STUDY

Global Carbon Restructuring Plan

How to decarbonize the 1,000 most CO_2-intensive assets

Roland Berger

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The likelihood of complying with the Paris Agreement and limiting global warming to 1.5°C currently stands at just 14%.[1] Only a quantum leap forward in global sustainability efforts can significantly improve these odds and put the world on track for a more sustainable future.

To do this, we must identify and implement the most impactful solutions as quickly as possible. By decarbonizing the 1,000 assets that emit the most CO_2, our research shows we can reduce global carbon emissions by 8.2 gigatons (Gt). This is a third of the 24 Gt reduction in CO_2 required by 2030 if we are to maintain our slim hopes of hitting the 1.5°C target. The 1,000 assets are a powerful source of momentum.

So what are these assets? Unsurprisingly, coal-fired power plants dominate, contributing 76% of CO_2 emissions among our 1,000 assets. Iron and steel plants are the second-biggest contributor (18%). More than half the 1,000 assets are in China, with India home to 13% and the United States 10%. Crucially, ownership of the 1,000 assets is concentrated among 406 companies. Indeed, just 40 companies own assets that produce half the 8.2 Gt of CO_2 emissions. Decisive action from a small number of businesses could drastically improve climate protection.

Our Global Carbon Restructuring Plan (GCRP) outlines how to achieve this significant impact by targeting the 1,000 most CO_2-intensive assets. It outlines four potential solutions for decarbonization: renewable energy, gas, nuclear, and carbon capture and storage (CCS). We calculate that each approach will cost between USD 7.5 trillion (renewables) and USD 10.5 trillion (nuclear and CCS) over the course of 26 years (2025-2050). This equates to less than 20% of the world's annual military or R&D spending.

Cost is not the only key factor to consider. Asset owners need decarbonization solutions to deliver a sufficient and secure supply of energy as well as profitability: renewables, nuclear, and gas all fit the bill. But CCS requires a more widely implemented CO_2 pricing scheme with sufficient price levels before it can be profitable.

Our study also analyzes the financeability of decarbonization solutions. On a global level, the owners of the top 1,000 assets have enough headroom to fund gas and CCS investment costs, but not renewables or nuclear. Some regions are more strongly positioned than others, with China and India facing serious financial challenges across all four solutions.

According to our calculations, renewable energy sources are currently the most suitable solution for assets in the power sector. They can fully eliminate CO_2 emissions at the lowest total cost and are readily financeable by existing headroom across most regions.

The message is clear: Deployment of renewable energy must be accelerated across all assets in all regions. This should be complemented by a regional emphasis on the next best local solution.

Achieving the required quantum leap in sustainability will not be easy; there are still many technological and financial hurdles. Overcoming these requires a new form of collaboration between regions, governments, companies, and financiers. We believe collectively embracing the steps outlined in this Global Carbon Restructuring Plan represents a significant move in the right direction. The journey to decarbonization may be long and daunting, but, asset by asset, we can generate momentum to change the energy system, realize impact that matters – and create a legacy that endures.

1 Emissions Gap Report 2023

Contents

Cover Patrizio Martorana/Getty Images

It's time to close the emissions gap

1/

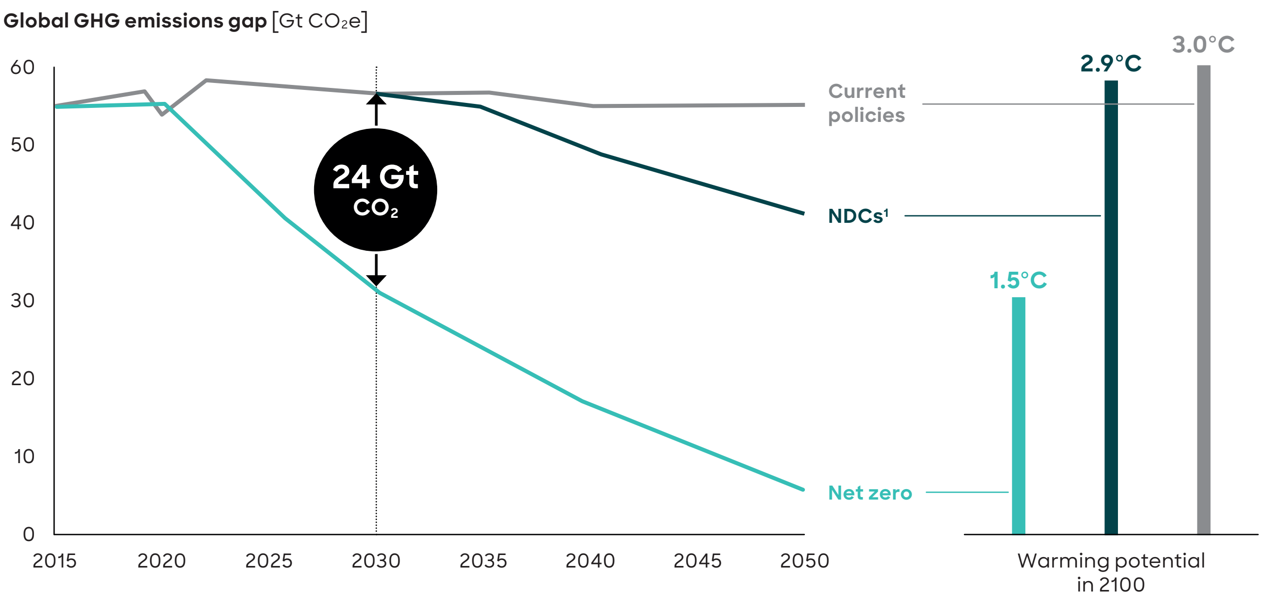
At the heart of the complex topic of climate change is a comparatively simple question: Can we limit global warming to 1.5°C as outlined in the Paris Agreement? Based on current trajectories, the answer is a resounding "No." According to the UN's Emissions Gap Report 2023, there is just a 14% chance of hitting this target considering the policies in place today. Pledges and incremental changes will not be enough to sufficiently improve these odds. Only a quantum leap forward in our decarbonization efforts can put the world on the right track for a more sustainable future. ▶ A

To make this leap, we must first identify the most impactful actions so both public and private sectors can channel their efforts and resources as effectively as possible. Addressing the most carbon-intensive assets – from coal-fueled power plants to iron and steel factories, among others – is a logical place to start.

According to our research, decarbonizing the 1,000 assets that emit the most CO_2 can reduce carbon emissions by 8.2 Gt. To be on track to limit global warming to 1.5°C, the world must eliminate 24 Gt of CO_2 emissions by 2030. This means reaching a third of this goal could be achieved by decarbonizing a very small group of assets – an extremely powerful lever to combat climate change.

A Mind the gap

Potential global warming under different scenarios



1 Unconditional Nationally Determined Contributions (NDCs) are displayed

Source: Emissions Gap Report 2023, Global Carbon Project, IPCC, National Oceanic and Atmospheric Administration, Roland Berger

The 1,000 most CO_2-intensive assets

2/

The 1,000 assets form the basis of our Global Carbon Restructuring Plan (GCRP), which contributes a fresh viewpoint to the decarbonization discussion. By looking at the world's largest individual carbon emitters, the GCRP includes the most powerful international levers to accelerate global decarbonization. And by laying out an asset-specific restructuring plan, it considers the owners' perspective on how to modify or replace these assets.

Before exploring the solutions and costs behind decarbonization, we must first look more closely at the assets themselves, which cover a range of industries across the globe.

In this study, we define an asset as a single-point emitter – one power plant, for instance, or one iron and steel plant. A large industrial complex may therefore comprise numerous individual plants, or assets, which belong to different owners. Asset owners may have multiple assets in their portfolio. Our study breaks down the top 1,000 assets by sector and region as well as analyzing the ownership structure of each asset.

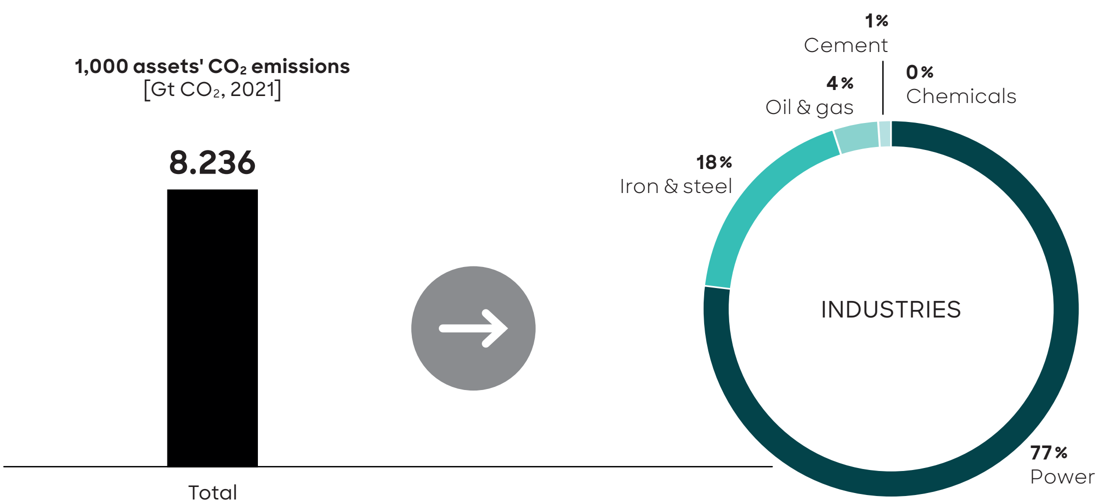
2.1 THE 1,000 ASSETS BY SECTOR

Unsurprisingly, power-related facilities dominate our 1,000-asset list, emphasizing the importance of moving away from fossil fuels. The power industry contributes 77% of the total CO_2 emissions produced by the 1,000 assets. Almost all these emissions come from coal-based power plants, which emit approximately 0.9 tons of CO_2 per megawatt hour (MWh) – twice as much as gas-fueled power plants.

Among the non-power sectors, iron and steel contributes 18% of CO_2 emissions, while oil and gas makes up 3.5%, cement assets contribute 1%, and chemical assets 0.2%. ▶B

B Industry breakdown

1,000 most CO_2-intensive assets by industry



Source: Roland Berger

2.2 THE 1,000 ASSETS BY REGION

From a geographic perspective, Asia dominates our 1,000 assets. China is home to 54% of them, followed by a group of countries defined as "Rest of the world" (RoW) with 20%, which includes Japan, South Korea, China Taiwan, Indonesia, and Australia, among others. India hosts 13% of the 1,000 assets. In the global West, the United States accounts for 10% of emissions and Europe for 3%, which includes the EU countries plus the United Kingdom (6% of Europe's emissions). ▶ C

2.3 THE 1,000 ASSETS BY OWNER

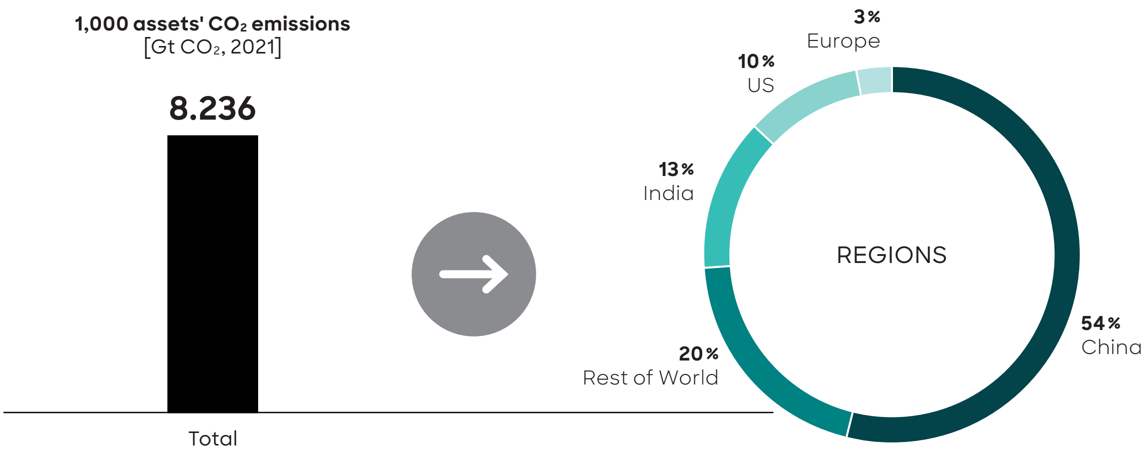
The ownership of major carbon emitters is concentrated among a relatively small number of companies: 406 firms own the 1,000 assets on our list. Dig a little deeper and this becomes even more apparent: of these, just 40 companies are responsible for assets that produce 4.1 Gt of CO_2. In other words, 40 companies "own" half the emissions addressed in this study, or 11% of the world's fossil-based CO_2 emissions (38 Gt fossil-fuel based CO_2 emissions worldwide in 2021).[2] Almost half these 40 companies are based in China (48%), with a quarter coming under RoW. The United States, India, and Europe each account for just under 10%.

Strengthening the decarbonization efforts of a mere 40 companies, then, could reduce global CO_2 emissions by 4.1 Gt of the 24 Gt needed by 2030 to restrict warming to 1.5°C. Expanding the scope, it's worth mentioning that 160 companies have the opportunity to start decarbonizing 80% of the carbon emissions analyzed here. This further emphasizes the concentration of ownership among emission-heavy assets. ▶ D

2 EDGAR - Emissions Database for Global Atmospheric Research, 2021

C Regional breakdown

1,000 most CO_2-intensive assets by region

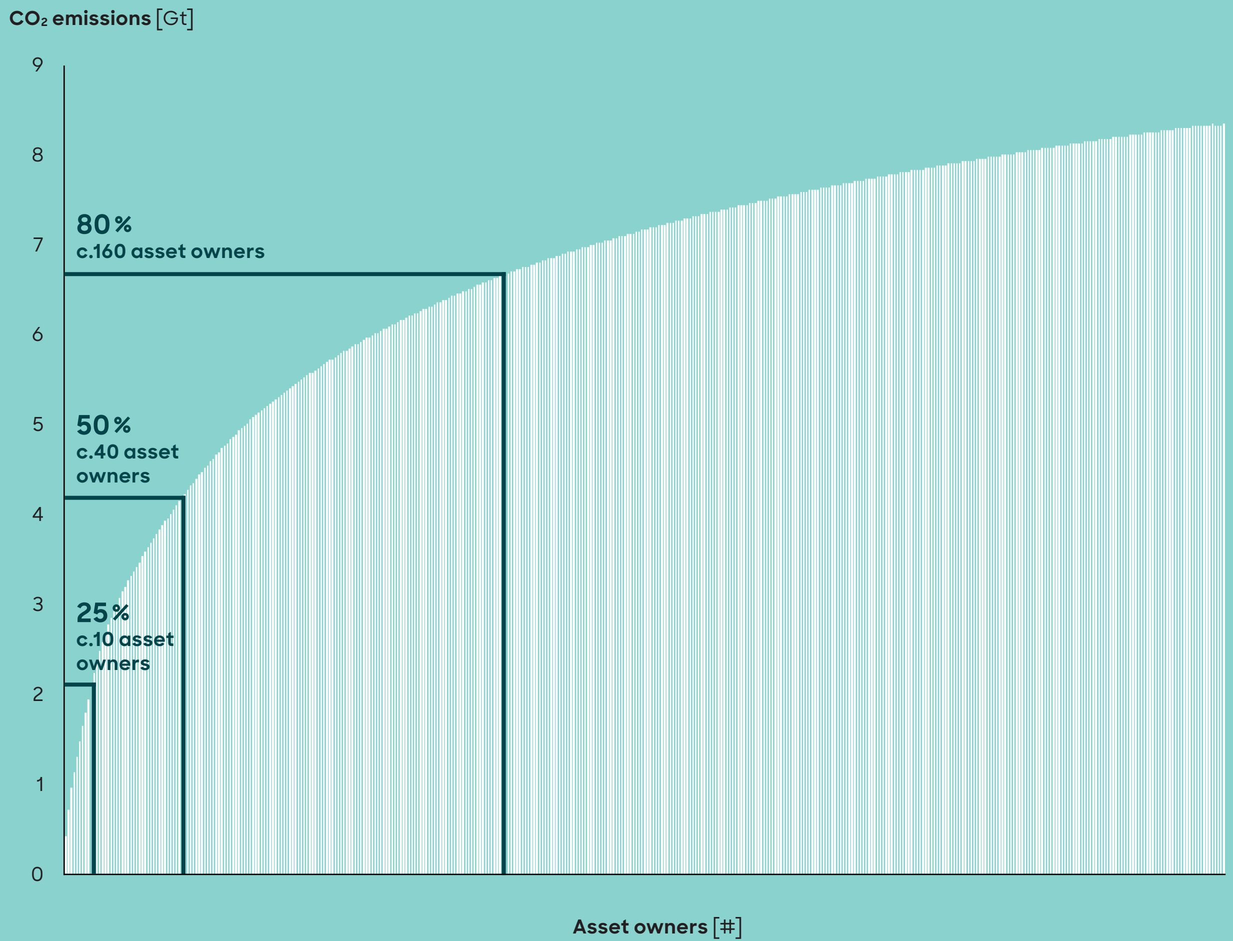


Source: Roland Berger

D Concentrated asset ownership

Just 40 companies can decarbonize 11 % of worldwide fossil-fuel based CO_2 emissions

1,000 assets' CO_2 emissions at consolidated asset owner level
[Gt CO_2]



50 % of emissions are derived from 40 parent companies, thereof **48 % Chinese**, 25 % from RoW and c.10 % each from the US, India, and Europe – Strengthening their decarbonization efforts can reduce global CO_2 emissions by about 11 %, particularly in China and India.

About **400 companies hold all of the assets analyzed** – however, **only 160 asset owners together account for c.80 % of all emissions**, revealing a high degree of concentration between ownership and high CO_2 intensities and/or number of assets owned.

Source: Roland Berger

Putting a price on decarbonization of the 1,000 assets

3/

The path to sustainability requires serious infrastructural changes and major investment. Our Global Carbon Restructuring Plan (GCRP) lays out the potential decarbonization costs for the owners of the top 1,000 assets.

The GCRP includes costs for four different solutions: renewable energy sources (RES), gas, nuclear, and carbon capture and storage (CCS). The result is tailored decarbonization pathways on an individual asset level.

3.1 FOUR SOLUTIONS FOR DECARBONIZATION

Not all solutions can be applied to each sector. While our restructuring plan covers all four solutions for assets in the power sector, it only covers CCS for non-power assets – for now. There are, of course, further solutions such as (green) hydrogen with serious decarbonization potential in key industries, but these are not covered in this iteration of the study. So what does each solution comprise?

- **Renewable energy sources** covers the replacement of electricity generated from fossil fuel sources with electricity from photovoltaics as well as onshore and offshore wind. The ratio of each specific energy source will vary depending on an asset's location. In certain cases, RES was excluded as a viable solution due to geographic characteristics (Hong Kong and Singapore, for instance, have a lack of land).

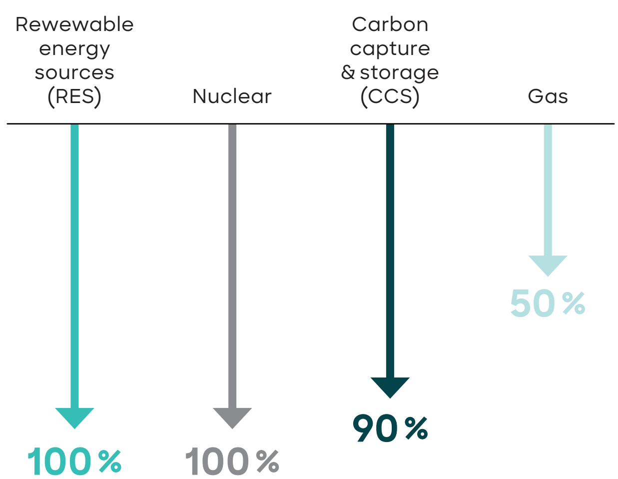
- **Gas** can be used to replace power generation from non-renewables like coal or oil. For greenfield power plants, retrofitting for green hydrogen and/or biogas at a later stage is now included in the planning and should be easier to implement compared to retrofitting older, gas-fired power plants.

- **Nuclear power** plants can provide assets with clean power, however the solution can only be applied in countries that have not announced a nuclear phase-out. For this report, we also included a minimum asset size of 700 MW for nuclear to be considered a viable alternative option – acknowledging the momentum but current lack of market placement for small modular reactors (SMR).

- **Carbon capture and storage** could theoretically be retrofitted to all asset types. Carbon transportation and storage costs are included as a global average cost component.

Some solutions are more effective than others. Both RES and nuclear can cut CO_2 emissions by 100%, while CCS has the potential to reduce emissions by an average of 90%, depending on where it is used. Gas is best used as an interim solution as it can only reduce carbon emissions by 50%. ▶E

E Comparing solutions
Effectiveness of decarbonization options
[average CO_2 reduction in %]



Source: Roland Berger

One of the GCRP's key assumptions is the like-for-like exchange of power generation capabilities. This approach ensures security of supply for all energy assets and corresponding decarbonization solutions for power generation, whether RES, nuclear, or gas.

For this, we consider both the utilization of the current solution(s) and the efficiency of the replacement(s). After establishing the full load hours of a specific asset, we can calculate how to replace it with an equivalent amount of energy derived from the full load hours of a RES, nuclear, or gas solution.

To calculate the cost of decarbonization, we then work out what it would cost to replace existing assets with newly built, cleaner assets or add CCS to existing assets. Our model calculates all costs associated with the building and running of these new assets for 26 years, between 2025 and 2050.

It is crucial to note that the GCRP looks at decarbonization from an asset-owner perspective. As a result, our calculations are based on the following formula:

At USD 7.5 trillion, renewables are, by some distance, the cheapest decarbonization solution for the 1,000 assets. Almost 40% more expensive than RES is gas at USD 10.3 trillion. The most expensive solutions are nuclear and CCS, which each cost USD 10.5 trillion. All of these costs include USD 2.2 trillion each to cover CCS for non-power assets. ▶ F

The chief drivers of these costs are CapEx, OpEx, and fuel costs, although the extent varies across each of the four solutions. Production and installation costs for RES are high, meaning CapEx makes up 70% of total costs. On the flip side, operation and maintenance costs are low, while fuel costs nothing. For CCS, OpEx makes up 64-71% of the total (lower for non-power assets), largely due to the cost of transport and storage. For gas, fuel costs make up almost two thirds of the total (63%). The cost allocation for nuclear is a little more evenly spread, with CapEx totaling 45% and OpEx 28%. Uranium fuel costs contribute 24%. ▶ G

Cost of decarbonization = [CAPEX + OPEX + Fuel costs] + Asset write-offs + Cost of residual CO_2 abatement

For more detail on these calculations, please refer to the methodology section.

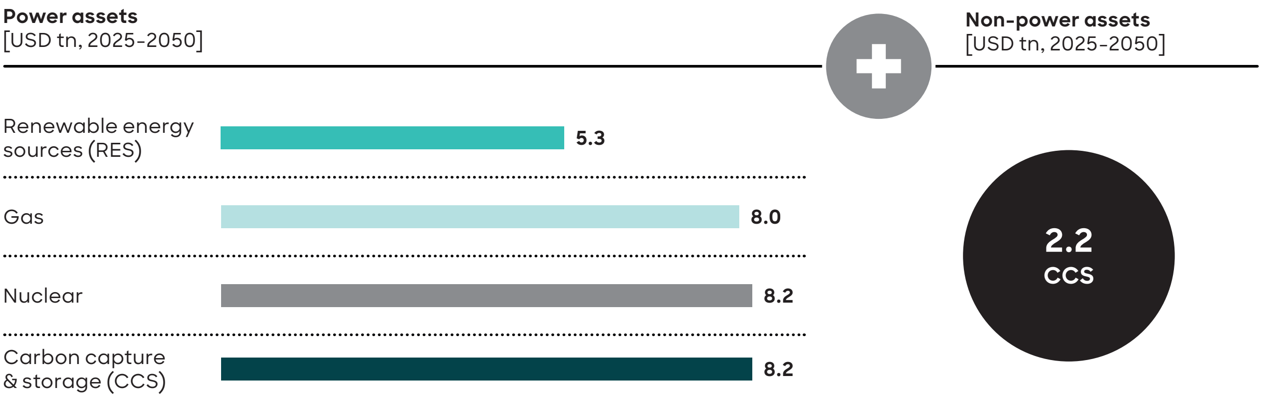
3.2 THE COST OF DECARBONIZATION

There's no escaping the importance of the bottom line in sustainability, making a clear picture on cost essential. Depending on the solution chosen, it would cost between USD 7.5 trillion and USD 10.5 trillion to decarbonize the 1,000 most CO_2-intensive assets over a time frame of 26 years. This includes all costs associated with writing off an existing asset and building and running the alternative between 2025 and 2050.

"The GCRP aims to identify and pull the biggest levers first to create maximum momentum on global decarbonization efforts – across country borders and from an asset owner's perspective."

Martin Hoyer
Senior Partner

F The bottom line
Costs for decarbonization solutions



Source: Roland Berger

The costs of asset write-offs and CO_2 abatement are less significant. Around 40% of power assets are yet to reach the end of a typical 20-year depreciation period. Most of these are in China (65%), followed by India (22%) and RoW (10%). As a result, asset write-off costs amount to 2-4% of global costs of decarbonization in these three regions. CO_2 abatement mostly applies to the gas solution, which only reduces CO_2 emissions to an average of 50%. Costs for residual CO_2 amount to about 15% of total costs.

Varying prices for aspects like raw materials and labor mean cost allocations vary by region. While CO_2 abatement for gas accounts for 56% of total costs in Europe, it only makes up 9-16% in China, India, and RoW, and 22% for the US. Varying gas prices have a similar effect on fuel costs, with the lowest prices currently in the US.

For nuclear, CapEx is lowest in China, India, and RoW due to the lower cost of nuclear material and labor. Less stringent regulations on nuclear power generation are also a factor.

3.3 HOW ACHIEVABLE IS THE COST OF DECARBONIZATION?

Having established an approximate budget of USD 10 trillion to decarbonize the 1,000 assets, we need to add some context: What does this really mean? Is this financially viable?

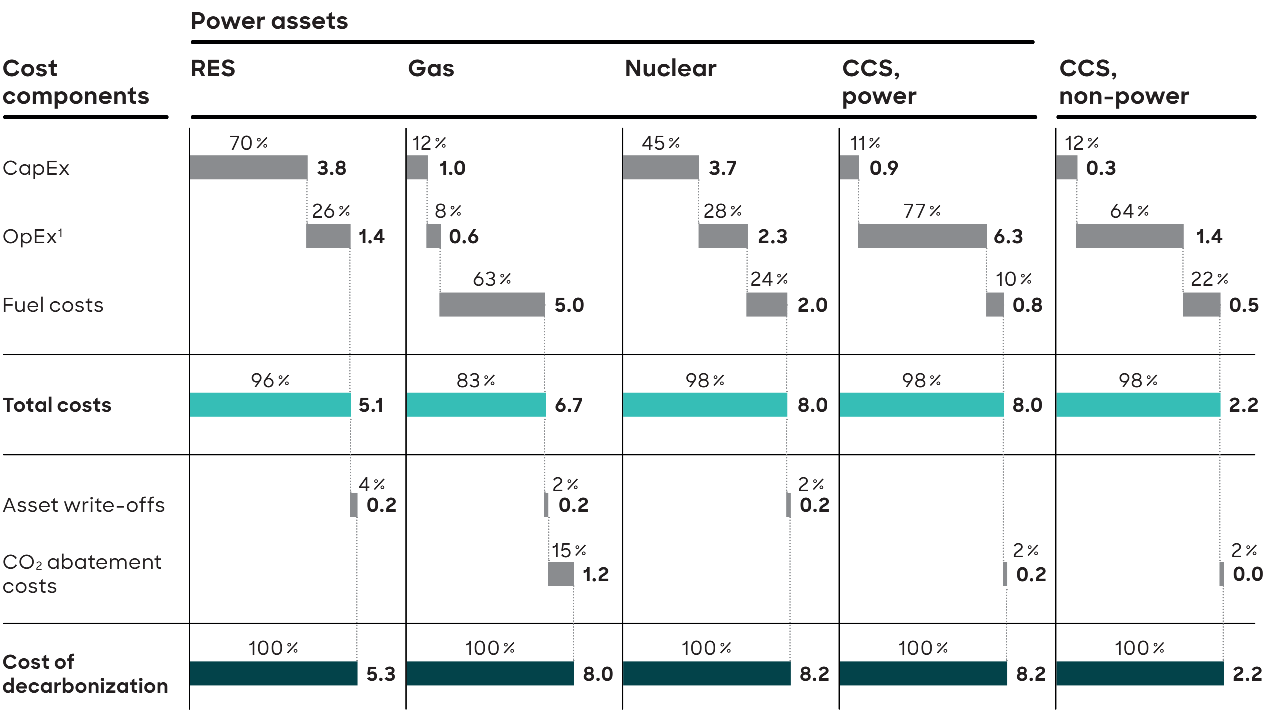
Spread across a 26-year timeframe, decarbonizing the 1,000 assets would cost USD 0.3-0.4 trillion each year. For comparison, this is less than 20% of what was spent on military equipment (USD 2.1 trillion), R&D (USD 2.3 trillion), or even Covid relief (also USD 2.1 trillion) in 2021. Compared to current spending on climate change mitigation (USD 1.3 trillion), the percentage rises to 30-40%.

In short, the cost required to close one third of the current emissions gap is eminently feasible.

G Where the money goes

Detailed analysis of costs per solution

Breakdown of cost components per decarbonization solution, 2025-2050 [%, USD tn]



1 Incl. OpEx of solution and, in the case of CCS, additional OpEx for the existing asset

Source: Roland Berger

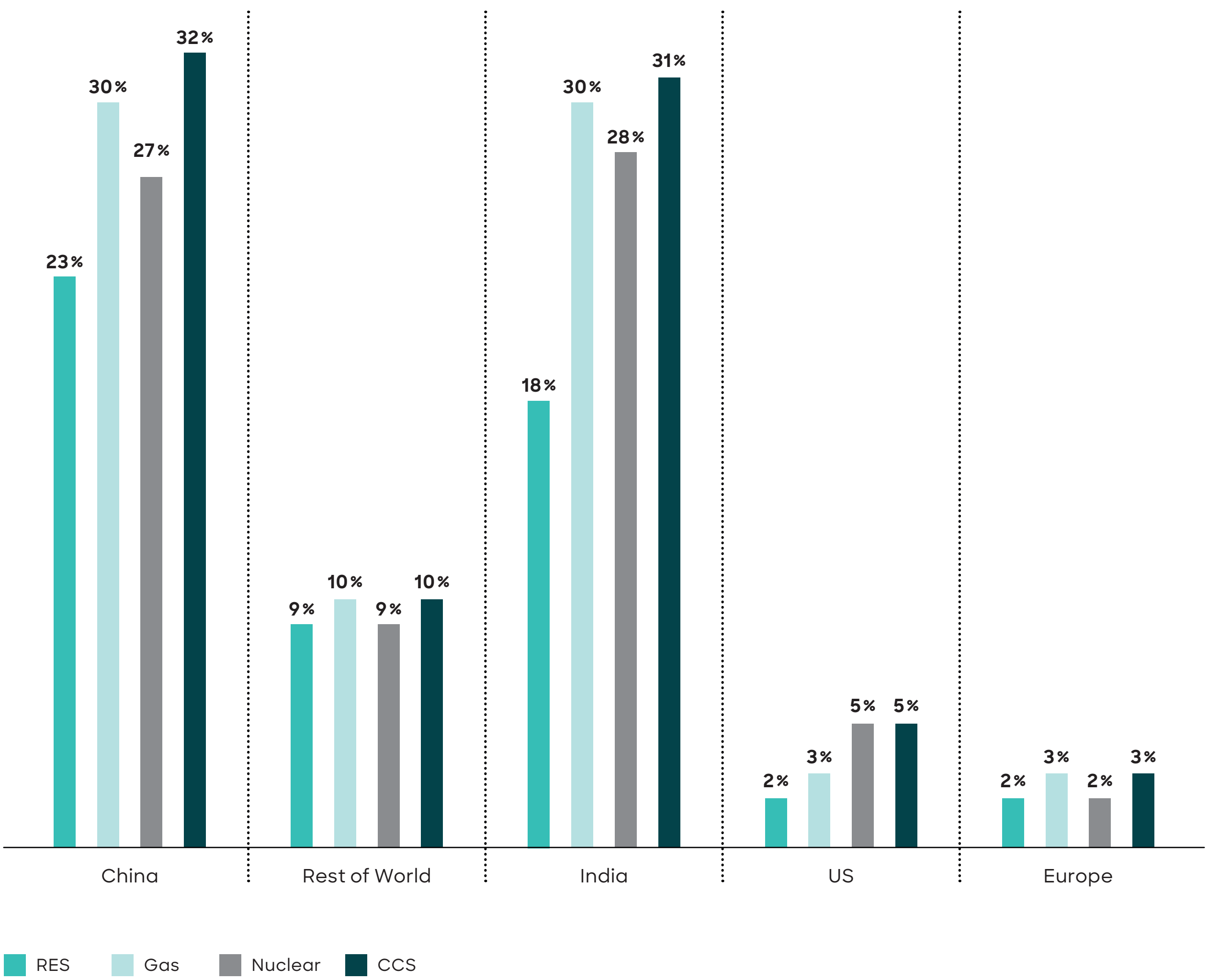
At a national and regional level, however, the picture does alter somewhat. Decarbonization will cost China and India comparatively more than Western areas such as the US and Europe. Taken as one-off expenses, decarbonizing the top 1,000 assets will cost China 23-32% of its GDP and will cost 18-31% of GDP in India. For the RoW cluster, it comes to 9-10%, but for Europe and the United States, it works out at just 2-5% of their respective GDPs.

Certain solutions will be more competitive in some areas than others. Low prices make gas a more viable option in the US than elsewhere, for instance. Overall, however, renewables are the most financially competitive solution in each region. ▶ H

H Geography matters

Regional decarbonization costs per solution

Costs of decarbonization per region as a one-off, 2025-2050 [% share of GDP]



Source: Roland Berger

Assessing the way forward

4/

4.1 WHERE IS PROGRESS ALREADY BEING MADE?

The drive for change inevitably comes from a variety of sources, both internal and external. In the best and most economically sound case, current asset owners will push change for their own assets. The good news is that around 20% of asset owners have already started to decarbonize at least one of their assets included in this study. A similar percentage of owners have also begun implementing decommissioning plans for their assets in our top 1,000 list. Companies in regions with the most ambitious decarbonization plans lead the way here, highlighting the importance of regulatory pressure.

The commitment to change varies by sector and some areas still have considerable room for improvement. Just 11% of the power assets identified in this study are already covered by decarbonization plans. Europe shows the most progress here, with half of its analyzed power assets having plans in place. It is followed by RoW (35%) and the US (29%). There are five decarbonization plans in place for China-based assets, while Indian assets currently have none.

Among non-power assets, iron and steel companies are making most progress: 82% of their European assets have decarbonization plans in place. In the United States and RoW, oil and gas companies display a high level of availability of decarbonization plans, closely followed by the iron and steel industry.

More than a third (39%) of the assets with decarbonization plans have also already established decommissioning plans. In total, 143 of the 1,000 assets have lined up decommissioning programs. The vast majority of these (88%) are for power assets due to plans to phase out coal in numerous countries. Non-power assets are more likely to modernize or switch to renewables or hydrogen.

While decarbonization is likely to be on the radar of every asset owner, these results show there is still plenty of work to do in terms of implementing concrete action plans. To accelerate this process, it is important to understand more about the decisions facing each asset owner when considering decarbonization.

4.2 KEY CRITERIA FOR SELECTING DECARBONIZATION SOLUTIONS

We believe asset owners look at three distinct aspects when deciding on the most applicable decarbonization pathway for their assets.

- **Security of energy supply:** Reliable and stable energy generation to match demand and grid requirements.
- **Profitability:** Economic viability of the decarbonization solution(s) that pays off for asset owners and stakeholders.
- **Financeability:** Affordable and financeable decarbonization pathways for companies, communities, and countries.

As mentioned previously, ensuring security of energy supply is a fundamental principle of the GCRP. Consequently, we'll only look at profitability and financeability in more depth here.

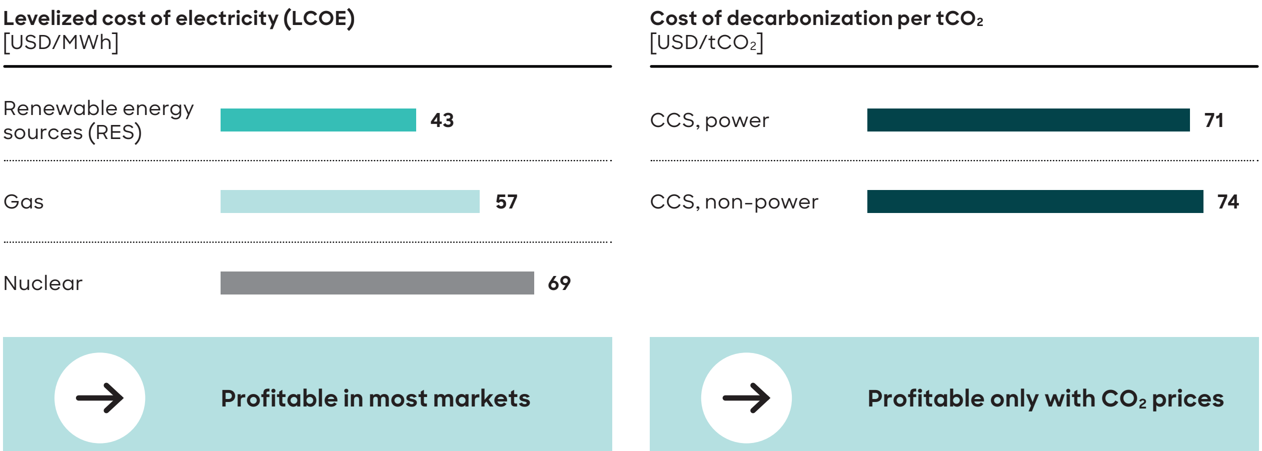
Profitability of the solutions

For the three power-segment solutions, we use the proven concept of levelized cost of electricity (LCOE), differentiated by country, which gives the average net cost of electricity over an asset's lifetime. On a global level, renewables produce the lowest LCOE at USD 43 per MWh, followed by gas (USD 57 per MWh), and nuclear (USD 69 per MWh). ▶I

Based on these figures, each energy solution should be profitable in most markets, depending on regional power prices. Renewables offer particularly low costs across all regions, while nuclear can provide enhanced profitability when electricity prices for the baseload contribution are high. Gas may find challenges to its profitability depending on fluctuating gas prices compared to coal, as well as local variables like regulations.

To assess the profitability of CCS, we use the cost of decarbonization per ton of CO_2 (tCO_2). For power assets, this is USD 71 per tCO_2; for non-power assets, the cost is

Mixed results
Profitability of decarbonization options



Source: Roland Berger

slightly higher at USD 74 per tCO_2. Given these costs, CCS is not yet a viable, large-scale option under current CO_2 price schemes and levels.

Changing this requires an adequate, widely implemented CO_2 pricing scheme. Currently, only countries producing around a quarter of global CO_2 emissions have some sort of CO_2 tax or trading scheme in place. Expanding this will help make CCS profitable and support the development of further technologies that reduce emissions.

Financeability of the solutions

Having established the cost and profitability of the decarbonization solutions, we need to know if the current asset owners can provide enough initial investment to implement them.

We carried out a financial analysis of the 406 companies that own the 1,000 assets. Data was available for just over half the asset owners on a global level. To assess the financeability of the required investment costs, we used the metric of company headroom – the availability of additional debt before net debt ratio reaches an untenable level.

For more detail on these calculations, please refer to the methodology section.

Based on our analysis, the 406 asset owners currently have a headroom of USD 2.2 trillion. Almost half this lies with RoW companies, particularly those in the oil and gas sector. Chinese companies account for 21% of the available headroom and US firms 20%. Companies in Europe account for 9% of the headroom, with just 3% covered by Indian firms. Much like the asset ownership itself, there is also significant concentration: approximately 80% of the headroom lies with just 10 asset owners. ▶ J

The key question is: Is this USD 2.2 trillion headroom enough? Depending on the solution, yes. CCS requires USD 1.2 trillion worth of CapEx, while gas needs USD 1.3 trillion; both solutions could be covered, with money to spare for further investments.

RES and nuclear show a different picture. Each solution requires approximately USD 4 trillion in CapEx – almost twice the amount available in headroom. As a result, further financing of almost USD 2 trillion, either public and/or private, would be required. ▶ K

Financeability doesn't just vary depending on the solution: some regions are more strongly positioned than others in terms of available headroom. This adds an extra factor to consider when assessing which solution is best suited to which region and, thus, which asset.

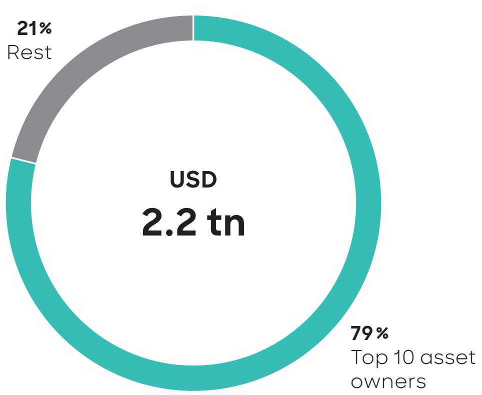
China and especially India face serious challenges across all four solutions. For Europe and the US, only going 100% nuclear would pose a financial obstacle. Companies in RoW could fully finance all four solutions. ▶ L

4.3 WHICH DECARBONIZATION PATHWAYS MAKE MOST SENSE?

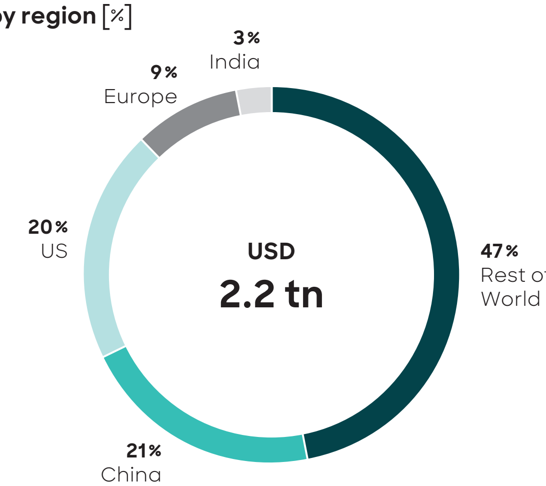
With the cost, viability, and effectiveness of each solution varying, there is no one-size-fits-all approach to decarbonization. That said, our findings clearly show that renewables are typically the most suitable solution for many assets in the power sector. They can fully eliminate CO_2 emissions at the lowest total cost, are generally profitable across all regions, and are readily financeable by existing headroom across most regions, except China and India.

J Can they afford it?
Financial headroom among asset owners

Headroom, 2019-2022 [USD tn]



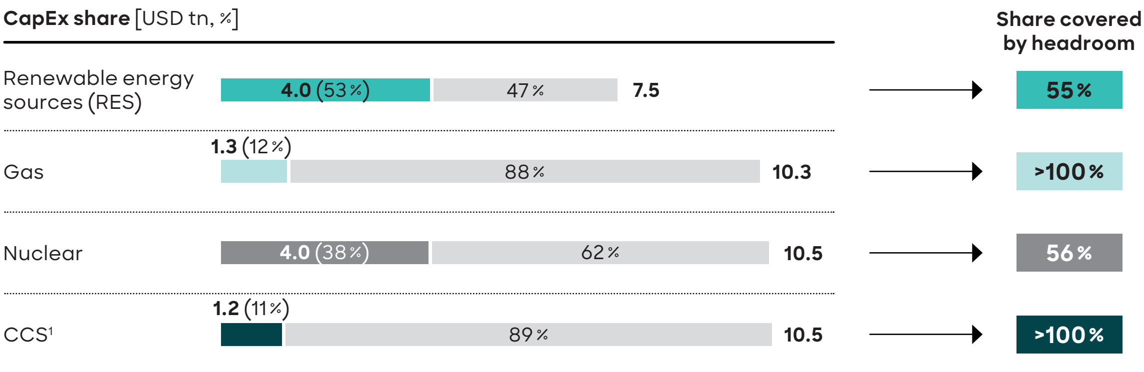
... by region [%]



Source: Roland Berger

K Further financing required?

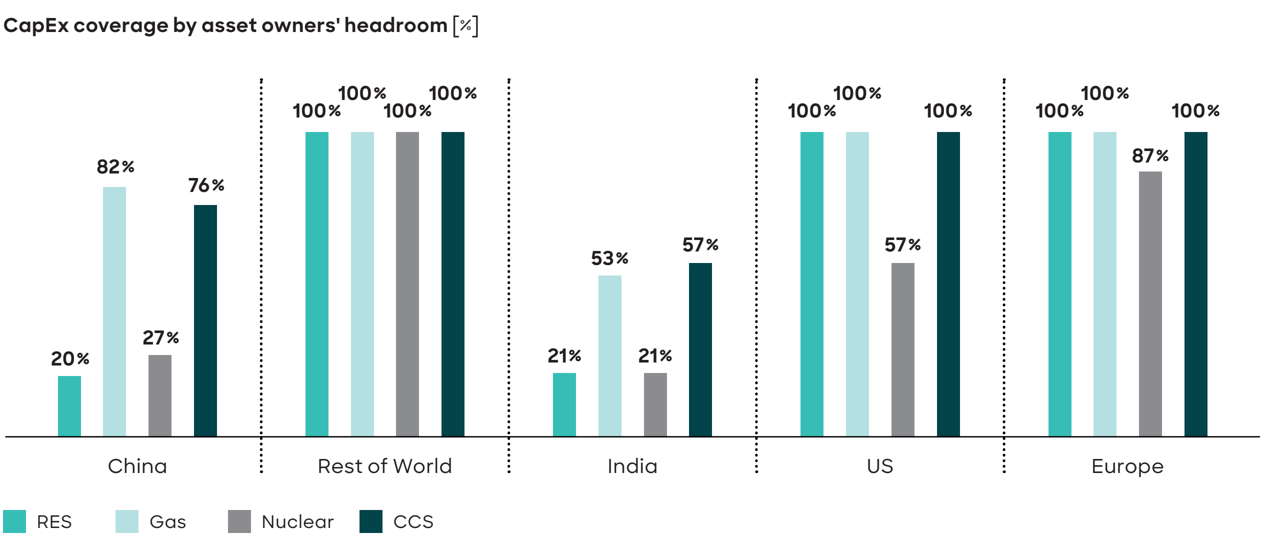
Financial headroom of asset owners vs. solution investment cost



1 Including carbon capture & storage for non-power assets

L Contrasting fortunes

Regional financeability per solution



Source: Roland Berger

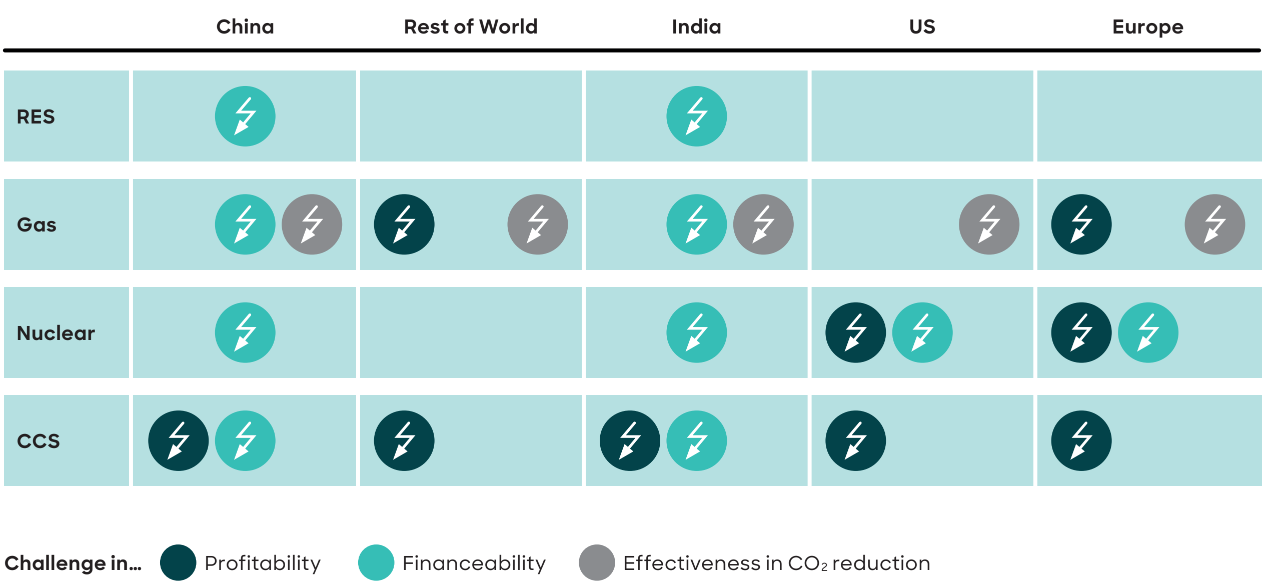
Each of the other three solutions faces multiple hurdles, with financeability in China and India an issue across the board. Gas only reduces CO_2 emissions by 50%, while high prices challenge its profitability in Europe. Nuclear would require additional financing in most regions except the RoW cluster. Meanwhile, CCS still faces major profitability hurdles in every region due to insufficient CO_2 pricing. ▶ M

The message is clear: As the most viable solution, deployment of RES should be accelerated across assets in all regions. At the same time, each region should play to its strengths by complementing this with the next best local solution.

- For **China and India**, this means employing CCS for their high proportion of young coal- and gas-fired power plants.
- In the **US**, switching from coal- to gas-fired power plants with CCS makes sense due to the low natural gas prices.
- **Europe** should strive for the deployment of CCS and (re-) consider nuclear as a zero-emission technology that can replace baseload energy supply.
- Like China and India, countries in the **RoW** cluster should focus on widespread incorporation of CCS for carbon-intensive assets.

M Why renewables lead the way

Summary of regional challenges per solution



Source: Roland Berger

What's next?

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We created the Global Carbon Restructuring Plan with something of a "Pareto's mindset" – to identify a small number of levers that could achieve major impact. Our analysis shows that, indeed, decarbonizing a selected number of the largest CO_2 emitters would make a significant contribution to addressing climate change. We believe that starting with these assets can kickstart momentum for fundamental change and accelerate the adaptation of our energy systems to meet future needs.

Decarbonizing the world's 1,000 most CO_2-intensive assets won't be easy. There are still numerous technological and financial hurdles to overcome. No individual actor can solve these challenges alone: we believe a new form of collaboration is crucial.

- **Regions and governments** must work together to implement regulations that support decarbonization such as CO_2 pricing schemes. They should also rethink asset allocation to provide a suitable distribution of resources with sufficient energy security where needed.
- **Companies** must cooperate more closely to transfer best practices, exchange on technology, and collaborate on R&D to create innovative new solutions.
- **Companies, financiers, and governments** need to make funding available, create the right financial instruments such as CapEx- or OpEx-oriented subsidies, and ensure investment security via credit guarantees, for instance. ▶N

Focusing these efforts on the 1,000 assets covered in this study could make a fundamental difference in limiting the negative effects of climate change. Restricting global warming to 1.5°C requires a 24 Gt reduction in CO_2 emissions by 2030 – decarbonizing the top 1,000 emitting assets would contribute a third of this.

As we stand at the intersection of economic growth and social responsibility, the path forward is clear: a transition toward decarbonized energy generation and zero-emission industrial production. The numbers speak loudly in favor of renewables, not just as a cost-effective solution but as the catalyst for transformative change. Our study shows that investing in decarbonizing the top 1,000 emitters is not merely an economic choice, but also a profound investment in a more sustainable world for generations to come.

There is power in collaboration beyond the borders of an individual company. Embarking on a transformation journey of any kind is no small feat; altering an entire business model is an incredible challenge. However, new collaboration models can help find the right solutions, partners, and financing to make it achievable.

Collectively, we can redefine our current trajectory. As businesses, governments, and as a society, we can embrace the Global Carbon Restructuring Plan as an opportunity to safeguard our environment and create a cleaner – and financially sound – future.

Recent events, such as the COP 28 pledge to transition away from fossil fuels, offer a clear invitation to action. The journey to decarbonization may be long and daunting, but, asset by asset, starting where the biggest impact lies, we can create maximum momentum, impact that matters – and a legacy that endures.

N Identified collaboration needs

Between regions and governments	→	CO_2 prices, asset allocation
Between companies	→	Best practices, technology transfers, R&D collaboration
Between companies/ financiers/governments	→	Funds, financial instruments, guarantees

Source: Roland Berger

Methodology

Explanation of key calculations and assumptions for the Global Carbon Restructuring Plan.

TIME HORIZON: 2025-2050
We chose to begin the time frame in 2025 to allow time for preparation. 2050 serves as the end date for net zero targets in both the EU and US as well as most global decarbonization strategies.

COST OF DECARBONIZATION
The total costs of decarbonization are calculated by adding CapEx (total fixed capital costs distributed across the assumed 26-year model duration), OpEx (variable operation and maintenance costs) and fuel costs (such as gas, uranium, etc.) to estimated asset write-off costs (for power assets younger than 20 years in the case of full replacement by RES, nuclear or gas) as well as estimated costs for residual CO_2 abatement for 2025-2050, primarily in the case of gas. The costs are adjusted for national inflation and discounted with the local interest rate to 2023 basis. CapEx is multiplied by a varying internal rate of return (IRR) according to the chosen solution to account for financing costs and then distributed equally across the model's timespan of 26 years. Other costs are implemented on a yearly basis. To calculate the USD price per ton of CO_2, we divide the total costs of decarbonization by the discounted annual CO_2 emissions accumulated over 26 years.

Cost of decarbonization = [**CAPEX** + **OPEX** + **Fuel costs**] + **Asset write-offs** + **Cost of residual CO_2 abatement**

INTEREST RATES
Cost components are discounted to 2023 basis by a regional interest rate that is based on the national 10-year government bond (from Oxford Economics).

FINANCING COSTS
To account for financing costs, the CapEx is multiplied by an internal rate of return (IRR) that varies depending on the chosen solution. The IRR is based on commonly referenced literature values: 5.0 % for RES, 8.0 % for gas, 12.0 % for nuclear, and 8.0 % for CCS.

INFLATION
Regional annual inflation rates are accounted for in all cost components. Figures are sourced from the International Monetary Fund (data available until 2028). An average of 2 % p.a. is incorporated beyond 2029.

GAS AND CO_2 PRICE FORECASTS

Figures are derived from the European Roland Berger forecast based on the enervis power price model (eMP), adjusted for an even price development. A similar gas price development is assumed for all regions except China, which remains unchanged up to 2030, before following a similar pattern to other regions. The gas price forecast uses market data from 2020 as a starting point to allow for comparability to typical values in published studies. For the CO_2 price forecast, weaker price increases are assumed for other regions compared to Europe: 50 % for China (on average) and India, 75 % for US and RoW.

LEARNING RATE

Based on a literature review of studies from the International Renewable Energy Agency and Fraunhofer Institute, a learning rate is applied to OpEx for RES, as scale effects in the coming years will enable reductions in operation and maintenance costs (including replacement costs). We assume the price decrease will be stronger in the near future due to the acceleration of RES deployment, before flattening after 2030 as technological and scaling milestones are reached. This means a decline of -3.2 % p.a. is assumed up to 2030 and -0.8 % p.a. beyond 2030.

ASSET WRITE-OFF

Depreciation is included for power assets, where the existing asset is replaced by a new plant (all solutions except for CCS). Linear depreciation over a period of 20 years is generally assumed for power assets (based on coal and gas plants, using US National Renewable Energy Laboratory data). With the solutions starting in 2025, plants with a commercial operation date after 2005 are affected (317 of 771 power assets, thereof 65 % in China). The resulting residual asset value in 2025 (20-1 year) is fully depreciated in 2025, assuming a conservative "maximum possible loss" approach.

COMPANY HEADROOM

Headroom is defined as the available additional indebtedness before the net debt ratio reaches an implausible level. The net debt ratio is further calculated by dividing net debt by EBITDA – a healthy, credible net debt ratio lies below 3.5. For a thorough analysis, the past four years, 2019 to 2022, are considered. From this, an average headroom is calculated over all four years to balance out the effects of individual years. S&P Capital IQ is used as the source for the financial data. On a regional level, companies in China and India had the lowest data availability; at a sector level, iron and steel firms published the least data.

Sources

All figures referenced and used as the basis for calculations in this report are from 2021.

Key CO_2 data was taken from the EU Emissions Trading Scheme for Europe, the Environmental Protection Agency for the US, and Climate Trace for China, India, and RoW.

Capacities for power assets were sourced from GEM Wiki. If available and reasonable, CO_2 data and energy generation for power assets were taken from these sources. In the case of low data availability or unreliable data, CO_2 emissions were calculated based on asset capacity and local assumptions on full load hours and CO_2 intensity.

Sources for assumptions and local variables include the International Energy Agency, International Renewable Energy Agency, National Renewable Energy Laboratory, and various other national and international institutes.

GLOBAL KEY EXPENDITURE FIGURES

- **Annual R&D spending:** According to the UNESCO Institute for Statistics and R&D WORLD
- **Covid relief spending:** Allowed amount of Federal Reserve Actions according to the Covid Money Tracker, annualized from 2020-2023 data
- **Annual military spending:** According to the Stockholm International Peace Research Institute
- **Annual climate finance:** Annual average for '21/'22 according to the Climate Policy Initiative

Credits

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FURTHER READING

- *THE ROARING '30S - A CLEAN HYDROGEN ACCELERATION STORY*
- *DECARBONIZING STEEL PRODUCTION - IT'S TIME FOR STEELMAKERS TO REDUCE EMISSIONS*
- *ACCELERATING DECARBONIZATION*

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