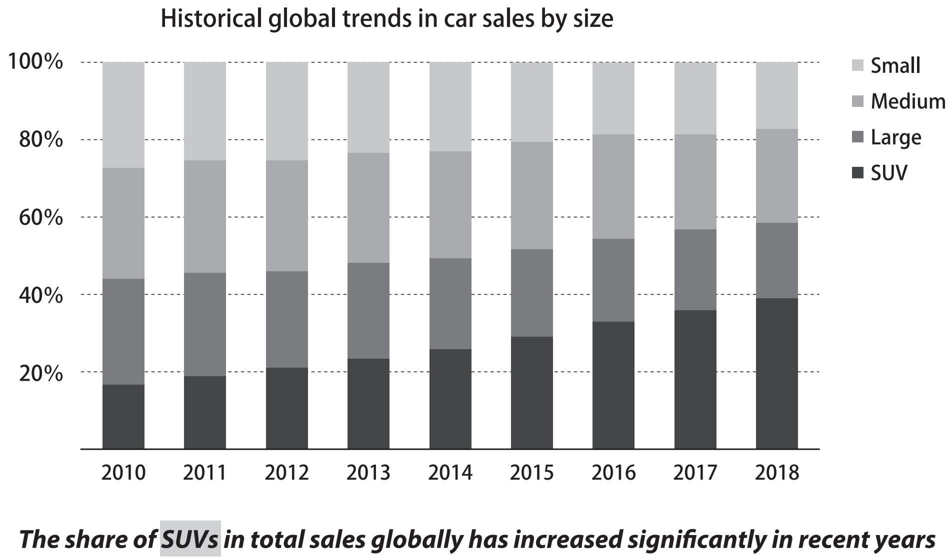

Source: FE Limited, 2019

Figure 57 Electric Vehicles and Critical Material Demand




Cozzi and Petropoulos, 2019

Figure 58 SUV Shares, by Market, 2010-2018



Cozzi and Petropoulos, 2019

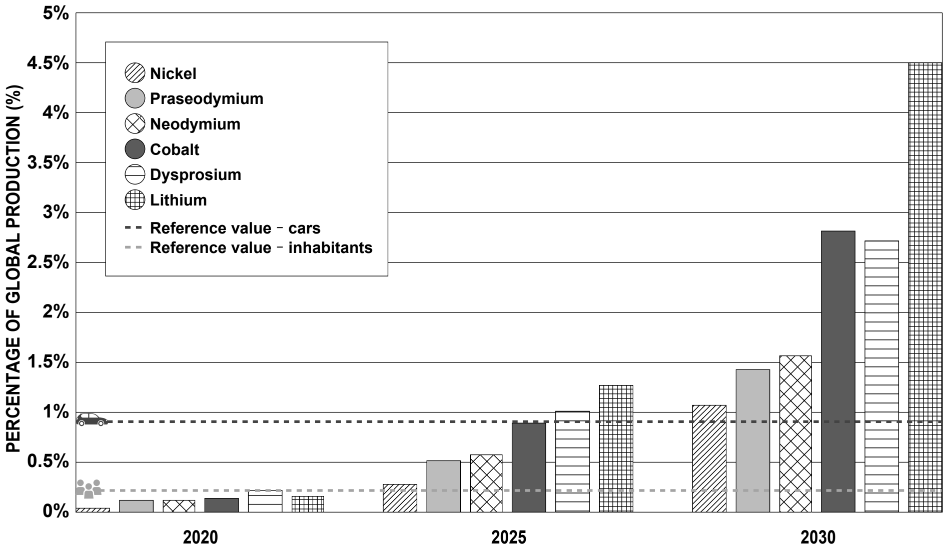
Figure 59 Vehicle Size, 2010–2018

goals for the Netherlands alone – whose population is only 17 million – begin to have significant impacts on global CRM output quite rapidly.

Figure 61 shows that the Metabolic researchers were careful to check the current numbers, so as to compare the Netherlands and European car fleets as a percentage of the global total. Their data show that there are 947 million passenger cars in the global fleet, and that the Netherland represents 0.9% of that total. The European share is much larger, at 25%, but most scenarios are for global EVs.

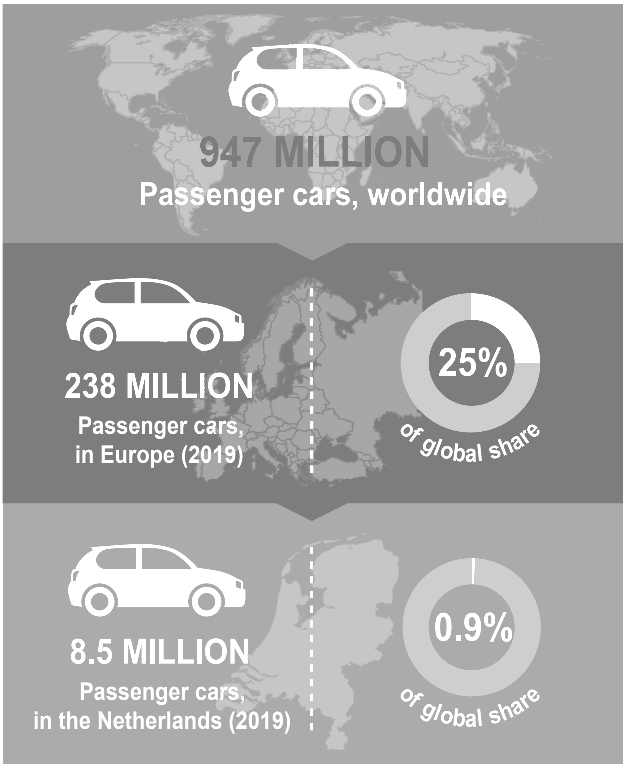
The Metabolic researchers then applied a similar estimate to Europe and the world, assessing how much of relevant CRM production would be required in a 30% by 2030 scenario. As the results in figure 62 show, the volumes of CRM rapidly become double or triple current global supply. And yet as we noted earlier, CRM such as nickel, lithium, and dysprosium are used in VRE, electronics, and a range of other areas. So the challenge is even greater than displayed in the figure. The Metabolic report also warns that the mining capacity to meet that kind of demand increase will take decades to ramp up.

Table 12 shows that the authors were careful to anticipate technological change. As they argue, "we assume further technological development of batteries. In that case, new cars will be fitted with modern batteries (such as the NMC 811) which contain less cobalt and lithium per kWh (Bosch et al, 2019). Their table 13 shows the expected ratios of these technologies over the next decade.



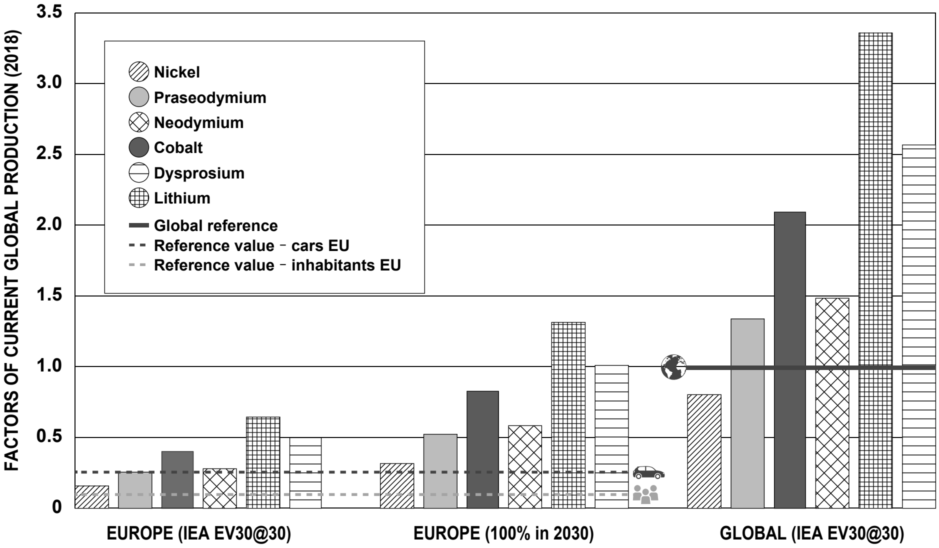

Source: Bosch et al, 2019

Figure 60 Critical Metals Required for Electric Vehicles in the Netherlands as Factor of Annual Global Production of These Metals




Source: Bosch et al, 2019

Figure 61 Key Figures for the Dutch and European Car Fleet in Relation to the Rest of the World




Source: Bosch et al, 2019

Figure 62 Basic Scenario for the Volume of Critical Metals Required Annually for Electric Passenger Transport in 2030 as a Factor of the Current Annual Global Production (2018)

Table 12 Metal Demand for Each Type of Battery in kg/kWh

| | Lithium | Cobalt | Nickel | Manganese | Carbon |
|---|---|---|---|---|---|
| LCO | 0.113 | 0.959 | 0 | 0 | 1.2 |
| NCA | 0.112 | 0.143 | 0.759 | 0 | 1.2 |
| NMC-622 | 0.126 | 0.214 | 0.641 | 0.2 | 1.2 |
| NMC-811 | 0.111 | 0.094 | 0.75 | 0.088 | 1.2 |

Source: Bosch et al, 2019

The table shows that the researchers assume an increasing technological sophistication and minimizing of the most strategic CRM. They state that "we assume further technological development of batteries. In that case, new cars will be fitted with modern batteries (such as the NMC 811) which contain less cobalt and lithium per kWh" (Bosch et al, 2019).

They are able to estimate with considerable accuracy as we see in table 14. This is because electric motors "contain a strong permanent magnet in which various critical metals are used. In contrast to batteries, the quantity of critical metals does not depend on the car's characteristics" (Bosch et al, 2019). So for these CRM, size is not a major influence. Lithium is a different matter, however.

The Metabolic team also sought to combine CRM demand for energy and mobility, as seen in figure 63. The 2030 global CRM demand for is multiples of current global production

Table 13 Expected Development in the Share of Battery Types in Electric Cars That Are Sold

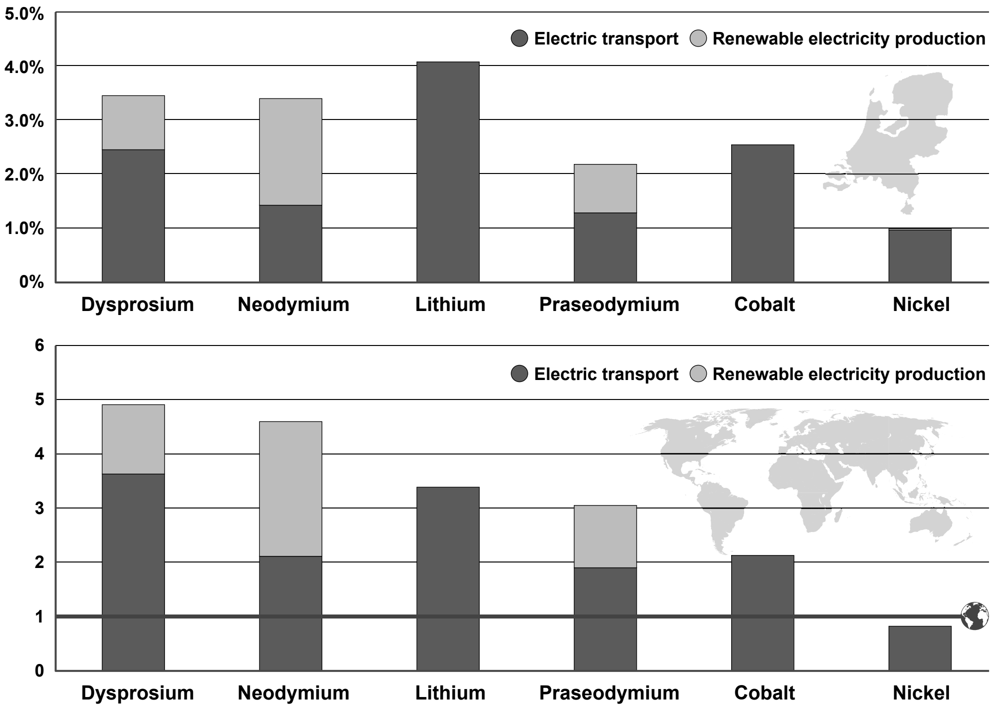
| | 2019 | 2025 | 2030 |
|---|---|---|---|
| LCO | 2% | 0 | 0 |
| NCA | 26% | 16% | 7% |
| NMC-622 | 40% | 28% | 16% |
| NMC-811 | 32% | 56% | 77% |

Source: Bosch et al, 2019

Table 14 Metal Demand for an Electric Motor in kg/vehicle

| METAL | DEMAND (KG / VEHICLE) |
|---|---|
| Neodymium | 0.34 |
| Dysprosium | 0.11 |
| Praseodymium | 0.11 |

Source: Bosch et al, 2019




Source: Bosch et al, 2019

Figure 63 The Aggregate Metal Demand for Electric Transport and Renewable Electricity in 2030 in the Netherlands (top) and the World (Bottom) as a Factor of the Current Annual Global Production for several CRM, including dysprosium, neodymium, lithium and others in the figure. The authors note that "[i]n absolute terms (mass), nickel is the metal that is required most. In relative terms (percentage of global production), nickel is however far less critical. Also, nickel production is spread across various countries." It is extremely difficult to substitute for these materials, and their supply chains are concentrated. The authors also point out that "China controls 71% of the global production of neodymium, praseodymium and dysprosium. Although cobalt is mined primarily in the Democratic Republic of the Congo, 80-90% of the worldwide refining takes place in China" (Bosch et al, 2019).

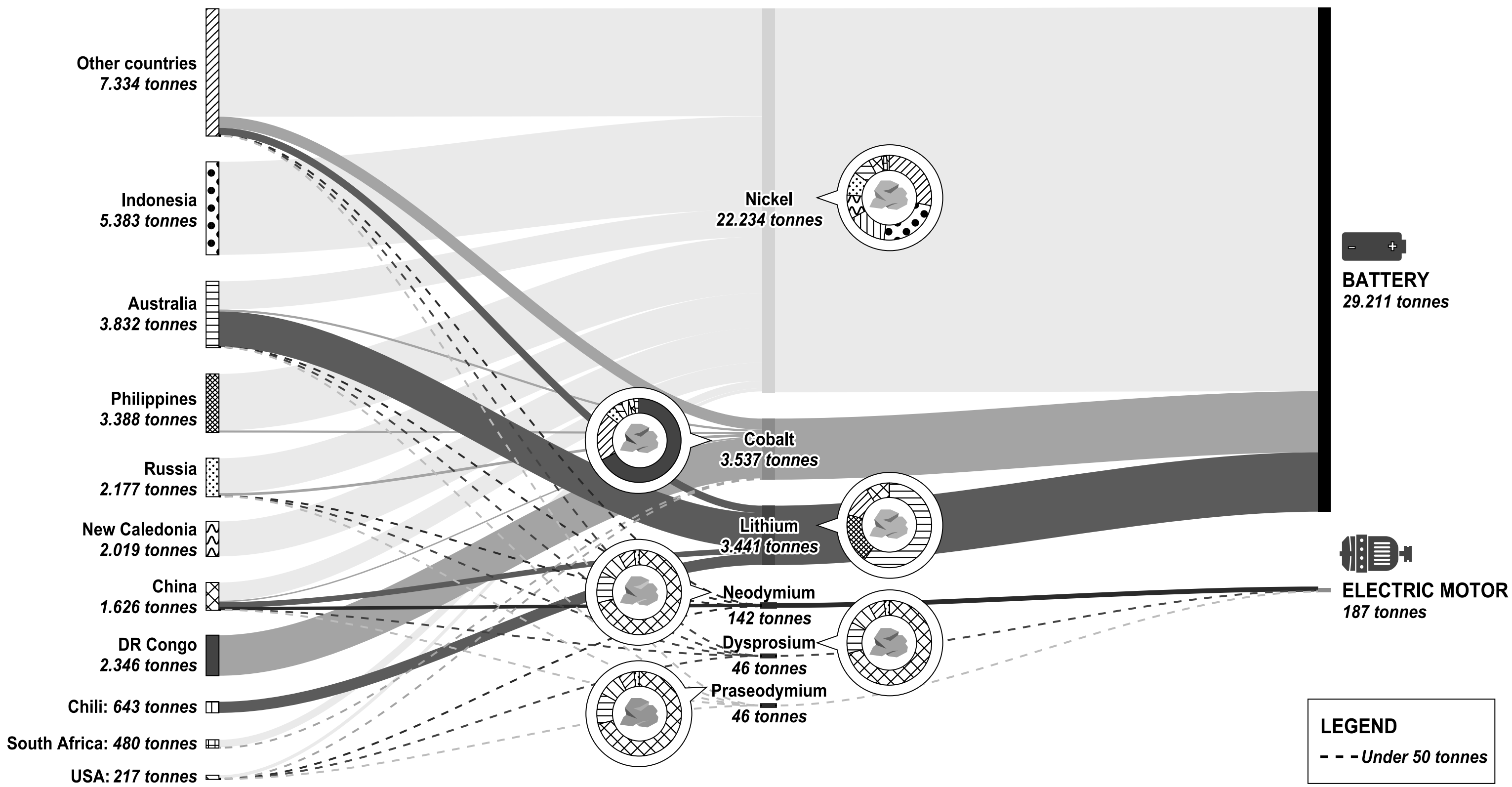
Figure 64 shows that in addition to the problem of substitution and supply, the materials have pronounced geopolitical risks. Most of the nickel, cobalt and other CRM used in Europe (and other developed areas) are imported from countries with rather poor governance and problematic human rights. Of course, much the same is true for fossil fuels. But the key difference is that CRM supply chains are very concentrated, amplifying the geopolitical risk.

So let us have a brief analysis of the geopolitical risk.

Figure 65 offers a glimpse at the reality of rare earths, a subset of CRM. We see that their production used to be concentrated in the developed countries. But over time, they became increasingly important and strategic even as their production became difficult (due to environmental constraints). Hence, the Mountain Pass era, when the US dominated production, gave way to the Chinese era. The authors suggest the emergence of a post-Chinese era, but that has not yet happened.

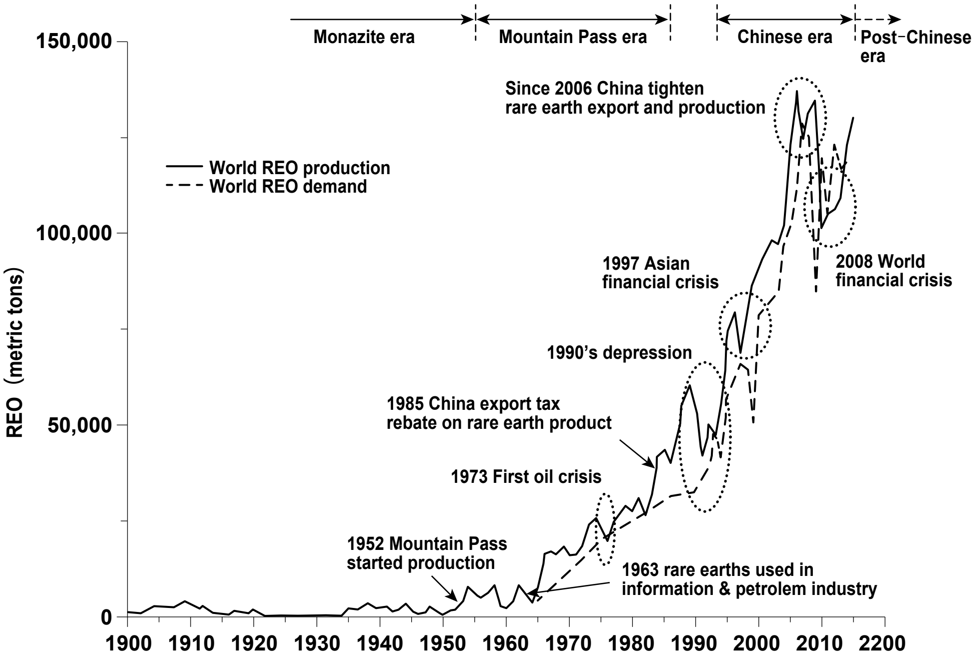
Figure 66 shows that China controls 84% of rare earths, with Australia second at 11%. It also shows that rare earths use in energy and mobility (largely batteries, magnets and some catalysts) is a small part of their role in industry and consumer products. Production of the rare earths is only 126,000 tons in 2016, compared to fossil-fuel production that is in the billions of tons. Rare earths are used in a myriad of competing applications, which makes it difficult to focus their use in an energy transition alone. The same fact is true of the larger universe of CRM.

Figure 67 shows that rare earth resources are plentiful, and that the term "rare earths" is misleading. The materials are also quite abundant outside of China, which is one reason the analysts forecast a post-China era. But in fact, it is very difficult to mine in the developed countries. As we shall see below, the EC has called for ramped-up supply chain investment, and has fostered it. But the investment is largely in processing rather than mining.



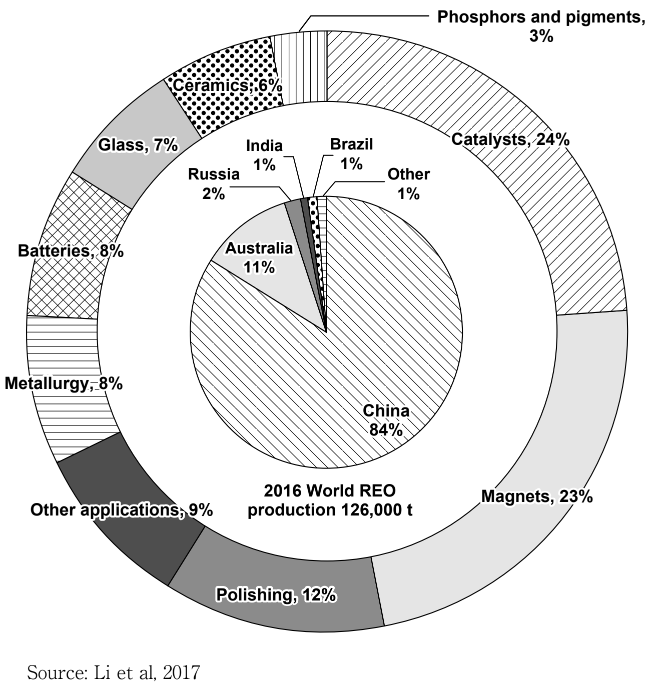

Source: Bosch et al, 2019

Figure 64 The Origin of Critical Metals in the Basic Scenario Based on the Metal Demand in 2030 and the Annual Global Production in 2018



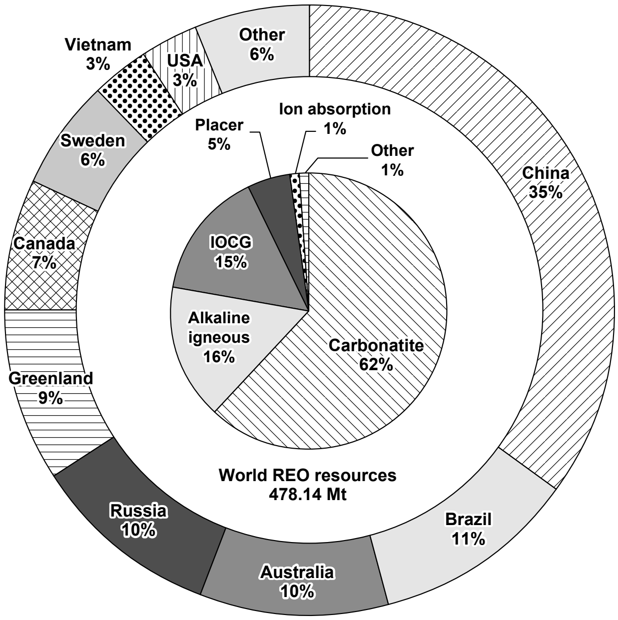

Source: Li et al, 2017

Figure 65　Global Production of Rare Earths, 1900-2020




Source: Li et al, 2017

Figure 66　Rare Earths Uses, by Sector



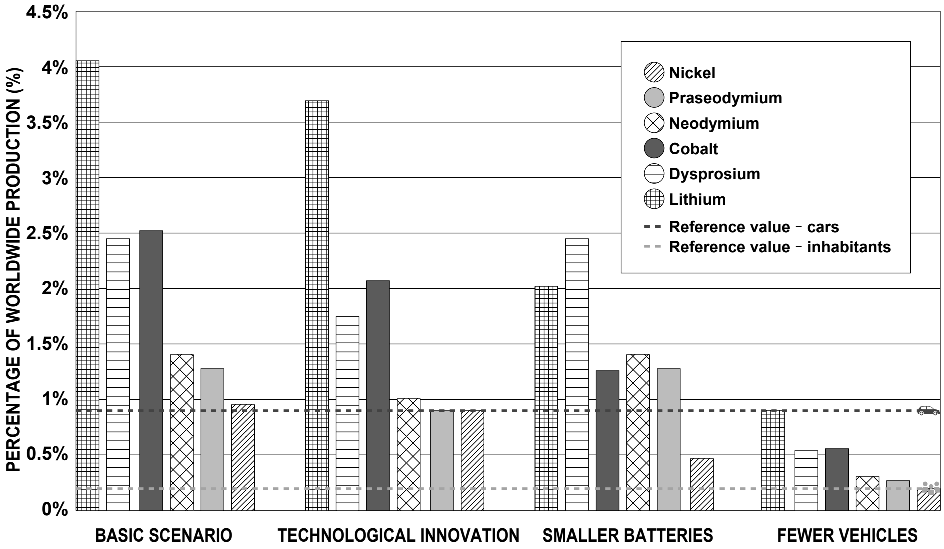

Source: Li et al, 2017

Figure 67 Rare Earths Uses, by Sector

With all these factors influencing CRM supply, the Metabolic team is understandably dubious about the capacity of new supply to meet projected demand. So they turned their analysis to means for increasing CRM-material efficiency. As figure 68 shows, they found that fewer and smaller vehicles had a pronounced impact in reducing CRM demand, much greater than optimistic assumptions about technological innovation.

It is important to keep in mind that the Metabolic team examine only select variables. The growing share of SUVs and other heavy vehicles also presents major challenges in decarbonization. Indeed, IEA data shows that the 2010-2018 increase in $CO_2$ emissions due to SUVs was second only to the power-generation sector, and far greater than heavy industry, trucks, aviation, and other areas (Cozzi and Petropoulos, 2019). The full scope of the challenge becomes clearer when we add in arguments for “overbuild” of RE, especially VRE, to cope with intermittency. The CRM-demand implications of such an approach are breathtaking, as are the proposals to generate hydrogen, desalinate water, and otherwise use VRE-derived energy in a host of applications.

Until 2020, attention to CRM challenges was quite limited to specialists. But as attention to the “green recovery” from Covid-19 increased, so did concern about CRM supply




Source: Bosch et al, 2019

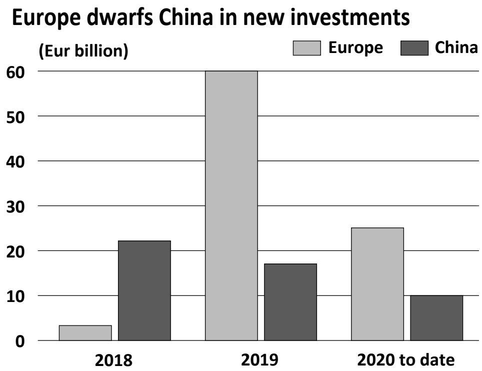
Figure 68 Three Scenarios for Limiting the Metal Demand for Electric Transport in the Netherlands

chains. One reason was that Covid-19 itself exposed the risky reliance on Chinese-dominated supply chains for medical materials. In any event, the EC accelerated its strategic industrial policy.

One result was a push for increased EC autonomy in lithium, which is actually largely mined in South America and Australia. Lithium is not a rare earth, but is a CRM. It is crucial for batteries, and China dominates in refining (less so in mining per se). So the EC has been trying to restore production, as the following two charts show.

Figure 69 portrays new investments are in the lithium supply chain. It shows the Europeans got very in 2019, charging ahead of China in 2019. What happens in 2020 remains unclear.

But the data in figure 70 suggest we confront a serious supply risk that the "green recovery" enthusiasts are not adequately studying. As is true with many other CRM, the investments are not going into mining but rather other downstream aspects of the supply chain. But without mined materials, the factories and other parts of the supply chain will have inadequate raw material supply. In the case of lithium, the problem is acute. As of this writing the battery-maker and other demand on lithium for 2023 is about 8 times greater than supply. And because of siloed business and government, the recognition of the supply-gap is confined to specialists who look at the entirety of the supply chain, from the mining activity at the top of the upstream, to the vehicle production frenzy far downstream. Almost




Source: S&P Global, 2020b

Figure 69 Lithium-Ion Battery Investments, 2018-2020

all participants within the supply chain evidently assume that the material can be mined rapidly (not understanding the time required to build new mining capacity) or that someone else is dealing with the problem.

But the investment in mining is not expanding. Even as EV makers and other CRM-intensive businesses become the largest businesses in the history of the global economy, the CRM mining they rely on is starved for investment. That reality hardly seems sustainable. And we should not be surprised, as the IEA data in figure 71 show declining public-sector R&D and project funding in the critical areas of energy research. One should expect an IEA publication and data series on investment in CRM mining capacity. At present, the most likely outcome of the demand-supply gap seems to be massive price spikes and geopolitical friction. These kinds of consequences, should they eventuate, seem likely to become a severe bottle neck on VRE and EV diffusion per se, let alone complacent projections of declining prices.

### CRM and Subsea Mining

Figure 72 shows us that there is concern among the RE enthusiast for the CRM dilemma. The figure is part of a publication from the International Institute for Sustainable Development (IISD), which is concerned about “Clean Power With a Clean Conscience.” The IISD believes that the dilemma can be resolved by better governance. They want the full slate of CRM to be covered by international rules that deal with “conflict minerals.” What they do not mention is that analyses of international and national governance mechanisms indicate that the rules are generally poorly complied with. And though the IISD add energy-related CRM to their list, they do not drill down into the quantities needed for RE, cooling,

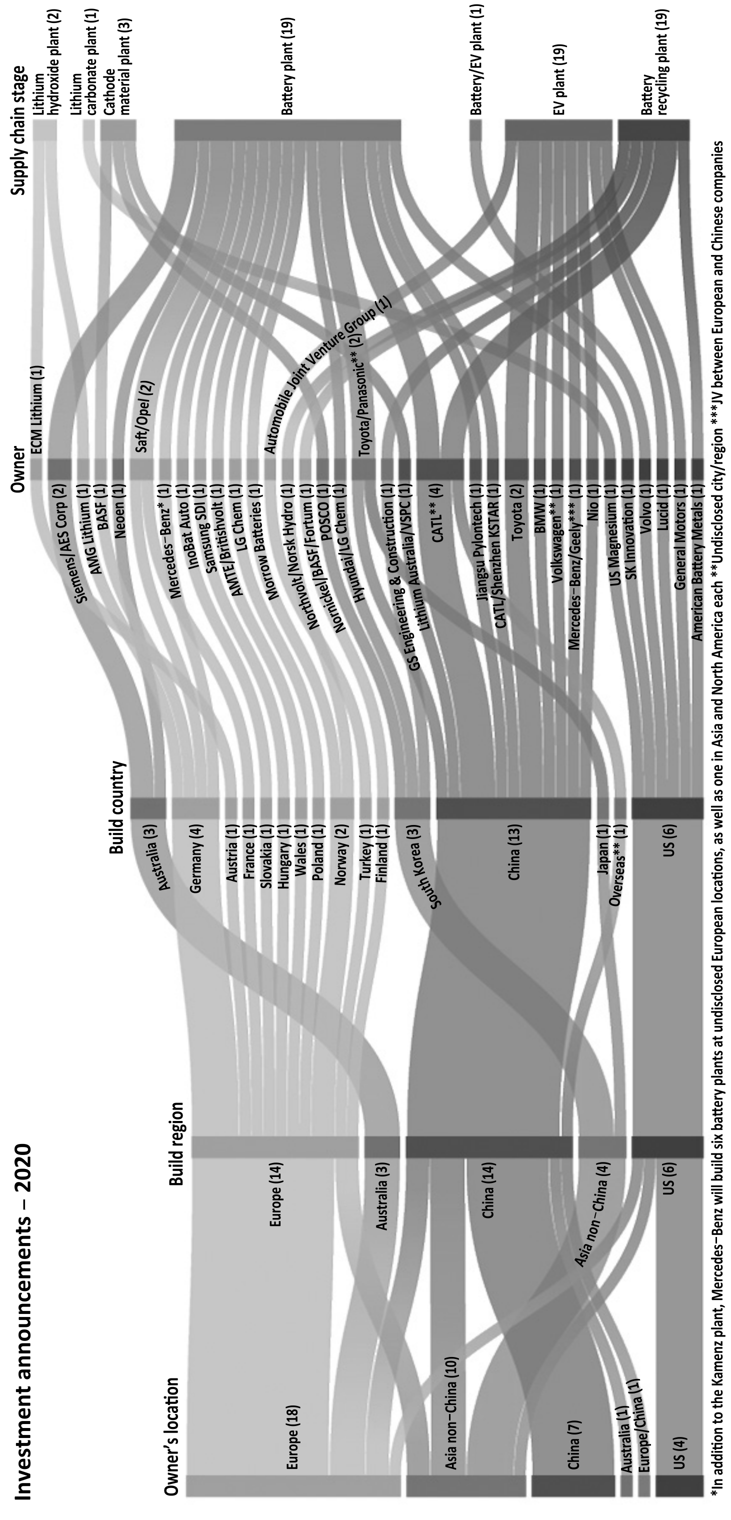
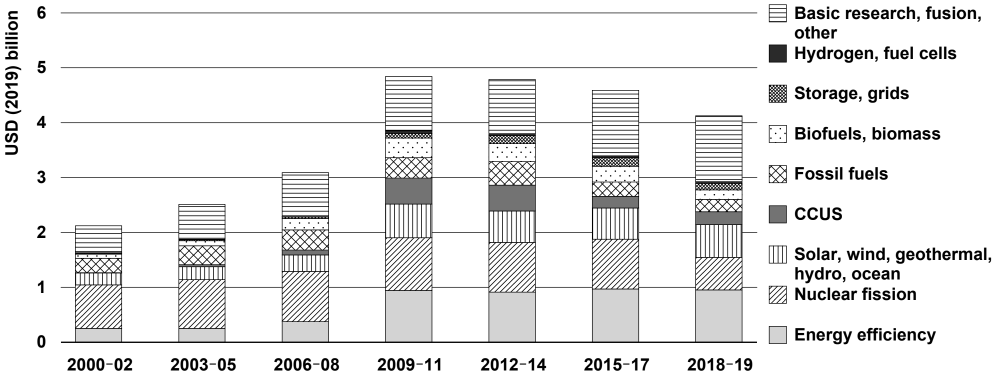


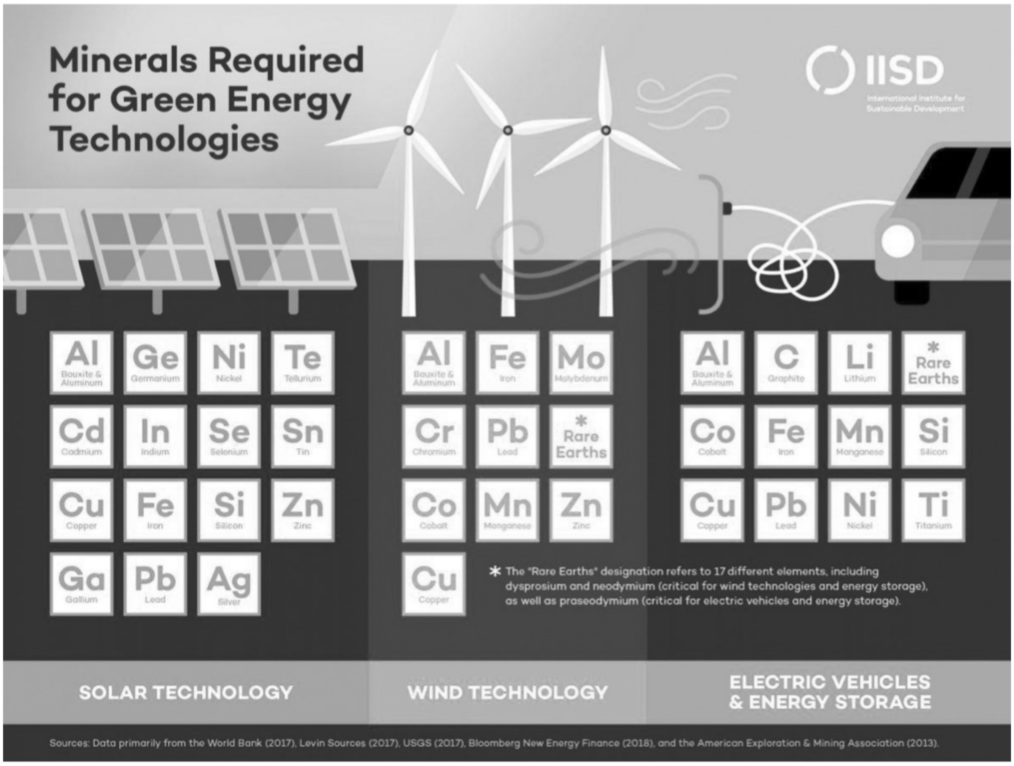

Figure 70 Lithium Investment Announcements in 2020

Source: S&P Global, 2020b




Source: IEA, 2020a

Figure 71 What About Mining?




Source: Church and Crawford, 2020

Figure 72 CRM and Green Technologies

mobility, and ther other items we reviewed earlier.

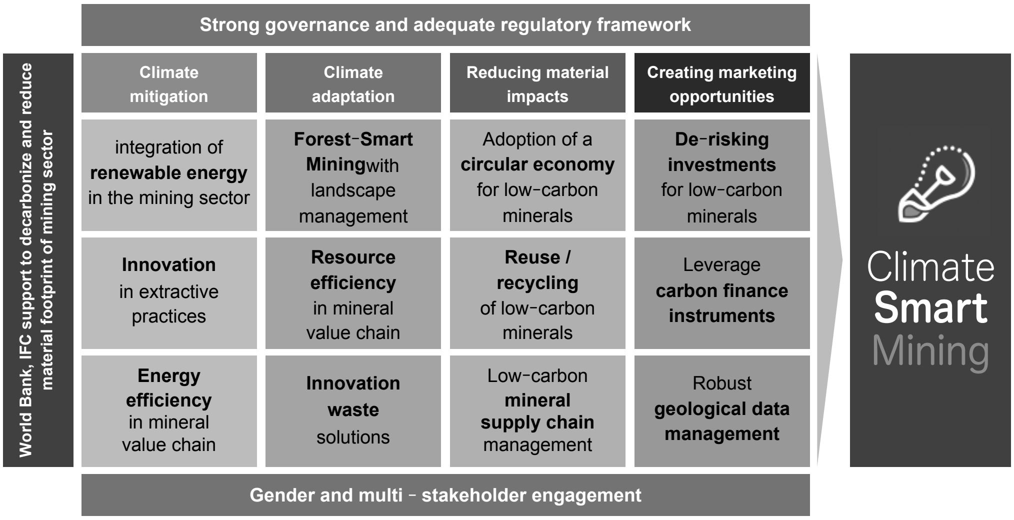
Some RE enthusiast are convinced that recycling will cope with the problem. To be sure, there are a lot of devices that could be recycled. But not all materials are readily recycled, and even if they all were they could not provide the expanded supply needed. It seems that one cause of this lack of the awareness of limits is the central role of Europe (especially Germany) in energy-transition scenarios. Most analysts seems to forget that the EU has special advantages compared to much of the rest of the world. Most low- and middle-income countries will have to grow their energy consumption in order to provide clean water, education, and the other public goods central to SDGs and the other elements of the 2030 Agenda. But in the EU, overall energy consumption is flattening and it has an international power grid to balance VRE with large hydro generation and pumped storage in Norway and Switzerland. There is also plenteous low-carbon nuclear power in Sweden and France, together with other baseload and low-carbon assets (biomass and biogas) that help back up VRE. Other countries aiming to depend on VRE would have to over-build and add in massive storage capacity, putting additional pressure of critical raw materials.

For example, consider that the average per-capita stock of copper in the developed world is 140-300 kilograms (kg) as compared to 30-40 kg in less-developed, lower-income countries (UNEP, 2010). These developed countries are generally the high-income countries, which account for 17% of the global population of 7.6 billion. The stock of copper in high-income developed countries is embodied in electricity grids, electric motors, plumbing, and a myriad other items in daily use. The high-income countries are being joined by many more billions in a wave of urbanization that could add about 2 billion new city dwellers over the next 15 to 20 years. The material implications of this urbanization are evident in the case of China. Recent estimates of per-capita copper stock in China indicate that it rose from 7 kg in 1990 to 60 kg in 2015, an eight-fold increase (Soulier, 2018).

Most of the rest of the world lacks the EU's capacity to balance various types of low-carbon power. So achieving 100% renewable energy globally, especially as a green response to Covid-19, would require an astoundingly inefficient (and critical material intensive) build-out of wind and solar plus battery storage, rapid construction of EU-style international grids, and other emergency measures.

Thus a global acceleration of VRE deployment, to meet pledges of 100% RE by 2030/2050 or whenever, would be a great many times more CRM-intensive than illustrated in most scenarios.

Against this backdrop, it is rather dismaying that the World Bank May 11, 2020 "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition" (World Bank Group, 2020) left the environment and related implications of material demand to the last section of its report. It recognizes that most additional extraction of materials will hap-




"Climate-Smart Mining: Minerals for Climate Action" (Brief), Extractive Industries, World Bank, https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action.

Source: World Bank Group, 2020

Figure 73 Climate-Smart Mining

pen in developing countries, in large part because so many of the resources are there. But as we see in figure 73, its proposal for climate-smart mining entirely disregards the water and other stresses of increased mining. Since ore grades are declining, the amount of overburden to be dealt with is increasing. That results in greater energy, water and other use, with corresponding impacts on the environment and human health - precisely the items that "climate -smart mining" is ostensibly aimed at protecting.

The World Bank Group report is worth quoting at length on these omissions:

> "Beyond specific climate-related risks, other environmental and social risks of increased mineral extraction also need to be considered throughout the supply chain. These have not been addressed in this analysis given the focus on GHG emissions.
>
> From a broader environmental perspective, for example, the water intensiveness of the mining sector and the impact of deforestation need to be integrated in how these minerals will need to be produced to sustainably supply clean energy technologies.
>
> From a social perspective, understanding issues such as the impact of mining upon local communities is vital to ensure that the transition to a clean energy system is beneficial for all. Given how critical minerals are to the low-carbon transition, a failure to address these wider environmental and social risks could facilitate a backlash against renew-

able electricity generation and energy storage technologies needed to mitigate GHG emissions" (World Bank Group, 2020).

Yet the World Bank Group may have overlooked a massive area of environmental risk and damage. Recent comprehensive research suggests that the issue is dramatically under-estimated. For example, researchers in geology and sustainable minerals mapped what they refer to as "critical mining areas" (where CRM-extraction is significant) on the terrestrial surface. Their research found that there are significant risks of additional damage, in excess of the avoided damage via decarbonization. They caution that careful strategic planning is essential, and lament that there is no noticeable action among international institutions. In their words, which are worth quoting at length:

> "There is urgent need to understand the size of mining risks to biodiversity (climate change, and efforts to avert it) and strategically account for them in conservation plans and policies. Yet, none of these potential tradeoffs are seriously considered in international climate policies, nor are new mining threats addressed in global discussions around post-2020 United Nation's Strategic Plan for Biodiversity. Necessary actions include strengthening policies to avoid negative consequences of mining in places fundamentally important for conservation outcomes, and developing necessary landscape plans that explicitly address current and future mining threats. These actions must also be supported by a significant research effort to overcome current knowledge deficits. A systematic understanding of the spatially explicit consequences (rather than potential threats, as investigated here) of various mining activities on specific biodiversity features, including those that occur in marine systems and at varying distances from mine sites (rather than within a predefined distance of 50 km, as done here), is required" (Sonter et al, 2020).

It is precisely these concerns that led Michael Moore and Jeff Gibbs to highlight environmental consequences in their 2020 documentary, "Planet of the Humans." The documentary is a warning about VRE and other renewable energies, insisting that they are not as environmentally friendly as reputed. The documentary attracted a great deal of criticism from fervent supporters of a VRE-led green shift or Green New Deal. Some of those critics – including "The Solutions Project" Jacobson – even attempted to have it banned in early 2020 (Bryce, 2020). Whatever its errors, the film certainly did correctly highlight the environmental and human rights implications of cobalt, as illustrated in figure 74. The documentary


Source: https://planetofthehumans.com

Figure 74 Cobalt in The Planet of the Humans

showed that CRM not only result in massive environmental damage, but also severe implications for human rights. Cobalt is especially problematic in this respect, because artisanal mining produces about 30% of the DRC's supply which in turn is about 70% of global supply. Thousands of children are exploited in these artisanal mines (Sanderson, 2018). Figure 74 is one visualization of that politically uncomfortable reality.

But again, pointing out the issues with CRM is not tantamount to opposing renewable energy. Rather, it is part of a necessary calculus for moving towards maximized material-efficiency. The fact that environmental damage and human rights are worsened by poor material efficiency should be energizing the debate rather than resulting in silence from 100% RE advocates.

The Moore/Gibbs film could be faulted for not adequately pursuing the question of how to implement 2030 Agenda goals in developing countries when the bulk of the materials they supply are used inefficiently in developed countries. We have seen that critical raw material resources are constrained, and in many cases difficult to recycle and repurpose. It therefore seems imperative to ask whether it is environmentally just that resource-efficiency not be first and foremost in proposals for greening. Many green enthusiasts in developed countries celebrate the diffusion of small-scale VRE without bothering to ask whether the low capacity factors and requirement for additional storage, transmission and other infrastructure imposes costs on the regions where the critical raw materials are extracted.

Yet it seems quite clear that the more rapidly the rollout of materially inefficient decarbonization in the developed world, the greater the risk of leaving the developing world with worsened environmental damage. And that damage might be exacerbated by even more constrained choices on clean development. That is because the critical materials used inefficiently in developed countries will almost certainly not be available in sufficient quantities and reasonable prices for low-income developing countries. There is, in short, the patent risk of a truly historic and possibly irremediable injustice. This prospect, plus the lack of attention to it, is a bitter irony considering the developed world green activists' emphasis on environmental justice in their own cities and countries.

Indeed, precisely this point was made by analysts at the European Environmental Bureau (EEB), concerning proposals to increase CRM mining in Europe. The EEB project officer for environmental justice, Diego Francesca Marin, warned as follows:

> "By relocating mining to Europe, we are likely to also import the environmental damage that has been inflicted on communities in South America, Asia and Africa for decades.
>
> The European Commission must ensure that local communities and civil society groups become part of a comprehensive consultation process so that they can raise concerns about new mining projects near their homes before it's too late" (Anastasio, 2020).

These uncomfortable realities have evidently led many analysts to confine the scope of their studies, leaving the larger issues to be mentioned – if at all – near the end of their work. That failure to take on the larger implications has left an enormous analytical hole.

But recent work on the CRM challenge has advanced the proposition that the environmentally sustainable alternative is deep-sea mining. The firm DeepGreen Metals commissioned a very thorough study on this issue. One result is displayed in table 15. The study compared the impacts for mining nickel, manganese, cobalt and copper from terrestrial sources and the sea floor. The focus was on the material needs of 1 billion electric cars, and not the much larger needs of decarbonizing the built environment. All the same, the work is instructive because it compares the sources of the materials. This work is without precedent, as these has been no previous estimation of the comparative impacts. As we see from the table, the results suggest that mining sea-floor nodules rather than terrestrial sources has considerably lower emissions, land use, water use, waste and even biodiversity impacts.

Table 15 Comparing Terrestrial and Sea Floor Mining

**Environmental, social and economic impacts**

Cradle-to-gate production of nickel sulfate, manganese sulfate, cobalt sulfate and copper cathode
Serving size **1 billion electric cars**

| | Land | Nodules | % change |
|---|---|---|---|
| **Climate change** | | | |
| GWP-$CO_2$ equivalent emissions, Gt | 1.5 | 0.4 | **−70%** |
| Stored carbon at risk, Gt | 9.3 | 0.6 | **−94%** |
| **Nonliving resources** | | | |
| Ore use, Gt | 25 | 6 | **−75%** |
| Land use, $km^2$ | 156,000 | 9,800 | **−94%** |
| Incl. Forest use, $km^2$ | 66,000 | 5,200 | **−92%** |
| Seabed use, $km^2$ | 2,000 | 508,000 | **+99.6%** |
| Water use, $km^3$ | 45 | 5 | **−89%** |
| Primary and secondary energy extracted, PJ | 24,500 | 25,300 | **+3%** |
| **Waste streams** | | | |
| Solid waste, Gt | 64 | 0 | **−100%** |
| Terrestrial ecotoxicity, 1,4-DCB equivalent Mt | 33 | 0.5 | **−98%** |
| Freshwater ecotoxicity, 1,4-DCB equivalent Gt | 21 | 0.1 | **−99%** |
| Eutrophication potential, PO4 equivalent Mt | 80 | 0.6 | **−99%** |
| **Human & wildlife health** | | | |
| Human toxicity, 1,4-DCB equivalent Mt | 37,000 | 286 | **−99%** |
| SOx and NOx emissions, Mt | 180 | 18 | **−90%** |
| Human lives at risk, number | 1,800 | 47 | **−97%** |
| Megafauna wildlife at risk, trillion organisms | 47 | 3 | **−93%** |
| Biomass at risk, Mt | 568 | 42 | **−93%** |
| Biodiversity loss risk | Present | Present | |
| **Economic impact** | | | |
| Nickel sulfate production cost, USD per tonne Ni | 14,500 | 7,700 | **−47%** |
| Jobs created (non-artisanal), worker-years | 600,000 | 150,000 | **−75%** |

Source: Paulikas et al, 2020

In more recent work, published in the *Journal of Cleaner Production*, DeepGreen's analytical team determined that seabed harvesting of nodules for battery metal CRM would be much less GHG-intensive than terrestrial mining. Their work identified a reduction of "active human emissions of $CO_2$e by 70-75%, stored carbon at risk by 94% and disruption of carbon sequestration services by 88%. The lead researcher declared that "[t]errestrial miners are handicapped by challenges like falling ore grades, as lower concentrations of metal lead to greater requirements of energy, materials, and land area to produce the same amount of metal. Furthermore, the actual collection of [seabed] nodules entails a relatively low energy, land, and waste footprint compared to a conventional mine. When it comes to emissions, even when we assume a complete phase-out of coal use from background electric grids for process inputs, our model shows that metal production from high-grade polymetallic nodules can still produce a 70% advantage" (Newswire, 2020).

There is no scope in this paper to delve at greater depth into the question of whether terrestrial or marine mining is more sustainable. Suffice it to say that because of mounting CRM demand, geopolitical risks, and other factors, many countries already seek to mine the sea floor. These countries include Germany, China, South Korea, Brazil, Russia, Japan, and others. Many are particularly interested in cobalt. As a recent article on the issue noted, "they have exploration contracts for cobalt-rich ferromanganese crusts. Cobalt is a vital component in batteries, including car batteries. It is a rare mineral and considered dangerous to mine on land" (Abbany, 2020). The marine resource base also greatly dwarfs the terrestrial resource base. We saw earlier that the USGS assessed terrestrial cobalt resources at 25 million tons. Its surveys indicate that more than "120 million tons of cobalt resources have been identified in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans" (USGS, 2020).

What can be said is that we clearly need a portfolio of options. Just as power and energy systems need multiple sources, so to do supply chains. Whether the sea bed becaome a significant source of CRM is an open question. What is clear is that resources are being deployed to do it efficiently and with decarbonizing impact. Similar options are expanding in mining (eg, advanced weathering), food production, land use, and other areas. Strategic vision and policy integration could greatly help to accelerate this larger portfolio's evolution, enhancing the mitigation-adaptation synergies that are crucial to meeting the decarbonizing targets identified by climate science.

## The Collaborative Industrial Policy Context

And so we turn to Japan. Japan's smart mitigation and adaptation measures are expanding within a larger holistic paradigm of collaborative industrial policy (DeWit, 2019). Japan's "Society 5.0" industrial policy regime predated Covid-19, and indeed was heavily funded in Japan's pre-pandemic, December 2019 stimulus. Society 5.0's policy arms include such critical cyber-physical linkages as digitalization in smart cities, "post 5G" next-generation communications, remote-sensing for disaster risk reduction, 3-D mapping for compact cities, monitoring and controls for integrating variable renewable energy, and other means to bolster evidence-based collaborative governance. Japan's Society 5.0 is also directly linked to the 2030 Agenda's Sustainable Development Goals (SDGs). Indeed, Japan's approach to SDGs initiatives appears to be unique among the developed countries: its multi-level SDGs collaboration deliberately uses the SDGs' 17 goals and 169 targets to focus local government projects on myriad domestic challenges in combination with overseas engagement and contributions. In short, Japan does not see SDGs as external aid but rather as a platform for integrating sustainable domestic and overseas development (Seki, 2019).

As is shown in table 16, Japan has organized a broadly inclusive Local SDGs Public-Private Collaborative Platform. As of August, 2020, the platform includes 745 local governments in addition to most of the national government's central agencies. It also includes 2,224 business firms, research institutions, NPOs and other members. This total membership of 2,982 is well over double the1,235 members in April 2020.

Table 17 shows the ongoing results of the Japanese Cabinet Office's efforts to disseminate best practice. Since 2018, the Cabinet Office has opened a competition for subnational governments to be designated as SDG Future Cities and for particularly well-integrated initiatives to be designated as Model Cases. As of September of 2020, there are 93 SDG Future Cities and 30 Model Cases. The increasing numbers are indicative of the prioritization of the program and its widespread impact.

A further important platform context for shaping Japanese action is its Smart City

Table 16 Japan's Local SDGs Public-Private Collaborative Platform (as of August, 2020)

| Member Class | Number |
|---|---|
| Subnational Governments | 745 |
| Central Agencies | 13 |
| Private Firms and others | 2,224 |
| Total Membership as of August, 2020 | 2,982 |

Source: Future City, 2020

Table 17 Japan's Local SDGs Communities and Model Cases (as of April, 2020)

| Category and Year | Number |
|---|---|
| 2018 SDG Future Cities | 29 |
| 2018 SDG Model Cases | 10 |
| 2019 SDG Future Cities | 31 |
| 2019 SDG Model Cases | 10 |
| 2020 SDG Future Cities | 33 |
| 2020 SDG Model Cases | 10 |
| Total Cities and Cases | Cities: 93, Model Cases: 30 |

Source: Kantei, 2020

Public-Private Collaborative Platform, whose membership is itemized in table 18. Of particular note is the growing number of local governments, 133 as of August 2020, a sharp increase over 114 in April of the same year. The platform is yet another venue via which the 2030 Agenda integration of decarbonizing and inclusive Paris Agreement, SDGs, and SFDRR best practices are shared among multiple stakeholders.

A more recent platform is Japan's Green Infrastructure Public-Private Collaborative Platform. Table 19 shows that its membership as of March 2020 exceeds 400 local governments, central agencies and other stakeholders. The local government membership includes Sendai City (the host city for the Disaster Risk Reduction program), Tokyo, and other influential cases. Moreover, the important role of central agencies is coupled with the participation of business, academe, NPOs and other stakeholders whose collective expertise encompasses water, energy, construction, and other areas crucial to designing and implementing comprehensive green-infrastructure solutions. This emphasis on green-infrastructure not only helps achieve the 2030 Agenda goals of mitigation, adaptation and inclusive sustainability; it also reduces the burden of future costs for maintain traditional "grey infrastructure" such as levees (Nakamura et al, 2019).

One of Japan's key governance platforms for designing, implementing and revising in-

Table 18 Japan's Smart City Public-Private Collaborative Platform (as of September 2, 2020)

| Member Class | Number |
|---|---|
| Subnational Governments | 133 |
| Central Agencies | 11 |
| Businesses, Research Centres, and others | 403 |
| Business Associations | 2 |
| Total Membership | 536 |

Source: MLIT, 2020a

Table 19 Japan's Green Infrastructure Public-Private Collaborative Platform (as of March, 19, 2020)

| Member Class | Number |
|---|---|
| Subnational Governments | 43 |
| Central Agencies | 4 |
| Businesses, Research Centres, and others | 200 |
| Individual Memberships | 232 |
| Total Membership | 439 |

Source: MLIT, 2020b

tegrated policy is National Resilience (DeWit, Djalante and Shaw, 2020). National Resilience predates the 2030 Agenda's SFDRR, formally adopted in 2015, and closely parallels the latter's content by emphasizing all-hazard disaster preparation, building back better, and "whole of government" inclusive collaboration. National Resilience also encompasses smart communications, sustainable energy systems, resilient water networks, and the other critical infrastructures that are essential to holistic resilience in the modern city. It should be no surprise that Japan is doing this, as it confronts innumerable natural hazards plus severe demographic, fiscal and other challenges. Japan has also historically been the leader on international disaster resilience frameworks, which is why the first international framework is the Yokohama Strategy (1994) and the second the Hyogo Framework (2005-2015). The 2015-2030 Sendai Framework of Disaster Risk Reduction (SFDRR) continues this tradition of Japanese leadership, which emphasizes community involvement and integration with other objectives (de la Poterie and Baudoin, 2015).

National Resilience is also Japan's program for closely linking national and subnational governments in a rapidly expanding portfolio of national and subnational NRPs that have legal precedence over other plans. NRPs are aimed at bolstering the country's resilience to natural disasters and other hazards, before they happen, as well as fostering the capacity to recover from such disasters when they occur. Since 2014, there have been 2 iterations (2014, 2019) of the NRP Basic Plan as well as 6 annual action plans that decide and then monitor the planning cycle and the achievement of Key Performance Indicators (KPI). These KPIs include hard measures, such as monitoring hazards via smart sensors, strengthening back-up power for hospitals and other facilities, reinforcing flood-control systems, and hardening critical communications infrastructure. The KPIs also include soft measures, such as skill-building, risk communication, and measures to break down governance silos. In the 2019 revision of the original 5-year NRP Basic Plan, the number of KPIs had increased to 179. The 2020 update of the NRP action plan is slated to raise the number of KPIs to 268. Moreover, Japanese National Resilience has been funded at roughly JPY 5 trillion per year since FY 2018. The investments finance soft and hard measures in addition to training and international engagement.

A key test of any such ostensibly collaborative initiative is how well it diffuses and how purposefully engaged the actors are. By September of 2020, all of Japan's 47 prefectures had adopted their own regional versions of the NRP. Moreover, as table 20 shows, 1,601 of Japan's 1741 cities, special wards, and towns had either adopted their own local versions of the NRP or were formulating plans. This number of local governments doing NRPs was

Table 20 Increase in Japan's Local National Resilience Plans (NRPs)

| Administrative Level | April 1, 2019 | September 1, 2020 |
|---|---|---|
| Local Government | 190 | 1,601 |

Source: National Resilience, 2020

more than seven times the 190 total from a year earlier, April 1 of 2019. That startling 760% rate of increase in one year is testament to the rapid spread of comprehensive risk-awareness in Japan. Recent years of unprecedentedly destructive typhoons, floods and other disasters have led to a consensus on the need for comprehensive planning and integrated counter-measures. Japan's subnational governments now routinely request increased regular budget and special fiscal stimulus spending on NRP, SDGs, Society 5.0 projects and their integration in the smart city. These fiscal and related requests are articulated collectively through such subnational representative organizations as the National Governors' Association, The National Mayors' Association and others.

## Conclusion

We have seen that many CRM 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. Doing that will almost certainly require Japanese-style comprehensive governance.

The first imperative is to reduce undue reliance on any particular material via substitution. The Japanese did this in the wake of 2010, when rare earth price rose and Chinese policies on rare earths indicated increased risks of export bans against Japan. In response, the Japanese invested heavily in alternatives. These strategic investments resulted in such innovations as new magnet technologies that greatly reduce the role of neodymium.

Yet substitution has its limits, because of the enormous projected increase in demand for nearly all these materials. One example is seen in the effort to use nickel to reduce reliance on cobalt in electric vehicle batteries. In collaboration with Panasonic, the US automaker Tesla has been at the forefront of this initiative. Indeed, Tesla's goal is to entirely eliminate the role of cobalt in electric-vehicle (EV) batteries, and it is achieving notable success in this objective. However, the initiative has encountered something of a "whack a mole" phenomenon. This is because supplies of nickel are increasingly constrained, posing a challenge to large-scale substitution of cobalt in the high energy-density batteries required for electrified transport. Global demand for nickel in EV batteries is projected to increase from 3% of all sources of demand (such as stainless steel, non-ferrous alloys, and other products) in 2018 to 12% by 2023, as global automakers are expected to introduce over 200 new EV models. But the volatility of prices for nickel have been a drag on investment in increased mining capacity. In consequence, metals analysts warn that "[t]here is no new nickel in the pipeline" even as other specialists highlight the time required to find alternatives (Hoyle, 2019).

Because options for substituting critical materials appear limited, and perhaps very problematic, increased attention to strategic, spatially-smart use of these scarce materials is required. The circular economy literature features some new work that attempts to examine the spatial issue across countries. This literature seeks to promote circularity (and carbon neutrality) within the far-flung supply chains that link prominent critical-material producers and exporters, such as Australia, to consumer countries within the global resource network. This macro-level perspective on circularity and CRM is important, but surely needs to be supplemented with a micro-level focus that starts from cities.

We have also seen that compact and resource-efficient community has long been an element of National Spatial Planning and other policy regimes, and is incorporated in Japan's National Resilience and Society 5.0 industrial policies. Japan's comprehensive approach to circularity places the objective within multiple other goals, and matches that with integrated institutions and ample public finance. This approach seeks to maximize the co-benefits for a very broad range of stakeholders, giving the paradigm enduring political legitimacy. The paradigm is also the focus of Japanese official development assistance, which has increased significantly in the midst of the Covid-19 crisis (IMF, 2020). In this respect, it is important to note that the Overseas Development Institute ranks Japan first in the category of "global cooperation," which measures support for multilateral institutions, tackling climate change by mitigation and adaptation, and combatting the spread of infectious diseases (ODI, 2019).

This paper has argued that Covid-19 has led the global community to stress a green recovery. It has also shown that the CRM required for a recovery are a fraught issue. Thus maximizing material-efficiency is clearly imperative. The data also show that during Covid-

19 Japan has been accelerating its diffusion of all-hazard, disaster-resilient, and silobreaking policy integration. Myriad other examples could just as easily have been adduced to illustrate Japan's inclusion of coping with Covid-19 while building on a larger, pre-existing industrial policy of holistic and transformative resilience.

The paper details why this resource-efficiency is essential in the CRM sector. We show that the challenges are of such enormity that seabed mining may be required to mitigate risks of zoonotic disease, geopolitical crises, price fluctuations, and other patent challenges. We have suggested that Japan's holistic, silobreaking policymaking and project implementation could be an important indicator of how to maintain momentum against climate change and other hazards. Japan's measures integrate the UN 2030 Agenda's three pillars of the Paris Agreement, Sustainable Development Goals (SDGs), and the Sendai Framework of Disaster Risk Reduction (SFDRR). Against the backdrop of extreme material challenges, Japanese increasingly integrated governance and resource-efficiency is an important model to learn from.

We would also ask why social science is minimally engaged on this issue of the material underpinnings of decarbonization. Most argument focuses on advocacy groups' claims that vested interests are the problem. Certainly, vested interests are part of the problem in tackling climate change. But there is also an enormous material reality that requires attention from public finance, political economy, political science, and other spheres of academe. After all, the core issues of justice, cost, and sustainability are implicated in CRM efficiency. Surely these facts suggest we need a multi-discplinary, pragmatic, and material-literate social science. Overcoming silos in academe is clearly as important as in government and business.

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