ERM SUSTAINABILITY INSTITUTE

RENEWABLES CONUNDRUMS

Building Benefit: Four steps to mitigate renewable energy's environmental downsides

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Executive summary

Renewable energy adoption is gaining speed as the world pivots to technologies like solar panels and wind turbines to reduce greenhouse gas (GHG) emissions and mitigate the worsening effects of climate change. Adoption is likely to only accelerate after parties at COP28 in Dubai agreed to triple global renewable energy capacity by 2030.[1]

Acceleration is welcome and essential if the world is to capture the full range of environmental benefits renewables offer over fossil fuels. Simply put, countries cannot achieve the goals of the Paris Agreement without them. Furthermore, decarbonization is not renewables' only environmental advantage. Compared to coal, natural gas, and oil, renewables can drive invaluable air and water quality improvements, while also consuming far less water.

Acceleration also means that renewables' environmental drawbacks are likely to be more pronounced. As renewables are needed in growing numbers to meet climate goals, the environmental externalities associated with raw material extraction, manufacturing, and end-of-life disposal could increase. Likewise, potential impacts to land, sea, and wildlife associated with renewable energy project construction could increase as renewable energy installations grow in number.

However, accelerating renewable energy adoption does not have to amplify associated environmental impacts. In fact, with the right actions, companies can turn some of these impacts into added benefits, maximizing renewable energy's environmental gains. We view four steps as being particularly key to building benefit.

Step 1: Opt for green production inputs and processes

1. Pursue low-carbon and low-waste raw material sourcing for renewable energy platforms.
2. Select low-carbon material inputs for renewable energy platforms.
3. Use low-carbon components when building renewable energy platforms.

Step 2: Introduce circular alternatives

1. Use circular materials when building renewable energy platforms.
2. Recycle or repurpose renewable energy platforms at end-of-life.

Step 3: Minimize footprints

1. Build renewable energy installations on brownfields.
2. Repower existing renewable energy installations.
3. Co-locate solar and wind developments together.
4. Incorporate Marine Spatial Planning into project design

Step 4: Consider wildlife from the start

1. Screen renewable energy developments for potential wildlife impacts during siting.
2. Incorporate wildlife-friendly project design into renewable energy installations.
3. Integrate native landscapes into renewable energy development sites.
4. Utilize offshore wind wildlife mitigation measures.

Maximizing renewable energy's net positive effect on the environment

Renewable energy is at the forefront of the energy transition. Everywhere you look, people and organizations are focused on how renewables will help the world meet its climate goals and provide innumerable other benefits to the planet and society. This focus had its seminal moment at COP28 in Dubai, where parties agreed to triple global renewable energy capacity by 2030.[2] This agreement is right in line with what is needed.

As we have written previously, the International Energy Agency (IEA) forecasted just a few months before COP28 that global renewable energy capacity must triple by 2030 if society is to achieve net zero emissions by 2050.[3]

With renewables growth set to accelerate, it can be easy to think only of their unquestionable environmental benefits both for the climate in terms of reducing GHG emissions and for the planet more broadly through benefits including air and water quality improvements. However, as with any type of energy solution, there are environmental drawbacks associated with renewables as well, ranging from the air and GHG emissions associated with renewable energy raw material sourcing, manufacturing, construction, and decommissioning to potential adverse land and wildlife impacts associated with renewable energy project site development.

This duality creates what our ongoing series has termed a renewables conundrum, or a set of issues that challenge companies' uptake of these energy solutions. In this briefing, we will explore the environmental conundrum by outlining some of renewable energy's most notable environmental benefits and challenges before presenting a set of actions to ensure renewable energy is a true win-win for the environment.

Our renewables conundrums series explained

This is the third briefing in our renewables conundrums series, which analyzes the biggest issues central to the success of the renewables growth and corporate climate action needed to limit global warming to 1.5°C. These briefings explore the benefits and challenges associated with these conundrums and how effective management, based on ERM's experience and expertise, can help maximize positives while minimizing negatives.

The first briefing introduced the series, examined what renewables conundrums are, and explored why they matter to successfully addressing the climate crisis.

The second briefing analyzed renewable energy supply chains' dependence on politically unstable countries with poor track records on human rights and strategies companies can take to overcome the challenges that this dependence creates.

The fourth briefing will consider how renewable energy developments can be sited and permitted in ways that increase social acceptance and generate benefits for local communities.

On the upside – Renewables' environmental benefits

When one considers renewable energy, thoughts are likely to turn to its ability to generate electricity with almost none of the GHG emissions that traditional fossil fuel-powered electricity generation processes create. As the climate crisis worsens, this capacity to generate low-emissions electricity will be critical to the world's climate change mitigation efforts. Still, as we highlight here, renewable energy generates other important environmental gains beyond GHG emissions reductions.

Cooling it down – Climate mitigation impacts

When it comes to the environment, renewable energy is arguably most associated with climate change mitigation, and for good reason. Using renewables to generate electricity produces essentially zero climate change-driving GHG emissions. Compared to fossil fuel generation, this reduced GHG emissions footprint is significant. For example, natural gas combustion for electricity generation produces 389 grams of CO_2e/kWh and coal combustion produces 1,010 grams of CO_2e per kWh.[4] Renewables also beat out fossil fuels in lifecycle GHG emissions. For example, solar and wind generate 43 and 13 grams of CO_2 per kWh of energy they generate, respectively, dominated by emissions associated with their manufacturing and construction.[5] These lifecycle emissions are dwarfed by those of natural gas and coal, at 486 and 1,001 grams of CO_2 per kWh, respectively. From the perspective of emissions intensity, renewables are thus the clear first energy choice for companies as they decarbonize their businesses and reduce their exposure to physical and transition climate risks.

Beyond the direct GHG emissions benefits of renewables, their ability to create economic value when accounting for the social cost of carbon (i.e., the societal cost associated with the estimated damage from each additional ton of carbon emitted) is also an attractive benefit. One study in the U.S. found that over eight years, wind electricity generation produced a median value of $29 billion in climate benefits across the period based on social cost of carbon estimates.[6] Solar generation showed a similar story, with the same study finding that it generated a median value of $2.54 billion in climate benefits across the period. Another study comparing wind to natural gas found that 602 MW of wind-generated electricity in the U.S. would produce over $4 billion in avoided-emissions benefits related to climate externalities and their impacts on human health over a 19-year period.[7]

Cleaning up the air we breathe – Air quality impact

GHG reductions are not the only emissions-related benefit of renewable energy. Replacing fossil fuel electricity generation with renewables also helps improve air quality. As with GHG emissions, aside from manufacturing and construction processes, renewables' electricity generation emits essentially zero air pollutants (e.g., sulfur oxides, nitrogen oxides, particulate matter, carbon monoxide, volatile organic compounds, etc.). On the other hand, fossil fuel electricity generation produces significantly higher emissions of these types of pollutants. For example, natural gas combustion produces an average of 7.6 pounds of particulate matter emissions and 0.6 pounds of sulfur dioxide emissions per million standard cubic feet of natural gas combusted.[8] Overall, in a scenario where the world decarbonizes through the use of renewables and limits global warming to 1.5°C, air pollutant emissions in 2050 fall by up to 90 percent from 2022 levels compared to a scenario where renewables adoption is slower and temperatures rise by 3.2°C.[9]

As with GHG emissions, renewables also create economic value as a function of their decreased air pollutant emissions. The same U.S. benefits study referenced in the climate change mitigation section above found that wind electricity generation produced a median value of $54 billion in air quality and public health benefits over the same eight-year period and solar produced a median value of $2.5 billion in benefits.[10]

Chart 1: Potential air quality impacts in 2050 under two energy transition scenarios

Potential air quality impacts under an energy transition scenario where continuing fossil fuel use leads to 3.2°C of warming by the end of the century versus another scenario where the rapid scale-up of renewables limits global warming to 1.5°C by the end of the century.[85]

Source: Building a Nature-Positive Energy Transformation (WWF)

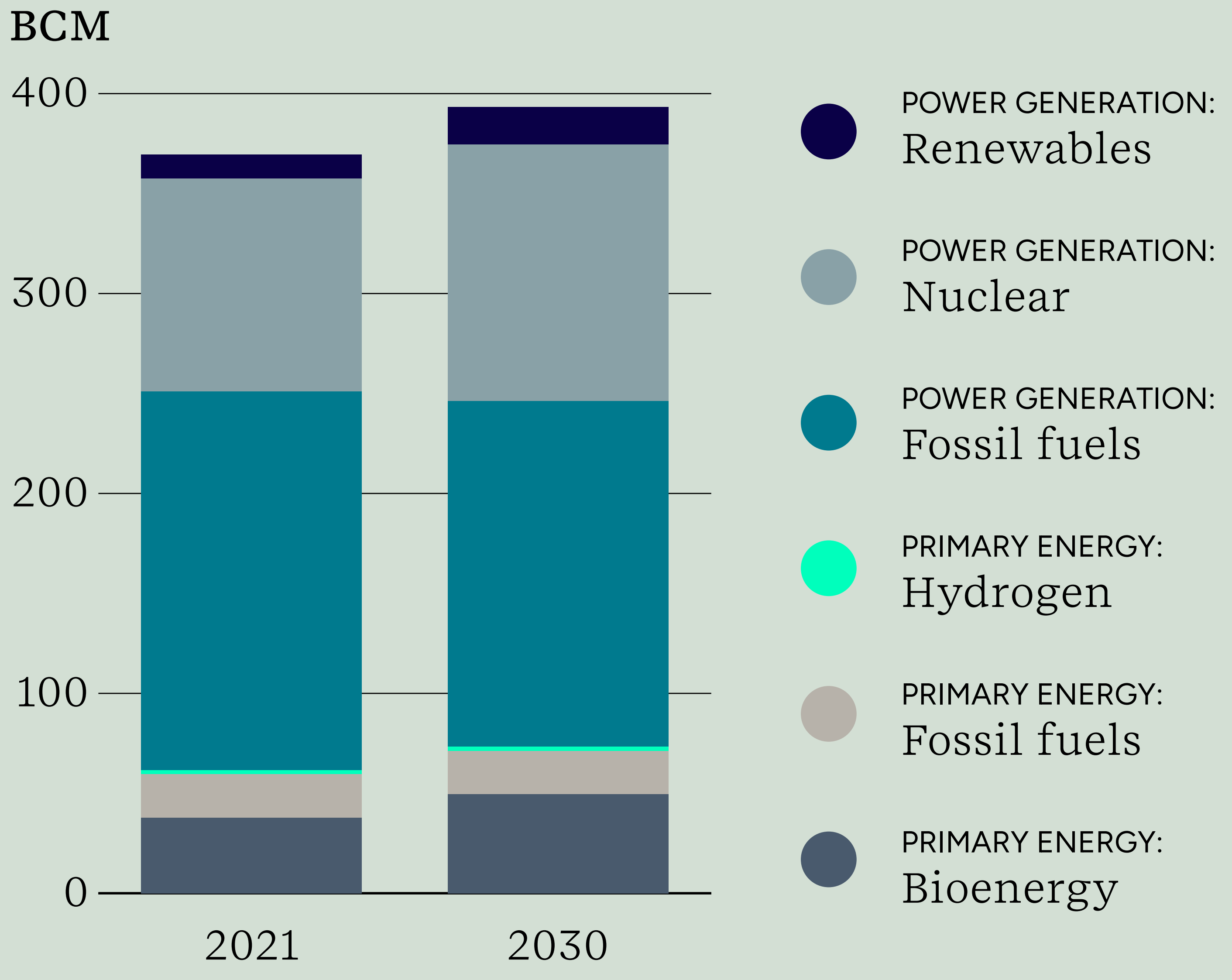
Beyond economic value, renewable energy's air quality improvements save lives. A 2023 study found that 5.13 million excess deaths a year globally could be avoided with the phaseout of fossil fuels in favor of renewables.[11] Further, another study found that in a world where global warming is held to 1.5°C through the adoption of renewables, global premature deaths and disabilities would be expected to fall by 86 percent in 2050, as compared to 2022 levels.[12]

Turning off the tap – Water use & quality impact

Electricity generation is notorious for its water impacts, as most generation systems rely on water for cooling and steam creation. When it comes to water consumption, the global energy system uses approximately 370 billion cubic meters (bcm) of fresh water per year, which equates to 10 percent of worldwide freshwater withdrawals.[13] Freshwater withdrawals for fossil fuel power generation equaled 189.6 bcm of that total in 2021, with nuclear power generation close behind at 106.3 bcm. In comparison, renewable energy applications withdrew just 12.1 bcm in 2021. At the individual source, an average coal power plant has a water-withdrawal intensity of 19,185 gallons per MWh, and though better, an average natural gas plant still has a water-withdrawal intensity of 2,803 gallons per MWh.[14] Conversely, solar panels and wind turbines do not use any water for cooling or steam creation. Instead, water for these technologies is primarily used for cleaning purposes like the washing of dust from solar panels or stabilizing soils during construction.

Renewables have water quality benefits too. Fossil fuel power plants can, even after wastewater treatment, discharge pollutants such as arsenic and lead into water bodies during electricity generation. In the U.S., power plants discharge 30 percent of the total amount of pollutants released into surface waters by industrial processes regulated under the Clean Water Act. Further, the discharged water that carries these pollutants is typically considerably warmer than a water body's ambient temperature, introducing another potential impact to aquatic life.[15] It follows then that if renewables were to grow to comprise 85 percent of global energy use in 2050, significant water quality improvements would be expected to follow. For example, it is estimated that energy-generated freshwater eutrophication, or the overaccumulation of nutrients in a body of water, would be ten times less and marine eutrophication 3.5 times less than a scenario where renewables only comprised 20 percent of the world's energy generation.[16]

Chart 2: Global energy sector water withdrawal by fuel and power generation method



Global energy sector water withdrawal by fuel and power generation method under the International Energy Agency's Stated Policies Scenario.

Source: Clean energy can help to ease the water crisis (IEA)

On the downside – Renewables' negative effects on the environment

Overall, renewable energy is a net environmental "plus", with its broad benefits over fossil fuel energy generation readily identifiable. Nonetheless, often less visible and considered beneath these benefits lurk negative environmental impacts. If not appropriately addressed, these negative impacts can diminish - but not eliminate - renewables' clear advantages over fossil fuels.

Two categories of often under-considered environmental impacts stand out: those associated with renewable energy platforms (e.g., individual solar panels and wind turbines) and those associated with renewable energy installations (e.g., solar and wind farms).

Renewable energy platforms

Solar panels, wind turbines, and other renewable energy platforms are of course essential to low-carbon energy generation and accessing its broad benefits. However, extracting and processing the inputs that go into these platforms and producing and disposing of them creates environmental challenges that must be accounted for.

The negative effects of input extraction and processing

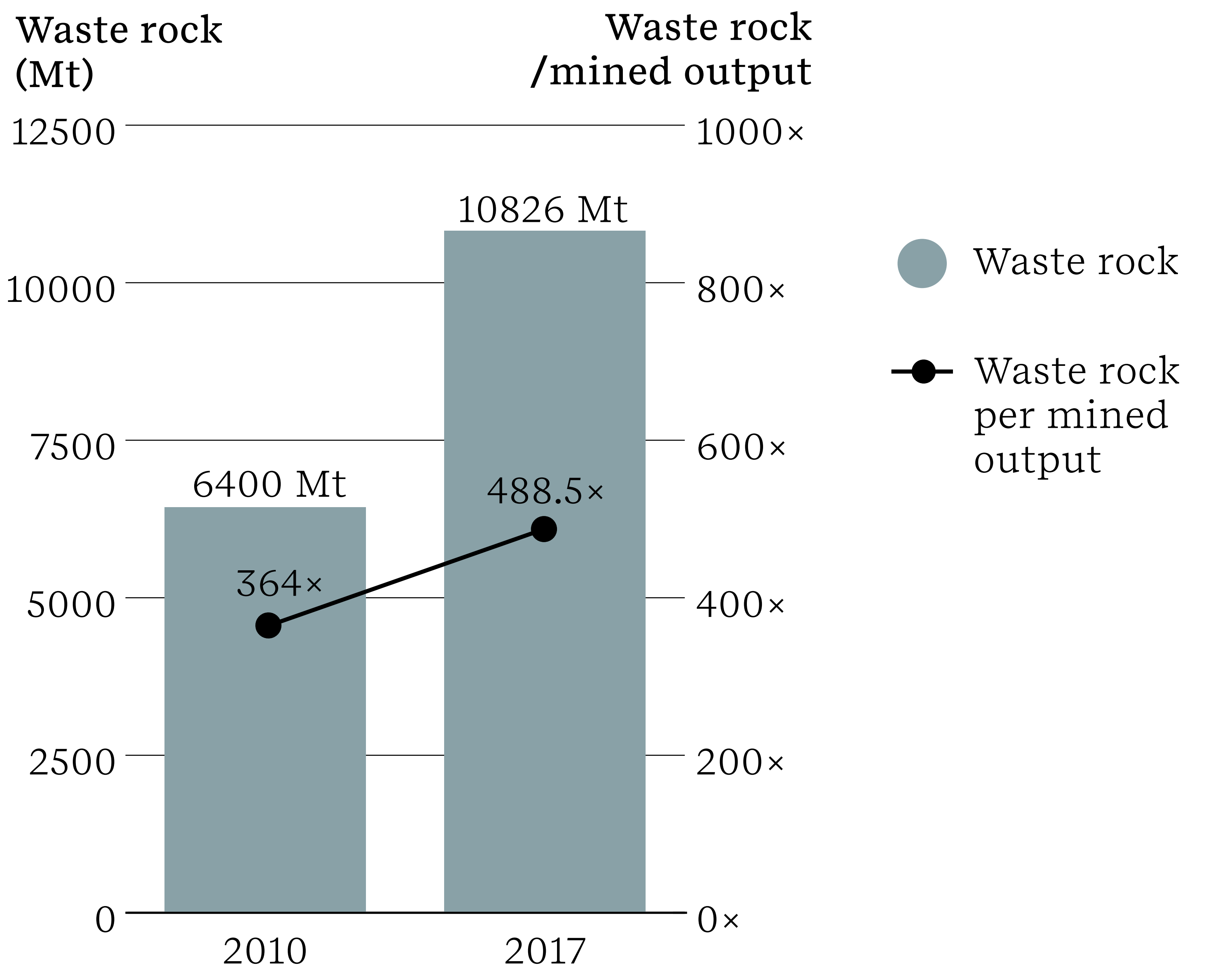
As we outlined in our second report in this Renewables Conundrums series, renewable energy platforms require increasing amounts of material inputs, with critical minerals and rare earth elements most prominent.[17] Extracting and processing these inputs generates environmental impacts.

GHG emissions, the very externality renewables are meant to combat, are the source of one such impact. For example, extracting and processing a metric ton of copper generates 4.6 metric tons of CO_2e, while extracting and processing a metric ton of neodymium oxide (a key component in wind turbine magnets) generates a staggering 75.8 metric tons of CO_2e.[18]

Water use and pollution are another issue. Mining a kilogram each of rare earth elements and lithium uses 0.635 and 0.773 cubic meters of water, respectively.[19] Mining rare earth elements and lithium can also result in water pollution. Extracting a kilogram of each generates 0.02130 and 0.00130 kilograms, respectively, of phosphorous-equivalent in process wastewater, the discharge of which can lead to algae growth and eutrophication.

Input extraction also generates considerable amounts of waste and tailings, which can contain harmful toxins that leach into the surrounding environment if not properly handled. In 2017, copper and nickel mining produced close to 11,000 metric tons of waste rock, which was 488.5 times larger than the combined total copper and nickel output.[20] Tailings (i.e., waste materials left over from mineral extraction) generation was also high compared to output. Copper and nickel mining generated 4,000 metric tons of tailings in 2017, 190.9 times more than the combined total output of these metals.

Chart 3: Growth in waste rock from copper and nickel mining from 2010 to 2017



Source: Sustainable and responsible development of minerals (IEA)

Lastly, material inputs are often extracted in areas with high biodiversity value. For example, eighty percent of cobalt is mined in areas with biodiversity risk as a result of its high concentration in the biodiversity-rich Democratic Republic of Congo.[21] Other inputs are also exposed to biodiversity risk, including nickel and lithium, where 54 and 20 percent of mining, respectively, occurs in biodiversity risk areas.[22]

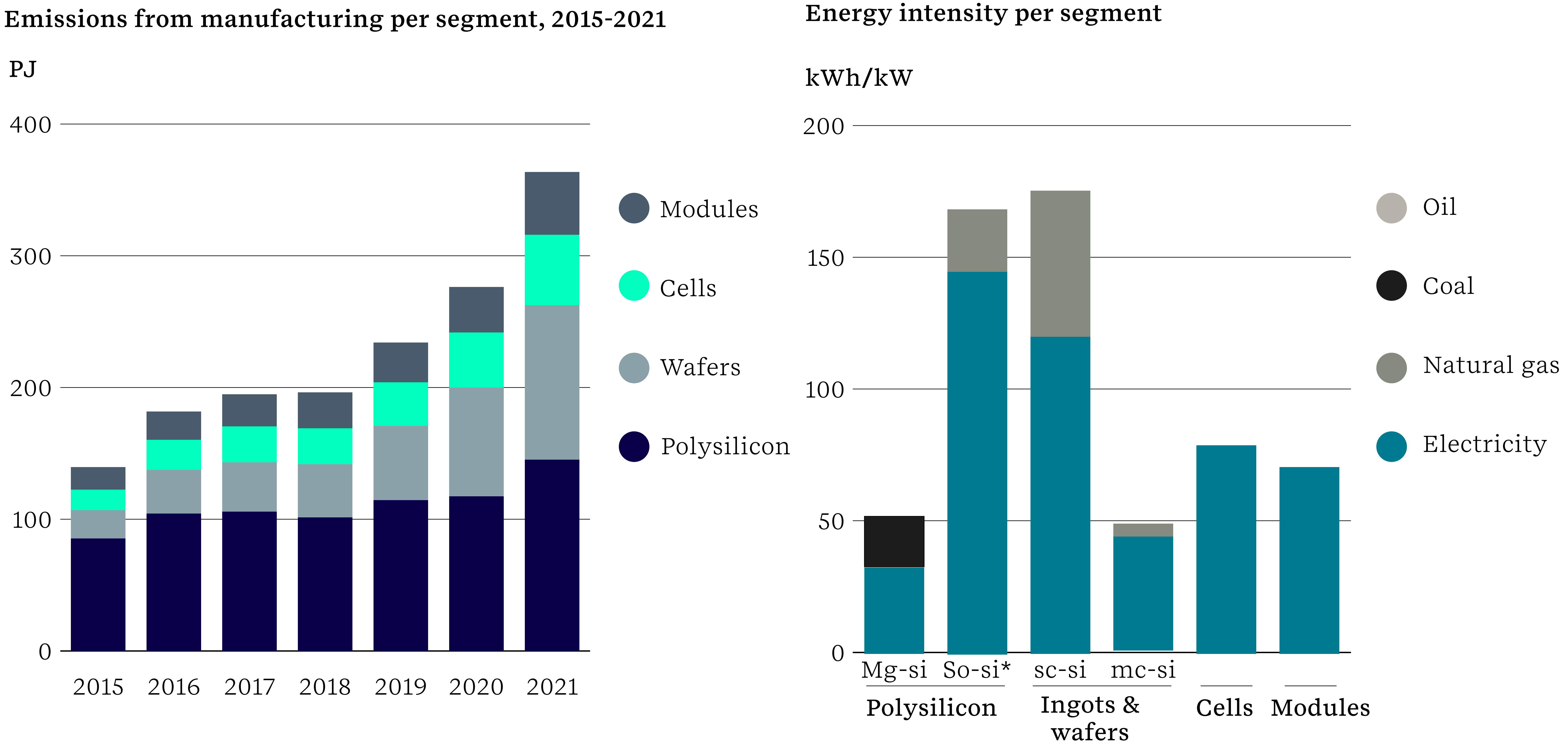
Unintended consequences – Pollution during Renewable Energy platform production

Like other manufacturing processes, producing renewable energy platforms generates environmental externalities that companies must account for when expanding their renewable energy capacities.

Starting with energy, platform manufacturing consumes significant amounts of electricity. For example, in 2021, solar panel manufacturing consumed 364 PJ of electricity globally, approximately equal to Croatia's yearly energy demand.[23] The manufacturing of polysilicon, a key panel input, is responsible for the largest portion of this consumption because of the high heat and extended time it takes to extract silicon and refine it for use in solar cells. Further, coal fuels much of this electricity consumption (62 percent) because most solar panel production is centered in China, where coal often comprises the largest portion of the power supply.

GHG emissions are another issue that companies must face. Between 2011 and 2021, GHG emissions from solar panel manufacturing increased nearly fourfold to 51,900 kt of CO_2, growing to 0.15 percent of global energy-related emissions in 2021, due to rapid production increases and manufacturing shifts to China.[24]

Chart 4: Solar PV manufacturing energy consumption and energy intensity

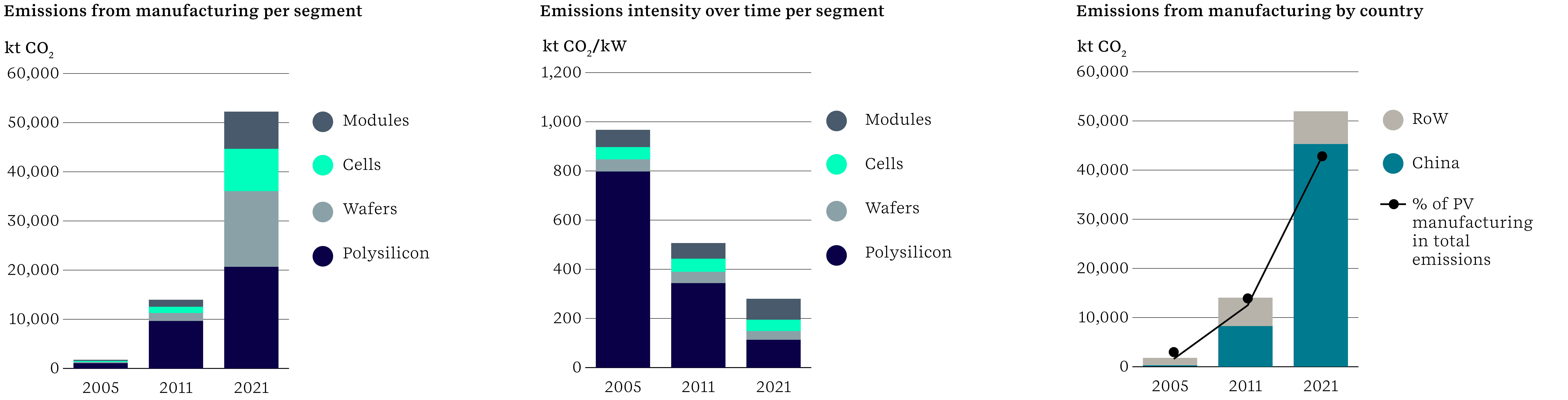


Notes: Mg-si = metallurgical-grade silicon. So-si* = solar-grade silicon using the Siemens process. sc-si = monocrystalline wafers. mc-si = multicrystalline wafers.

Solar PV manufacturing energy consumption by input between 2015 and 2021 and energy intensity by input.

Source: Special Report on Solar PV Global Supply Chains (IEA)

Chart 5: PV manufacturing absolute emissions and emissions intensity globally



Notes: RoW = rest of world. This report does not consider emissions derived from manufacturing intermediate products involved in PV module assembly (glass, cables, etc.). Total energy emissions refers to CO_2 emissions from energy combustion and industrial processes.

PV manufacturing absolute emissions and emissions intensity by input and country globally. Source: Special Report on Solar PV Global Supply Chains (IEA)

Still, emissions associated with solar panel manufacturing are quickly offset once panels are installed and operating, with panels only taking 3-5 months to offset their production-related emissions in most instances.

Wind turbine manufacturing also produces GHG emissions, accounting for almost 90 percent of a wind turbine's total lifecycle CO_2 emissions due in part to carbon-intensive inputs like concrete and steel.[25] One estimate puts total manufacturing-related GHG emissions for a 2 MW onshore wind turbine (slightly smaller than the average 3.2 MW turbine installed in the U.S. in 2022) with an 80 meter blade length at 695.84 tons of CO_2e.[26,27] That said, when manufacturing-related emissions are spread over the course of a typical wind turbine's full lifecycle, they equate to between 5 and 26 grams of CO_2e per kilowatt hour of electricity produced (compared to 437-758 grams of CO_2e per kilowatt hour for a natural gas-fired power plant).[28]

Beyond manufacturing, the transportation and construction of renewable energy platforms also generates environmental externalities, most notably GHG emissions. A study on the lifecycle GHG emissions within U.S. solar panel supply chains found that ocean and on-road transportation accounted for 1.6 percent of total lifecycle emissions.[29] Construction emissions on the other hand compose a greater share of total emissions. A study examining wind turbine lifecycle emissions in China concluded that 46.86 percent of a wind turbine's total lifecycle emissions comes from wind farm construction.[30] This of course is just one example in one country; however, it shows that GHG emissions are for the most part unavoidable in the manufacturing and construction stages of renewables' lifecycles.

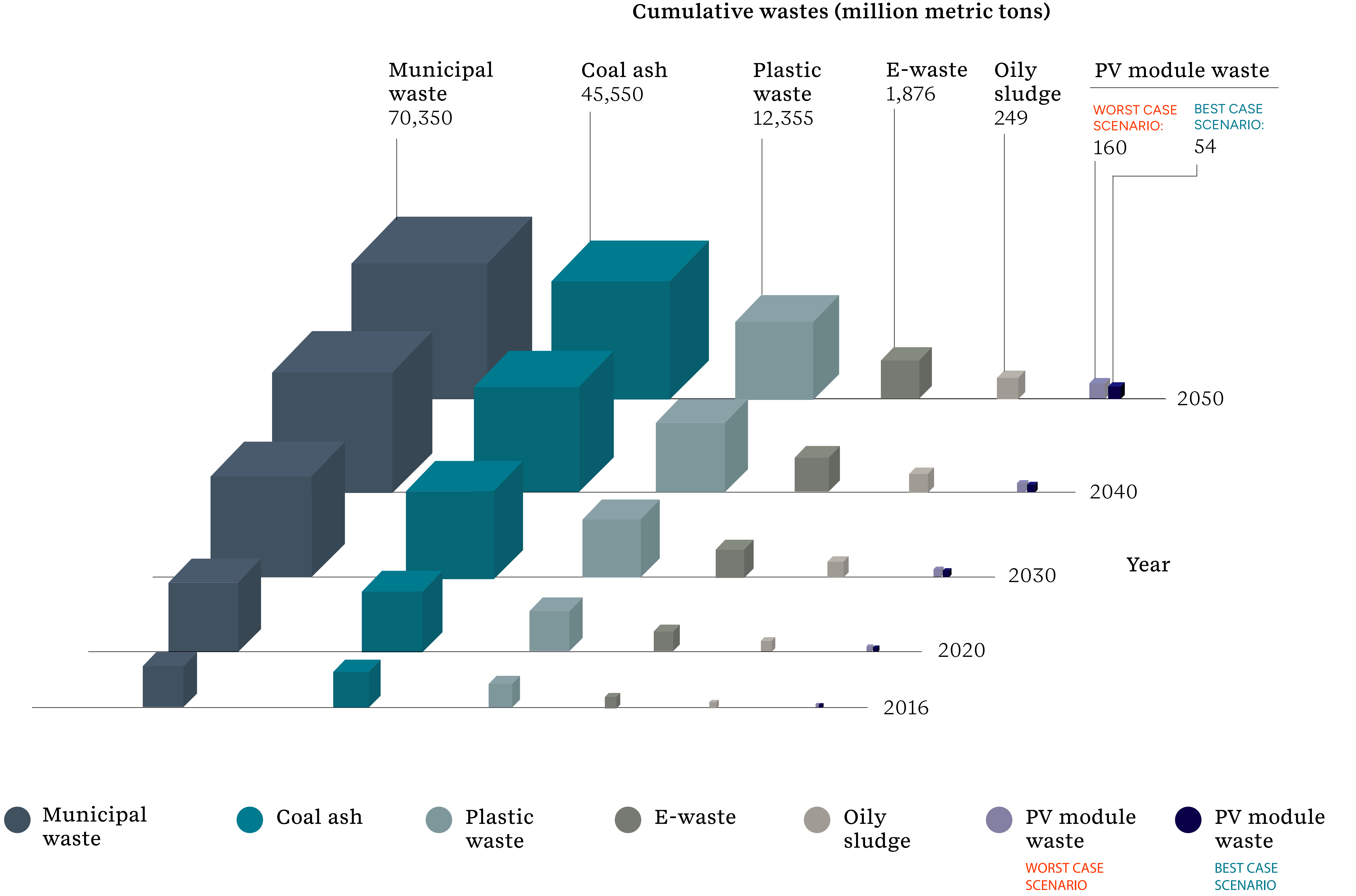
The end-of-life dilemma – The fast-growing mountain of decommissioned renewable energy platforms

Renewable energy platforms have relatively long lifespans. For example, the operational lifespan of the average solar panel is approximately 30-35 years and the operational lifespan of the average wind turbine is approximately 25-30 years.[31,32] These lifespans mean that platforms easily offset the energy and emissions impacts from their manufacture. However, they also mean that these platforms do not last forever and that operators must dispose of them at end-of-life, which can generate negative environmental impacts if not handled appropriately.

Most prominent among end-of-life challenges is what to do with decommissioned solar panels and wind turbines. Solar waste is set to balloon in the coming years. In 2050, an estimated 78 million tons of solar panels will reach end-of-life.[33] Although most materials inside solar panels are recyclable, they are difficult to separate and recycle when combined. Further, recycling is expensive. It costs $20-$30 to recycle one panel using current methods, while the recovered materials are only worth around $3.[34] As a result, limited quantities of solar panels are currently recycled. In the U.S., for example, only 10-15 percent of solar panel materials are recycled, with the majority of others ending up in landfills.[35]

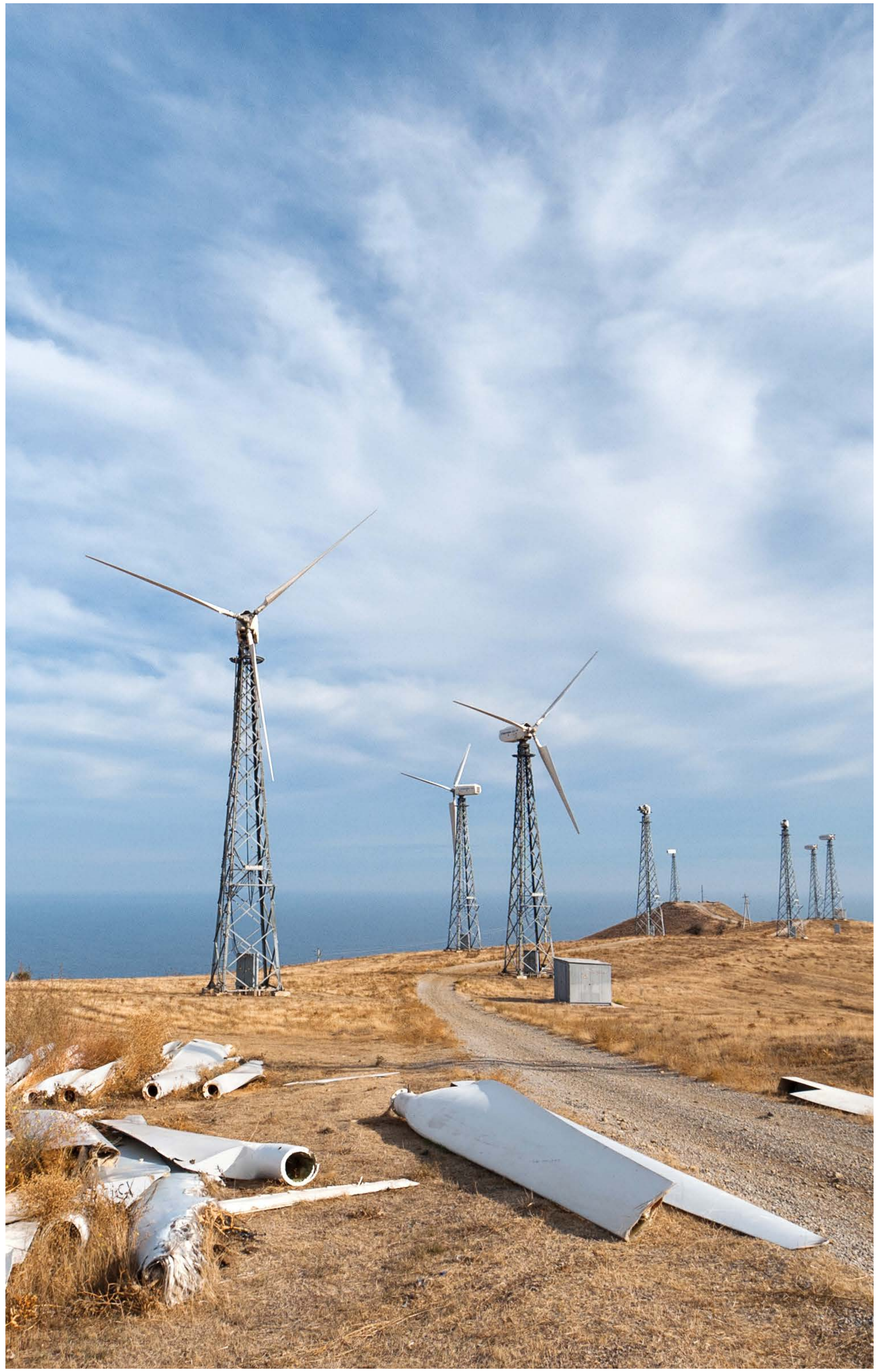
For wind turbines, most materials included in the turbines themselves are recyclable, such as steel and copper wire. Turbine blades are a different story. They are primarily composed of fiberglass, which is notoriously difficult to recycle due to its composite structure of fine plastic and glass strands.[36]

Chart 6: Cumulative global waste estimates from select sources



Cumulative global waste estimates between 2016 and 2050 from select sources.

Source: Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization (Nature Physics)



And thousands of blades will soon reach the end of their lifespan. In just the U.S., up to 20,000 blades will be decommissioned annually between 2025 and 2040.[37]

Because of their fiberglass composition, many wind turbine blades will eventually end up in the landfill or be incinerated at end-of-life, creating environmental externalities in the process. One estimate puts the percentage of wind turbine blades that will end up in the landfill by 2050 at 78 percent in the absence of policy change and/or new recycling technologies.[38] Blade waste will only grow in the future, with a study projecting that there will be 43 million tons globally by 2050.[39]

Materials toxicity is another issue. Some solar panels, for instance, include small amounts of heavy metals like lead and cadmium that, if not properly disposed, could contaminate soils and water.[40] For example, solar panels in landfills are a potential source of leachate (i.e., liquids that drain from landfills that can pollute underlying soils and water bodies).[41] Even so, solar panel waste is still dwarfed by that produced from fossil fuel generation, with the amount of coal ash generated per month equal to projected solar panel waste over the next 35 years.[42]

Wind turbine blades include fewer toxic materials than solar panels. However, this does not mean that their disposal does not pose contamination risks. When recovering or incinerating a blade's constituent materials at high temperatures, toxic gases (and GHG emissions) are produced, posing a risk to human health and the environment.[43]

Renewable energy installations

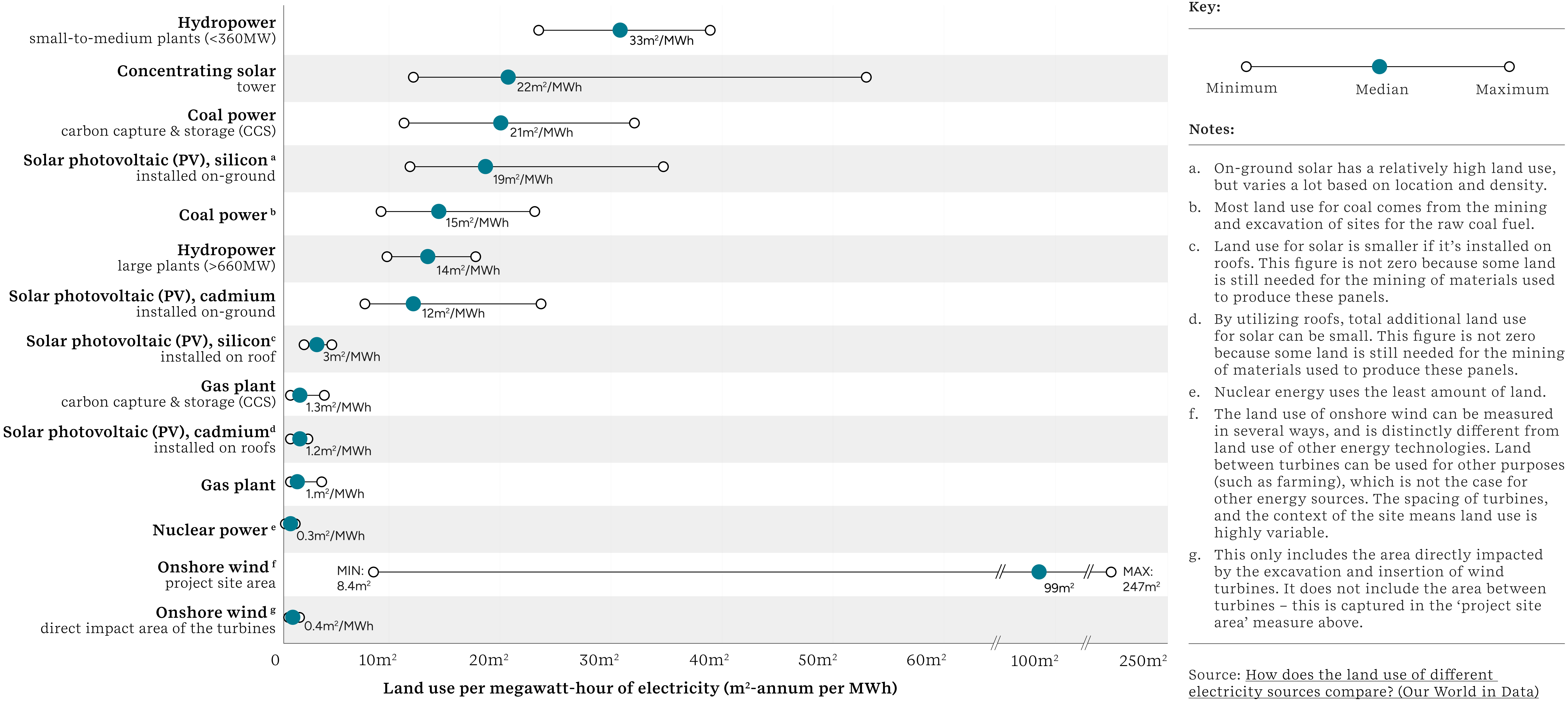
A single installed renewable energy platform may not cause significant environmental impacts on its own. However, a platform is rarely installed alone, as companies and developers look to maximize energy generation capacity with large solar and wind farms. At these renewable energy installations, negative environmental impacts can arise if companies and developers do not take proper mitigative action.

Living large – The lurking land impacts of renewable energy

Unlike most fossil fuels and nuclear energy projects, renewable energy projects generally have large land footprints. For example, when accounting for mining and generation, the average nuclear power plant uses 0.3m^2 of land for every MWh of electricity it produces and the average natural gas plant uses 1m^2 of land per MWh.[44] While coal power plants are large land users at 15m^2 of land per MWh (primarily because of coal mining-related land use), renewable energy installations use more. An average onshore solar farm uses 19m^2 of land per MWh and an average onshore wind farm uses at a minimum 8.4m^2 per MWh and up to 247m^2 per MWh.

Chart 7: Land use of different energy generation methods per unit of electricity

Land use is based on life-cycle assessment; this means it does not only account for the land of the energy plant itself but also land used for the mining of materials used for its construction, fuel inputs, decomissioning, and the handling of waste.



Notes:

a. On-ground solar has a relatively high land use, but varies a lot based on location and density.

b. Most land use for coal comes from the mining and excavation of sites for the raw coal fuel.

c. Land use for solar is smaller if it's installed on roofs. This figure is not zero because some land is still needed for the mining of materials used to produce these panels.

d. By utilizing roofs, total additional land use for solar can be small. This figure is not zero because some land is still needed for the mining of materials used to produce these panels.

e. Nuclear energy uses the least amount of land.

f. The land use of onshore wind can be measured in several ways, and is distinctly different from land use of other energy technologies. Land between turbines can be used for other purposes (such as farming), which is not the case for other energy sources. The spacing of turbines, and the context of the site means land use is highly variable.

g. This only includes the area directly impacted by the excavation and insertion of wind turbines. It does not include the area between turbines – this is captured in the 'project site area' measure above.

Source: [How does the land use of different electricity sources compare? (Our World in Data)]

The large land footprints of renewables pose problems, particularly as they rapidly grow in scale to combat climate change. A study examining solar land use requirements in the European Union (EU), India, and South Korea found that as solar energy composes a larger and larger portion of a geography's electricity mix, land use change emissions also increase.[45] Because solar energy expansion will often occur on land currently used for agriculture and forestry, these activities would shift to unused arable land in other regions, leading to natural land cover losses. These natural land cover disturbances would then release the carbon stored in local soils and vegetation. Emissions would vary by region. For example, in the EU, land use change from solar energy expansion would generate between 13 and 53g of CO_2 per kWh of electricity produced (or approximately 4 to 16 percent of the CO_2 emissions of natural gas electricity generation).

Wind energy also generates land use change-related emissions, although these depend on the land on which companies and developers build projects. A study in Scotland found that constructing close to 4,000 wind turbines generated 4.9 million tons of CO_2 emissions from land use change.[46] Emissions were highest when turbines were built on peatlands (560g CO_2 per kWh), and, in some cases, comparable to the lifecycle emissions of coal and natural gas electricity generation. Emissions were much lower in other environments, including forests, cropland, and pastureland, where wind turbine-associated land use changes generated 88g, 45g, and 30g of CO_2 per kWh, respectively.

Wary of wildlife

Renewable energy installations can sometimes impact the wildlife that inhabit local landscapes as a result of habitat degradation and loss and direct physical impacts.

Habitat alteration can lead to changes in wildlife populations. A study exploring the effects of a 96 MW solar installation in South Africa found that bird species diversity and density within the installation was much lower after the solar panels and short grasslands that surround it replaced the arid savanna landscape that previously existed on the site.[47] Large solar developments can also disrupt terrestrial wildlife migratory patterns due to fencing and the panels themselves, which create barriers that stop or divert terrestrial animals' movements or break up their populations.[48] Wind installations can create similar issues. Although they have smaller footprints than solar installations, some bird and mammal species avoid wind farms (for reasons still not entirely understood), effectively altering their life patterns.[49]

Marine life can be similarly affected by habitat alteration caused by offshore wind energy installations. Wind turbine structures on the seafloor can alter sediments and create new habitats for attached organisms like algae and mussels.[50] These alterations can attract fish and other sea life, leading to higher-than-normal species concentrations and potential increases in invasive and nonindigenous species. Using small pelagic fish (i.e., species that inhabit open waters) as an example, the attractiveness of wind turbine habitats can alter migration patterns, heightening predation risk. Offshore wind turbines can also affect marine primary production where organisms like marine algae synthesize organic compounds from carbon dioxide via photosynthesis, forming the basis of marine food chains. A study of offshore wind farms in the North Sea found that turbine wakes, which reduce wind speed downwind, can either increase or decrease local marine primary production by up to 10 percent.[51] These changes are thought to occur because of the upwelling and downwelling wind wakes cause in the ocean below.

Wind turbine avian mortality (due to birds flying into turbine blades or towers) is a prominent renewable energy issue as well. One recent estimate put the number of wind turbine-related bird deaths in the U.S. at 538,000 annually, with numbers potentially far higher.[52]

Despite renewable energy's wildlife risks, it is still a much better energy generation option – in terms of net wildlife benefit - than fossil fuels. Under a scenario where the world rapidly decarbonizes in line with holding global warming to 1.5°C by 2050 (and renewables comprise 80 percent of energy use globally), projected risks to biodiversity, natural habitats, and ecosystems are up to 75 percent less than in a business-as-usual scenario (where the losses of species richness and potential species extinction increase 400 percent) because of reduced eutrophication, acidification, ecotoxicity, and climate change impacts.[53]

Taking Charge
- Four steps to build benefit in renewable energy expansion

With clear environmental gains like decarbonization and air quality improvements to realize and unseen environmental impacts such as end-of-life waste and land use change to mitigate, managing the environmental conundrums associated with renewable energy is key to companies successfully building out their renewable energy capacities. However, with so many issues to consider, determining what this management should look like is not easy. While there are no quick solutions, the four actions we outline here can help companies get started.

STEP 1:
Opt for green production inputs and processes

STEP 2:
Introduce circular alternatives

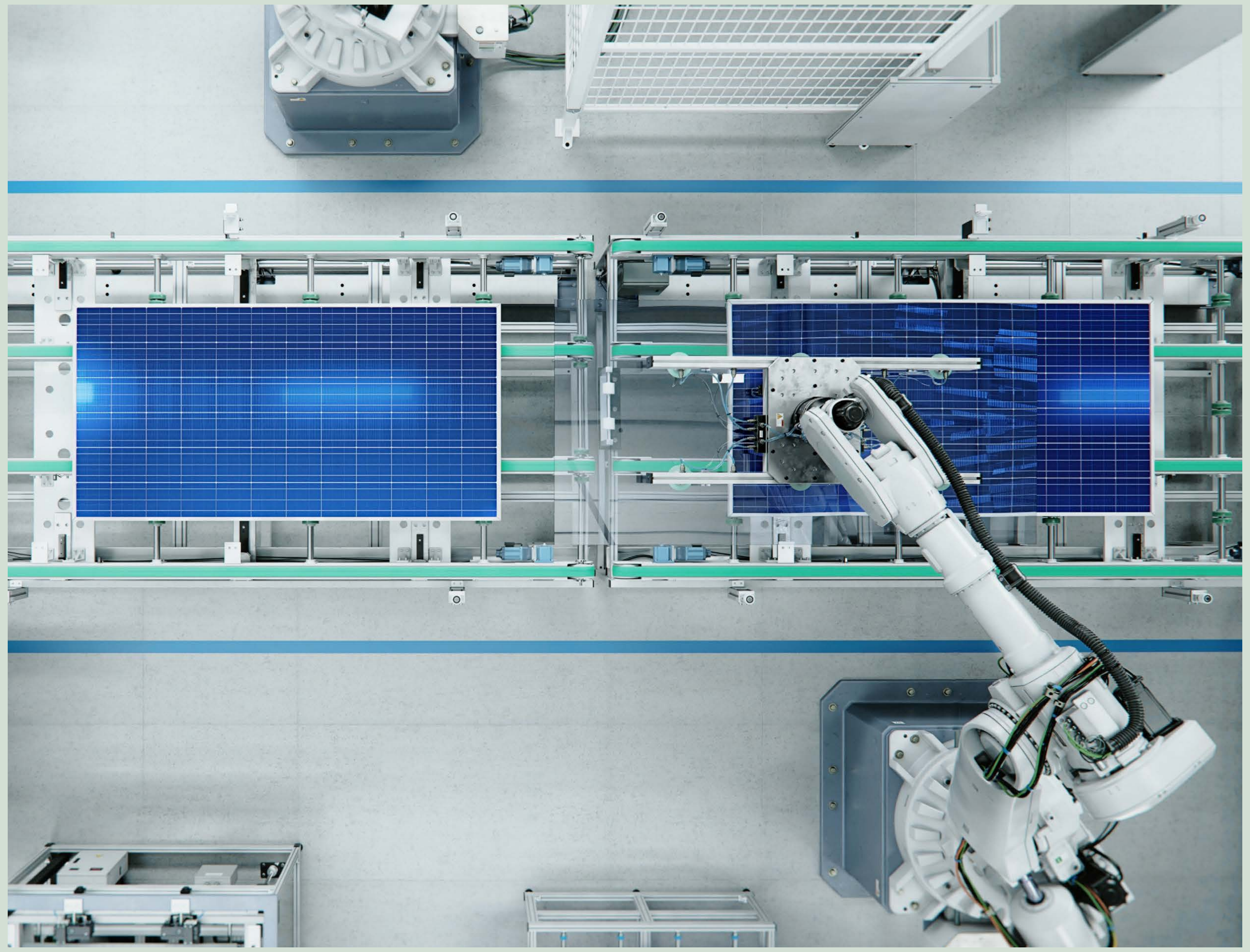
STEP 3:
Minimize footprints

STEP 4:
Consider wildlife from the start

Step 1: Opt for green production inputs and processes

The challenge

Extracting and processing material inputs for renewable energy platforms and the actual manufacturing of these platforms generates environmental externalities that can reduce the environmental benefits of low-carbon energy generation. However, these externalities are not unavoidable. Green alternatives offer companies opportunities to disconnect environmental impact from renewable energy growth.



The solutions

1. **Pursue low-carbon and low-waste raw material sourcing for renewable energy platforms. As we described above, extracting raw materials essential to renewable energy generates considerable environmental externalities from GHG emissions to end-of-life waste. While traditional extraction methods are the main drivers of these externalities, some extractive companies are testing new approaches to reduce them. Companies involved in renewable energy supply chains should focus their sourcing on producers pursuing these types of methods.**

   Real world example: Copper mining generates GHG emissions. Once unavoidable, extractive companies are now implementing new solutions to mitigate them. The Canadian miner Teck is one. In 2022, it announced that the entire power needs of its Quebrada Blanca copper mine in Chile will be met by renewable energy beginning in 2025.[54] The deal will eliminate an estimated 1.6 million tons of GHG emissions annually, equal to the emissions of 340,000 combustion engine cars. Waste is another traditional externality companies are looking to address. In April 2024, U.S. miner Talon Metals partnered with the U.S. Department of Energy's Argonne National Laboratory to reduce the amount of waste generated by nickel mining.[55] For the partnership, Talon will recover iron sulfide by-products from nickel mining that Argonne researchers will use to develop a lithium iron phosphate (LFP) synthesis process to create LFP cathodes for use in lithium-ion batteries.

2. **Select low-carbon material inputs for renewable energy platforms. Solar panels and wind turbines contain numerous inputs that traditionally come with high carbon footprints (e.g., aluminum for solar panels, fiberglass for wind turbines, and copper for both). Companies involved in the manufacturing of renewable energy platforms should prioritize material inputs with low carbon footprints to minimize the emissions impacts of their creation.**

   Real world examples: Copper cathodes are essential components in both solar panels and wind turbines due to their ability to efficiently conduct electrical currents. Still, copper cathode production generates GHG emissions via processes that concentrate and smelt the metal before refining it via electrolysis.[56] Companies like Boliden and BHP are devising methods to reduce these emissions. In Boliden's case, the Swedish metals firm uses clean energy to lower the carbon footprint of refined copper to 1.5 kilograms of CO_2 for every kilogram of copper it produces (compared to the global average of 4 kilograms of CO_2 per kilogram of copper).[57] BHP is also working on operational strategies to make copper cathode production carbon neutral. In the meantime, it delivered the first carbon-neutral cathode after it used blockchain technology in partnership with Southwire to track and offset GHG emissions associated with copper cathode production processes.[58]

3. **Use low-carbon components when building renewable energy platforms. The final components that form the basis of solar panels and wind turbines have normally come with high carbon footprints thanks to the energy intensive manufacturing processes used to create them. Take wind turbine towers. In the past, there were few low-carbon alternatives to produce these mostly steel structures as their production depended on high temperatures generated by fossil fuels. However, this is changing as companies charge ahead with new components created from low-carbon production methods.**

   Real world examples: Wind turbines use substantial quantities of steel for the towers that hold the turbine blades in the sky. Historically, these towers were constructed from steel created via traditional steelmaking processes with high carbon intensities. With more alternatives available, companies are changing the narrative. For example, Vestas partnered with steelmaker ArcelorMittal in early 2024 to source low-emission steel for its wind turbine towers, steel that is produced from steel scrap melted by a 100 percent wind-power electric arc furnace.[59] Compared to traditional steelmaking, this type of steel has at least 52 percent less emissions. Vestas is not the only company pursuing 'green steel' wind turbine towers. Siemens Gamesa now offers the "GreenerTower" composed of steel with a maximum of 0.7 tons of CO_2e per ton, which represents an emissions reduction of at least 63 percent compared to a turbine tower made of traditional steel.[60] Other companies like Modvion are considering steel alternatives. The Swedish start-up is developing wooden wind turbine towers that provide all the strength and durability benefits of steel with substantially lower GHG emissions.[61] The wood in each of the 150-meter towers it produces captures 2,000 tons of CO_2, reducing the turbine's overall carbon footprint by over 25 percent.

The benefits

1. Prioritizing raw materials (e.g., alumina and copper ore) sourced via low-carbon and low-waste extraction methods will reduce the supply chain GHG emissions associated with renewable energy platforms, lessening their emissions impact.
2. Using material inputs (e.g., copper cathodes) produced via low-carbon processing methods will reduce the embodied GHG emissions in renewable energy platforms, minimizing the emissions impacts associated with their manufacture.
3. Assembling renewable energy platforms with low-carbon components (e.g., wind turbine towers) will lower the emissions associated with their final construction and increase the emissions savings the platforms will generate over their operational lifespans.
4. For companies operating in jurisdictions where carbon pricing or other emissions-related regulations are in place, the emissions savings generated by opting for green production processes and inputs will reduce operating and compliance costs.
5. Minimizing the environmental externalities associated with the sourcing and manufacturing of renewable energy platforms will reduce the risk that your organization will be exposed to stakeholder controversies that could lead to financial and reputational impacts.

Step 2: Introduce circular alternatives

The challenge

As with any device or product, renewable energy platforms will eventually reach the end of their useful life and need to be disposed of. It is imperative that platform disposal is done responsibly. Nevertheless, as the world rapidly scales its renewable energy capacity, many questions remain about how to produce platforms using materials and processes that enable circularity and reuse. Still, these questions are not stopping potential solutions from emerging.

The solutions

1. **Use circular materials when building renewable energy platforms. Solar panels and wind turbines are complex devices requiring all kinds of inputs to properly function. In the past, few companies considered how well these inputs could be repurposed at end-of-life into new renewable energy platforms or other uses. However, innovators are now exploring how circular materials can enable old renewable energy platforms to live on well past their last kilowatt-hour. Following in the footsteps of these organizations could reap dividends, both in terms of environmental impact and financial savings.**

Real world examples: Since wind turbines first emerged, recycling their blades has been an incredibly difficult process due to the complexities of recycling the intertwined carbon fiber and fiberglass that compose most of their structures. The issue lies in breaking down the thermoset resin that connects the component materials together. A Taiwanese materials company has developed an alternative resin to help solve this problem.[62] Swancor's EzCiclo does everything that thermoset resins like epoxy do except that it can be dissolved when submerged in the company's CleaVER liquid solution. After dissolution, the carbon fiber component materials can be separated and reused in other applications (although not wind turbine blades, as the recovered materials lack their original strength). Vestas on the other hand created a solution that will enable recycled blade materials to be reused in new blades.[63] Their idea is like Swancor's in that the company will use an undisclosed chemical process to break down epoxy resin-based blades into virgin-grade resources that can be reused in blades again and again. Lastly, the U.S. National Renewable Energy Laboratory recently developed a turbine blade created from inedible sugar derived from wood, plants, used cooking oil, and agricultural waste.[64] While still a prototype, the blades perform just like traditional fiberglass ones. However, unlike traditional blades, these blades can be recycled using heated methanol baths that turn them into a liquid that can be used to create new blades.

2. **Recycle or repurpose renewable energy platforms at end-of-life. As we have mentioned here, renewable energy-related waste will increase exponentially over the coming years as existing solar panels and wind turbines are decommissioned because of their age or replaced in favor of larger and more efficient models. The growing quantity of waste makes it imperative that companies scale recycling solutions to meet the challenge.**

Real world examples: Few solar panels are fully recycled because of the complexity of doing so and the high costs involved. Ørsted is one company looking to change this narrative. In June 2023, the Danish renewable energy firm committed to reuse or recycle all its solar panels.[65] Alongside this announcement, Ørsted disclosed that it is partnering with the solar recycling company SOLARCYCLE to help achieve its goals.[66] For the collaboration, SOLARCYCLE will examine old panels to determine if they can be reused. In cases where they cannot, the company will instead recycle the panel's components starting with its aluminum frame, junction block, and glass, before shredding what is left. SOLARCYCLE will then use a proprietary method to recover metals and plastics from the shredded material, which will then be reused in new solar panels and other products. EDP Renewables North America (EDPR NA) is also collaborating with SOLARCYCLE as part of its Close the Loop recycling program that aims to recover 90 percent of the total waste from its renewables projects by 2030.[67]

The benefits

1. Using circular materials to build renewable energy platforms and recycling and repurposing them at end-of-life will reduce the amount of waste sent to landfills, both reducing potential environmental impacts such as soil and water contamination and generating cost savings from reduced waste disposal and virgin material spending.
2. Accounting for circularity, recycling, and repurposing in your company's renewable energy plans will limit the need for the mining and sourcing of virgin material inputs. Whether your company is involved in their direct extraction or acquisition, using fewer virgin materials will save your organization money and reduce its exposure to stakeholder controversies that could arise over mining-related environmental impacts.
3. Investing in circular alternatives and recycling and repurposing will open new commercial opportunities and financial savings for your company. For example, selling old solar panels to other businesses for refurbishment and reuse could generate additional revenue sources for renewable energy expansion, while also saving money that would otherwise be spent on properly disposing of these panels.

Step 3: Minimize footprints

The challenge

As renewable energy continues to grow in scale, the traditionally large land footprints of installations pose challenges both in terms of land use and impact that companies must account for. While the footprints of solar and wind farms are not likely to significantly decrease, several emerging strategies can help mitigate some of the issues associated with renewables' considerable land use.

The solutions

1. **Build renewable energy installations on brownfields. Although companies have little control over the size of renewables' land footprints, they do have a choice over the types of land on which they place them: greenfields or brownfields. Greenfields, or land that has yet to be developed, can be attractive given their blank slate. However, they are often better utilized by other land uses such as agriculture and companies can face pushback from communities who want the open space to remain undeveloped. On the other hand, brownfields, or land that has previously been developed, often have many advantages such as existing grid connections and lower land costs.**

   Real world examples: The appeal of brownfields for renewable energy installations is starting to catch on with companies. Amazon, for instance, announced in November 2023 that it is building its first brownfield renewables project on a recently closed coal mine in western Maryland. The project will include 300,000 solar panels (which will make it the largest solar farm in Maryland) on a site that was previously contaminated by over 45 acres of coal refuse.[68] Instead of old mines, Veolia is opting to build solar farms on restored landfills in France.[69] In February 2024, it announced that it plans to develop more than 40 solar projects with a combined generation capacity of 300 MW on non-hazardous restored landfills. In its announcement, the company cited an emerging land shortage in France just as demand for clean energy demand grows as a driving factor behind the move.

2. **Repower existing renewable energy installations. Advances in renewable energy technologies are accelerating as larger and more efficient platforms are introduced on a regular basis. In 1985, the average wind turbine had a generation capacity of 0.05 MW.[70] Fast forward to 2023 and new wind turbine generation capacities reached 3-4 MW and 8-12 MW for onshore and offshore use, respectively. Because of this rapid growth, existing renewable energy installations quickly become out-of-date. Beyond the clear emissions reduction benefits of these technological advances lie opportunities to reduce renewables' land impacts.**

   Real world example: The land impact opportunity lies in repowering, or the retrofitting of existing renewable energy installations with modern parts to maximize generation capacity. In Spain, Iberdrola is repowering four of its onshore wind farms, the oldest of which was constructed in 1998 and has a generation capacity of 660 kW.[71] In comparison, their modern replacements will have a generation capacity of 4.5 MW. Because of this tremendous difference, the initiative will remove almost 200 wind turbines from the farms while still increasing overall energy output by 30 percent. Iberdrola's repowering will bring two land use benefits. The first is the direct reduction in the land area taken up by wind turbines at the site due to the turbine removal taking place. The second is that by repowering an existing wind farm rather than building a new one on a new site, Iberdrola is forgoing the need to develop additional land, leaving other spaces open or free for other types of land use.

3. **Co-locate solar and wind developments together. Solar and wind farms take up space, and as renewable energy expands to meet the world's climate ambitions, associated land use demands will only grow. While most renewable energy installations are built separately, locating solar panels and wind turbines together on one site (where sun and wind conditions allow) can help minimize overall space requirements.**

   Real world example: Solar and wind colocation can either be designed from the start of a renewable energy project or designed into an existing one. Whirlpool is pursuing the latter strategy for its Ohio operations. In January 2024, the home appliance company announced that it would install solar panel arrays at two of its Ohio plants.[72] Whirlpool had already installed onsite wind turbines at one of these plants, meeting 22 percent of its electrical demand. As part of this project, they will add new turbines to a second plant and co-locate ground solar arrays alongside the turbines. The solar panels and wind turbines at both plants will generate 40.8 MW of electricity, satisfying 70 percent of their collective energy needs.

4. **Incorporate Marine Spatial Planning into project design. Although offshore wind farms do not have as many of the space competition issues that onshore farms do, offshore turbines still take up space that might otherwise be used for fishing, shipping, sand mining, or other marine activities. Companies can use the results of MSP, or a process used by countries to assess and allot the temporal and spatial distribution of marine activities to ensure an equal balance between ecological, economic, and social goals, to help inform their efforts to minimize spaces issues in offshore wind development.**[73]

    Real world example: The Offshore Coalition for Energy and Nature (OCEaN), a group of European NGOs and companies active in the offshore wind space, formed its MSP working group to support their members use of MSP results.[74] *The working group's activities are broad, ranging from knowledge sharing on MSP activities and outcomes across different jurisdictions, understanding nature impacts, identifying existing economic activity conflicts, and identifying and discussing multi-use options with stakeholders. In addition to these activities, the working group also acts to improve MSP across Europe. In late 2022, OCEaN published a set of recommended actions for European Union (EU) member states that would improve MSP practices in line with what is required to meet the EU's climate and nature goals.*[75]

The benefits

1. Building renewable energy installations on brownfields takes advantage of the existing grid connections these sites often already have because of prior activities. With existing connections, solar and wind farms can more quickly be connected to transmission networks, saving the time and money associated with new interconnections.
2. Selecting brownfields for solar and wind farms can bring new utility to formerly disused spaces that are unsuitable for other types of development because of previous environmental contamination and the costs associated with remediation.
3. Repowering existing renewable energy installations can increase the overall generation capacity of a solar and wind farm without the need to expand its existing footprint, while also, in many cases, reducing a farm's overall footprint.
4. Co-locating solar panels and wind turbines can generate cost savings given that companies only need to build the infrastructure needed to construct and operate the platforms once.
5. Grouping renewable energy installations together can ensure more reliable energy generation. The sun does not always shine, and the wind does not always blow. This intermittency has long been a critique of renewables; however, by grouping solar and wind together, companies can ensure platforms are still generating energy at times when the sun is bright, but the wind is low and vice versa.
6. Incorporating MSP results into offshore wind farm planning can help avoid potential conflicts with other marine space uses that could lead to backlash from important stakeholder groups such as conservationists and the fishing industry.

Step 4: Consider wildlife from the start

The challlenge

Human-made solar panels and wind turbines are, like the rest of Earth's built environment, artificial additions to otherwise natural landscapes. Just as buildings and other infrastructure pose threats to wildlife, so too does the construction and operation of renewable energy platforms. Because these technologies are central to fighting the climatic changes that are stressing many ecosystems to the brink, companies must make every effort to ensure that the construction and operation of renewable energy developments is as nature friendly as possible.

The solutions

1. **Screen renewable energy developments for wildlife impacts during siting. While some impacts will be unavoidable, proactively identifying potential wildlife impacts before developing a solar or wind farm can help companies avoid areas of high biodiversity value, reduce the adverse effects of construction, and help developments coexist with local fauna over their life cycle.**

   Real world example: SSE Renewables follows a comprehensive plan to screen potential renewable energy developments for wildlife impacts during project siting.[76] It all starts with the concept of biodiversity net gain (BNG) or ensuring that a development has an overall net positive biodiversity impact. The UK firm is committed to each of its projects delivering a BNG. Pre-screening is a key part of accomplishing this goal. For every project, SSE conducts what it calls a "pre-development biodiversity value baseline" to evaluate the habitats on the site and their conditions, connectivity, and strategic significance. The strategic significance value is key as it tells the firm whether a site is located in an optimum location for biodiversity based on a high, medium, or low score. The results of the baseline then inform SSE's project design decisions and plans to ensure it meets its targets for BNG at each site via habitat creation or enhancement activities.

2. **Incorporate wildlife-friendly project design into renewable energy installations. After accounting for wildlife in the planning phase of a renewable energy development, companies must design solar and wind farms to minimize their impacts on nature once they enter operation. Both direct and indirect impacts must be considered.**

   Real world examples: Bird collisions with wind turbines are one of renewable energy's most prominent wildlife impacts. Although wind turbines hurt or kill birds on a much smaller scale than fossil fuel activities or even house cats, companies are still working to reduce collisions.[77] For example, American utility PacifiCorp is painting one wind turbine blade black on 36 different turbines to study if it reduces collisions by helping birds visually identify blades by interrupting what would otherwise appear to be uniform space.[78] The project follows in the footsteps of a smaller scale study in Norway that found that black painted turbine blades reduced annual bird fatality rates by more than 70 percent.[79] Besides direct wildlife impacts like bird collisions, companies are designing projects to allow wildlife to better transverse solar and wind farms. In Canada, Pattern Energy builds eco-passages that allow local wildlife like turtles and snakes to safely cross under wind farm roads.[80]

3. **Integrate native landscapes into renewable energy development sites. Fields of uniform solar panels and towering wind turbines can interrupt native landscapes, making life difficult for animals that inhabit and make use of the same land. However, solar and wind farms do not have to be a drag on ecosystems. With the right actions, they can help enhance local environments.**

   Real world examples: Utility-scale solar farms are big, requiring on average between 5 and 10 acres per MW of generating capacity.[81] Not all that land is solar panels, however. Farms are designed with open space between rows of panels to allow workers to maintain and repair the installations. It is in these spaces that companies like Lightsource BP are creating enhanced habitat for local pollinators. At its Black Bear Solar farm in Alabama, Lightsource worked with local ecologists and wildlife biologists to develop a vegetation plan to support pollinators like bees and butterflies.[82] The plan worked in two parts. First, the company planted a wildflower garden outside of the 130 MW solar farm with more than 24 native species of pollinator-friendly grasses and flowering plants. Second, Lightsource seeded several species under and around the solar panels themselves that were specifically selected for their ability to ensure pollinator coverage over the range of environmental conditions (e.g., shaded, sunny, etc.) found at the site.

4. **Utilize offshore wind wildlife mitigation measures. Whether the significant subsea noise generated by the pile-driving of turbine foundations or seafloor habitat disturbances, the wildlife impacts of offshore wind turbines can be less visible than those onshore. No matter their visibility, offshore wildlife impacts are a factor that companies must still consider. With decades of experience constructing and operating offshore wind farms, renewable energy firms have developed measures to mitigate marine wildlife impacts.**

   Real world examples: There are many options companies can pursue to reduce the subsea noise generated by piledriving activities. For example, Dominion Energy is limiting the length of time pile drivers are continuously operating to an hour and a half as it builds out 176 turbines off the coast of Virginia.[83] Dominion is also using what is know as a "soft-start" wherein piling power builds gradually to disperse mobile wildlife in the area before subsea noise could injure animals. Lastly, Dominion is employing curtains of high-pressure air near piling locations, creating a "wall" of bubbles that absorbs piling sounds and prevents them from propagating. Before a project even begins construction, companies undertake surveys to identify potential habitat impacts and devise plans to avoid them. In northern California, RWE is surveying the site of its forthcoming Canopy floating wind turbine project using an autonomous underwater vehicle (AUV) to collect biological data on the local habitats within the site, which they will then use to minimize local ecosystem disturbances.[84]

The benefits

1. Identifying potential wildlife impacts during project siting will help your company develop mitigation strategies and integrate them into the project's design. Proactive mitigation helps avoid instances where an operational project's unidentified wildlife impacts require costly remedial action and result in regulatory fines if, for example, a threatened or endangered animal is affected.
2. Ensuring that renewable energy installations are wildlife-friendly from the start will make it more likely that the project will be smoothly approved by environmental regulators, saving both time and money.
3. Designing renewable energy installations to minimize wildlife impacts reduces the risk that the project will face reputation-testing stakeholder controversies over direct fauna effects like wind turbine bird collisions and indirect effects like habitat disconnection.
4. Planting native landscapes alongside renewable energy installations will support local biodiversity and ecosystem services like pollination that might otherwise be diminished by the construction of uniform solar panels and wind turbines.
5. Accounting for wildlife impacts can help your company meet its nature protection goals and generate the information it needs to report in line with the rapidly emerging world of voluntary and mandatory nature-related disclosure.

Maximizing impact in the face of environmental conundrums

Renewable energy's environmental benefits are its most important selling point over traditional fossil fuels. From producing essentially zero GHG emissions when generating electricity to air and water quality advantages, these benefits are central factors driving corporate adoption of solar and wind energy technologies. However, renewables are not without environmental downsides, whether they be the air and GHG emissions associated with their raw material sourcing and manufacture, the waste associated with their decommissioning, or their potential land and wildlife impacts.

This environmental conundrum complicates corporate renewable energy transitions but does not by any means make them infeasible. As we show with the four steps outlined here, solutions to address this conundrum exist and companies are already implementing them in their own renewable energy journeys.

Moreover, rather than just minimizing environmental effects, these solutions present opportunities for companies to quite literally build benefit and ensure that renewable energy is a win-win for the environment. The path is there, companies just need to take it.

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