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Goldman Sachs | Research

Carbonomics

Five themes of progress for COP26

COP26, scheduled to be held in the UK between Oct 31 and Nov 12, is a historical opportunity to accelerate the de-carbonization pledges laid out by COP21 (the Paris Agreement) in 2015. In this report we analyse **five key themes of change** we believe can drive progress:

1) Carbon pricing: Carbon pricing is a key instrument for de-carbonization, but it also needs to be a fair instrument, prevent carbon leakage, and provide greater confidence and transparency for voluntary offsets.

2) Consumer choice: Governments could mandate carbon footprint disclosure on products/services and set the standards in a globally coordinated fashion, empowering consumers to choose low carbon goods and manage their carbon budgets.

3) Capital markets pressure: The rise of ESG is driving capital towards de-carbonization through a divergence in the cost of capital of high carbon vs low carbon investments, but needs better instruments to gauge temperature alignment of corporate strategies and more regulatory visibility to accelerate clean-tech investments. We show that regulatory uncertainty and lack of global coordination are generating structural underinvestment in key materials, oil & gas and heavy transport sectors, raising price inflation and affordability concerns.

4) Net Zero: National commitments to Net Zero and further cuts to carbon emissions by 2030 will be at the core of inter-governmental discussions. We model two paths to Net Zero Carbon by sector and technology, highlighting the importance of clean tech ecosystems including renewable power, batteries, hydrogen, carbon capture and the circular economy.

5) Technological innovation: We expect a cumulative US$56 tn of green infrastructure investments to meet Net Zero by 2050 in our GS 1.5° scenario, driving technological innovation throughout our Carbonomics cost curve.

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Executive Summary: Five key themes of de-carbonization for COP26

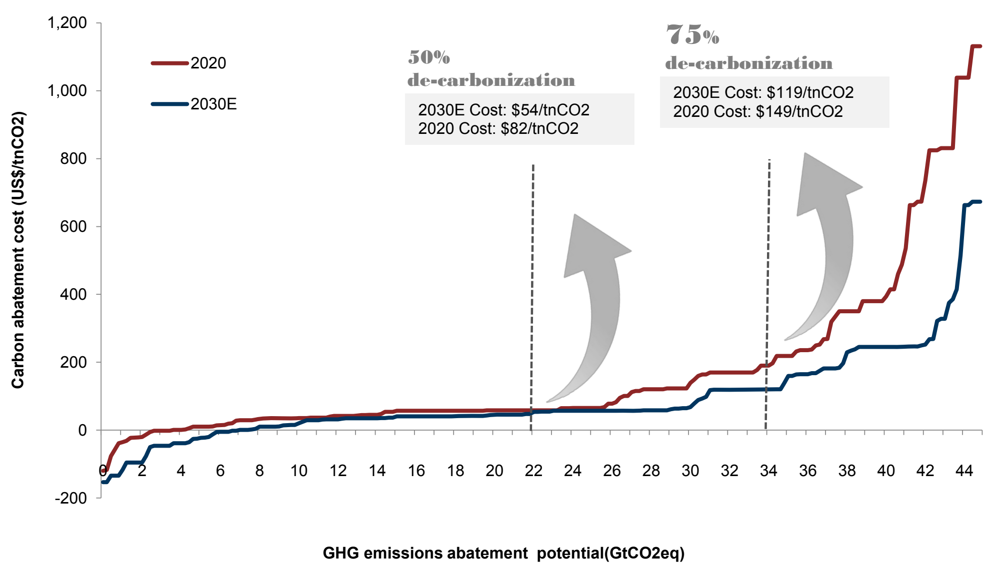
COP26, scheduled to be held in the UK between Oct 31 and Nov 12, is a historical opportunity to accelerate the de-carbonization pledges laid out by COP21 (the Paris agreement) in 2015. The negotiations are likely to focus on climate change-related topics, including ambitious emission reduction targets by country to keep 1.5 degrees of global warming within reach, a framework for global carbon markets including the implementation of Article 6 (Article 6 of the Paris Climate Agreement is designed to enable voluntary international co-operation on climate action. It presents the possibility of trading emissions reductions between countries and could provide the foundations for an international carbon market), climate finance with a focus on developed countries pledge to mobilize at least $100 bn in climate finance per year by 2020, and focus on collaboration, fairness and preparedness to adapt and protect communities and natural habitats. We do not aim to cover all of these topics in this report, but rather focus on five key themes of de-carbonization that we believe can drive material progress towards a Net Zero Carbon future, **mobilizing capital markets, consumer awareness, corporate investments and technological innovation to deliver affordable de-carbonization that fosters employment and economic growth.**

Carbon pricing: Carbon pricing is a key instrument for de-carbonization, but it also needs to be a fair instrument, prevent carbon leakage, and provide greater confidence and transparency for voluntary offsets.

The EU ETS is a powerful example of early adoption of carbon pricing, which has led to the largest reduction in carbon emissions of any major global economy over the past decade, covering c.40% of the EU's greenhouse gas emissions. Notably, China's introduction of a national carbon trading scheme this year raises the **% of global emissions covered by carbon schemes to >20% for the first time in history, providing strong momentum to carbon pricing,** even though the national schemes remain largely uncoordinated on a global basis and price levels differ dramatically. Our Carbonomics Cost curve, which we introduced in 2019, shows **that higher carbon prices will be needed to achieve Net Zero, with a required carbon price of $82/$149/$268/ton at the 50%/75%/90% percentile of the abatement cost curve today.** Technological innovation will however add a dynamic element to this cost curve and help to lower the cost of de-carbonization over time. Our expectations on cost deflation led by technological improvements and benefits of scale suggest that the required carbon price could fall to $54/$119/$245/ton at the 50%/75%/90% percentile of the abatement cost curve by 2030. Technology-specific incentives can go a long way to incentivize investments and technological developments (e.g. subsidies for solar panels, offshore wind or EVs), as we have seen across renewable power, electric mobility and bio-fuels over the past decade, with implied carbon pricing as high as $1,000/ton in some instances on our estimates. However, we believe that explicit carbon schemes (such as the EU ETS) can be a more efficient, technology agnostic instrument of de-carbonization and clean tech innovation. Carbon leakage and unfair competition can however be an issue in the absence of a globally coordinated carbon pricing, hence focus on a border adjustment to ensure a level playing field. Carbon offsets are also a powerful instrument for de-carbonization and the only global (although poorly regulated) carbon market at present. Carbon emissions abatement alone is highly unlikely, in our view, to achieve the Net Zero by 2050 ambition, and **we believe that carbon offsets are a crucial driver of carbon removal through nature Based Solutions and Direct Air Carbon Capture, contributing to around 15% to the de-carbonization of harder-to-abate sector emissions by 2050 as shown in the Exhibit 2.** We believe that discussions surrounding tighter standards, stronger supervision and better liquidity of global voluntary carbon credits could materially contribute to a cost-efficient path to Net Zero Carbon.

Exhibit 1: Our Carbonomics cost curve suggests c.$100-200/ton carbon prices may be needed to achieve Net Zero Carbon by 2030 ...

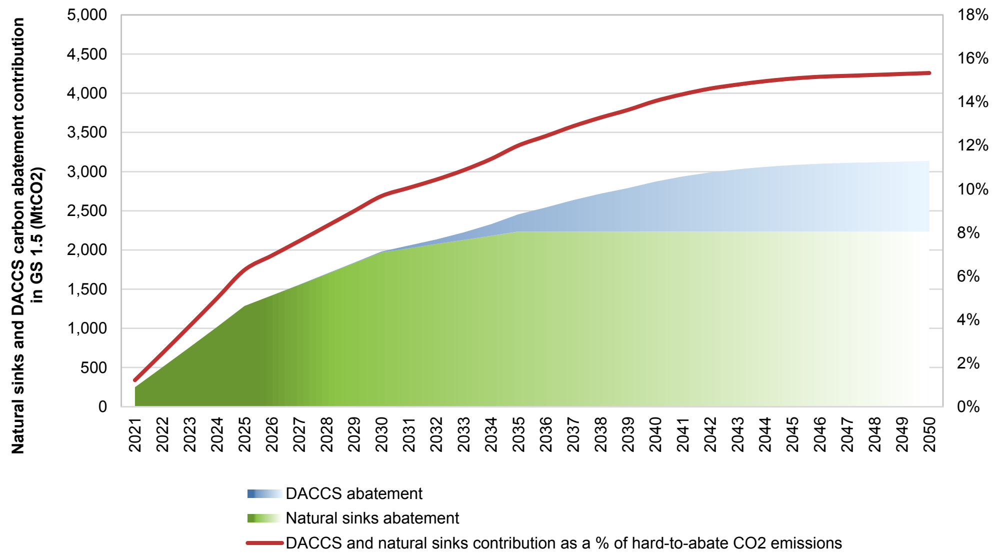
Carbon abatement cost curve for de-carbonization of anthropogenic GHG emissions, based on current technologies



Source: Goldman Sachs Global Investment Research

Exhibit 2: ...with a key role for carbon removal offsets that could account for c.15% of the de-carbonization of hard-to-abate sectors

Natural sinks and DACCS carbon abatement contribution in GS 1.5° scenario (MtCO2)

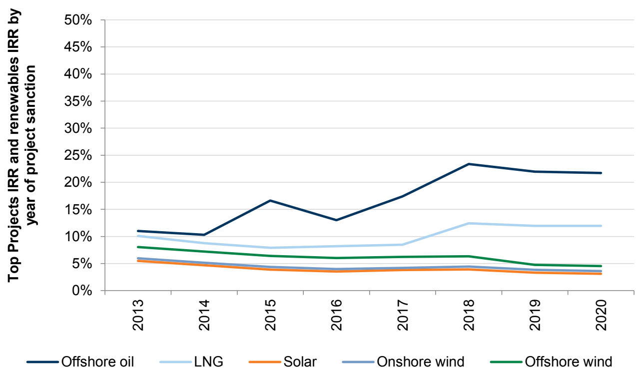


Source: Goldman Sachs Global Investment Research

Consumer choice: Governments could mandate carbon footprint disclosure on products and services, empowering consumers to choose low carbon goods and manage their carbon budgets informatively.

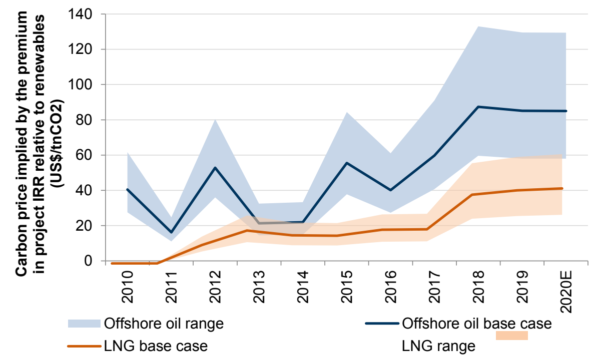
Today, global consumers have information available to them to understand the calorie and nutritional content on packaged food, however there is a lack of information disclosed with regard to the carbon footprint of products and services. We believe this is a missed opportunity to leverage consumer pressure on global companies to de-carbonize their value chain, finance carbon offsets and aim for a Net Zero carbon label. The disclosure of calories and nutrient content on packaged food has helped to increase awareness surrounding nutrition and health, and we believe the same could hold true with the disclosures of carbon emission labeling on purchased goods and services. Therefore, raising consumer awareness of their carbon footprint could put pressure on global companies to enhance their de-carbonization strategies, and further accelerate the path towards Net Zero. An example of an innovative carbon labeling scheme is Foundation Earth, a pilot scheme supported by the UK Government and food and beverage companies such as M&S and Nestlé, which aims to label a range of products with their carbon footprint as of Autumn 2021. In addition, Unilever has laid out plans to roll out carbon footprint labeling for a range of selected products in Europe and North America by the end of 2021.

Exhibit 3: Investor ESG pressure has led to a 10%+ WACC premium for carbon-intensive investments...
Top Projects IRR for oil & gas and renewable projects by year of project sanction



Source: Goldman Sachs Global Investment Research

Exhibit 4: ...translating into an implied carbon price of $80/ton for new oil developments
Carbon price implied by the IRR premium for offshore oil and LNG projects compared with renewables (US$/tn CO2)



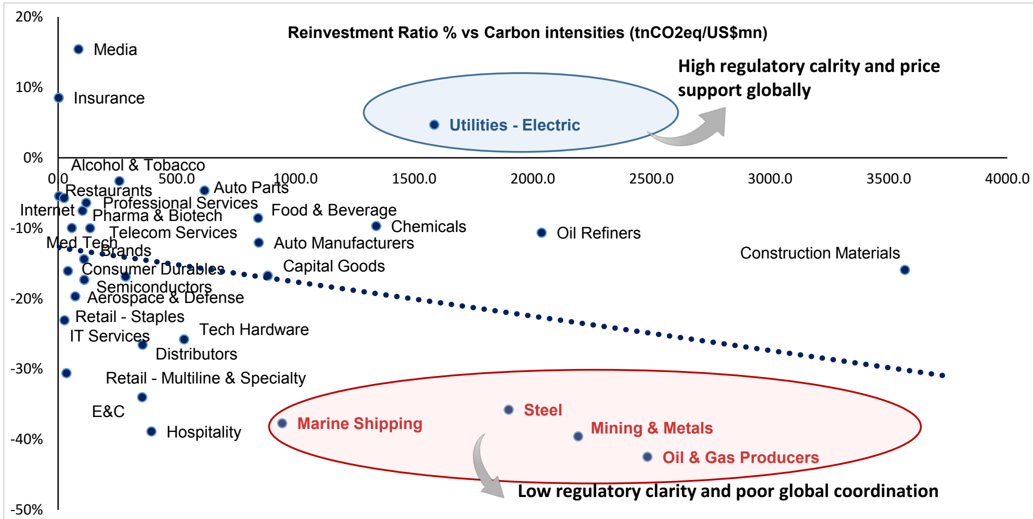
Source: Goldman Sachs Global Investment Research

Capital markets pressure: The rise of ESG is driving capital towards de-carbonization, but regulatory uncertainty and lack of global coordination are generating structural underinvestment in key materials, oil & gas and heavy transport sectors, raising price inflation and affordability concerns.

Capital markets pressure on de-carbonization has been on the rise in recent years. With the increase in global GHG emissions, investors have been driving the climate change debate by placing pressure on corporate management to incorporate climate change into their business plans and strategies. Today >$100 tn of global assets under management have signed up to UN PRI and are implementing ESG metrics as part of their investment process. This wave of "green" investments is driving capital towards de-carbonization technologies through a divergence in the cost of capital of high carbon vs. low carbon investments. Looking at the energy sector, we estimate that the spread in the cost of capital of hydrocarbon vs. renewable developments has widened by > ten percentage points over the last five years. This is equivalent, on our estimates, to a global carbon tax of $80/ton, and is driving a historical turning point in energy investment, with global renewable power spend overtaking oil & gas developments for the first time in history. Uncertainty around future carbon regulation and the lack of global coordination on carbon pricing are impacting investment in several sectors, mostly in energy, materials and heavy transport. On our estimates, there has been a decline in the re-investment ratio (10 year average vs. 2022E) of c.40% in Oil & Gas, Steel, Mining and Marine Shipping: global carbon intensive sectors which suffer from lack of clear policies around de-carbonization. In contrast, Electric Utilities is an example of a sector where clear de-carbonization incentives and strategies are actually leading to higher investment than in the past, as shown in Exhibit 5. We believe that the continued lack of coordination runs the risk of severe under-investment in core parts of the 'Old Carbon Economy' that could lead to supply tightness, as we already are starting to experience in parts of the materials, oil & gas and transport industries.

Exhibit 5: High cost of capital and regulatory uncertainty have led to a collapse in investment in carbon intensive sectors throughout energy, materials and heavy transport

Reinvestment Ratio % (2022E vs. 10 yr average) vs. Carbon intensities (Scope 1,2,3 emissions intensity per revenue (tnCO2eq/US$mn))



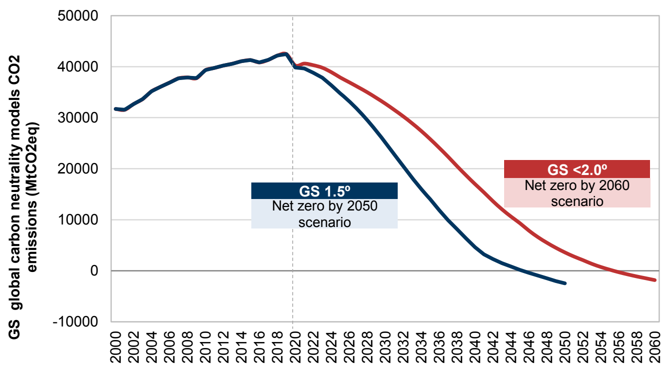
Source: Company data, Goldman Sachs Global Investment Research

Net Zero: National commitments to Net Zero and further cuts to carbon emissions by 2030 will be at the core of inter-governmental discussions. We have modeled two paths to Net Zero Carbon.

We have constructed two global carbon neutrality scenarios: one aspirational scenario consistent with 1.5°C and one consistent with <2.0°C global warming in order to better understand the challenges and opportunities emerging from the Paris Agreement. The first scenario reaches global net zero carbon by 2050, which would be consistent with limiting global warming to 1.5°C, with limited temperature overshoot (GS 1.5°). We also introduce a less aspirational, but also what we see as a likely more achievable global net zero model which is consistent with the Paris Agreement's aim to keep global warming well below 2°C (GS <2.0°) and which achieves global net zero around 2060. For our global net zero carbon scenarios we adopt a sectoral approach, leveraging our Carbonomics de-carbonization cost curve and allocating the available carbon budget across different emitting industries on the basis of cost positioning and technological readiness.

Exhibit 6: We have constructed two global carbon neutrality scenarios: one aspirational scenario consistent with 1.5°C and one consistent with <2.0°C global warming

GS Net Zero global models, CO2 emissions (incl. AFOLU)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research

Exhibit 7: Table summarizing our corporate carbon intensity pathways by industry for a global net zero by 2050 scenario (GS 1.5°)

Sector	Industry	Carbon intensity measure	Activity indicator	Scopes coverage	% Reduction in carbon intensity vs 2019 base						Carbon intensity value (stated units)						
					2025	2030	2035	2040	2045	2050	2019	2025	2030	2035	2040	2045	2050
Energy	Oil & Gas Integrated producers	gCO2/MJ	energy sold	Scope 1,2,3	-8%	-20%	-41%	-71%	-85%	-93%	70.2	64.8	56.1	41.3	20.3	10.2	5.1
	Oil refiners	gCO2/MJ	energy sold	Scope 1,2,3	-8%	-24%	-46%	-71%	-87%	-97%	74.8	68.5	57.0	40.2	22.0	9.9	2.4
	Gas producers	gCO2/MJ	energy sold	Scope 1,2,3	-6%	-13%	-32%	-73%	-83%	-83%	63.2	59.4	54.7	43.0	17.2	10.7	10.6
	Electric Utilities	kgCO2/MWh	energy produced	Scope 1,2	-38%	-71%	-92%	-99%	-100%	-100%	504.3	310.4	147.1	38.8	5.0	0.8	0.8
Transportation	Airlines	gCO2/pkm	fleet	Scope 1,2	-14%	-29%	-50%	-68%	-82%	-94%	110.4	95.3	78.2	55.1	35.1	20.0	6.8
	Aerospace & defence	gCO2/pkm	aircrafts sold	Scope 1,2,3	-13%	-29%	-50%	-68%	-82%	-94%	67.6	58.5	48.0	33.9	21.6	12.3	4.2
	Automotive manufacturers - LDV	gCO2/km	vehicles sold	Scope 1,2,3	-14%	-45%	-84%	-99%	-100%	-100%	175.6	151.5	96.1	28.4	1.7	0.3	0.3
	Automotive manufacturers - HDV	gCO2/km	vehicles sold	Scope 1,2,3	-9%	-30%	-76%	-98%	-99%	-99%	631.3	577.1	440.8	151.9	9.5	6.5	6.0
	Maritime Shipping	gCO2/tkm	fleet	Scope 1,2	-17%	-35%	-51%	-68%	-86%	-97%	6.9	5.7	4.5	3.4	2.2	1.0	0.2
	Logistics & Shipping	Index		Scope 1,2,3	-15%	-31%	-52%	-71%	-85%	-96%							
Basic materials	Copper	tnCO2/tn	tonnes refined	Scope 1,2	-30%	-58%	-78%	-88%	-93%	-96%	4.0	2.8	1.7	0.9	0.5	0.3	0.2
	Steel	tnCO2/tn	tonnes produced	Scope 1,2	-18%	-38%	-59%	-77%	-91%	-97%	1.81	1.49	1.12	0.74	0.42	0.17	0.05
	Cement (Construction materials)	tnCO2/tn	tonnes produced	Scope 1,2	-11%	-22%	-40%	-56%	-72%	-91%	0.62	0.55	0.49	0.38	0.27	0.17	0.05
	Aluminium (all)	tnCO2/tn	tonnes produced	Scope 1,2	-28%	-60%	-78%	-83%	-85%	-89%	10.1	7.2	4.0	2.2	1.8	1.5	1.2
	Aluminium primary	tnCO2/tn	tonnes produced	Scope 1,2	-29%	-59%	-77%	-80%	-82%	-83%	14.8	10.6	6.1	3.5	2.9	2.6	2.5
	Iron ore	tnCO2/tn	tonnes produced	Scope 1,2	-16%	-46%	-73%	-95%	-98%	-98%	0.0105	0.0089	0.0057	0.0028	0.0005	0.0002	0.0002
	Iron ore	tnCO2/tn	tonnes produced	Scope 1,2,3	-18%	-38%	-59%	-77%	-91%	-97%	1.21	1.00	0.75	0.49	0.28	0.11	0.03
	Coal mining	tnCO2/tn	tonnes produced	Scope 1,2	-18%	-40%	-56%	-72%	-84%	-90%	0.061	0.050	0.037	0.027	0.017	0.010	0.006
	Nickel	tnCO2/tn	tonnes produced	Scope 1,2	-26%	-52%	-71%	-83%	-90%	-94%	11.20	8.25	5.38	3.30	1.94	1.12	0.66
	Diversified metals & mining	Index		Scope 1,2	-24%	-52%	-71%	-82%	-88%	-92%							
	Diversified metals & mining	Index		Scope 3	-15%	-35%	-55%	-72%	-84%	-92%							
	Paper & packaging	tnCO2/tn	tonnes produced	Scope 1,2	-33%	-64%	-87%	-95%	-97%	-98%	0.8	0.5	0.3	0.1	0.0	0.0	0.0
Chemicals	Chemicals- ammonia	tnCO2/tn	tonnes produced	Scope 1	-7%	-21%	-44%	-63%	-79%	-94%	2.3	2.1	1.8	1.3	0.8	0.5	0.1
	Chemicals- methanol	tnCO2/tn	tonnes produced	Scope 1	-8%	-22%	-41%	-61%	-81%	-97%	2.1	1.9	1.6	1.2	0.8	0.4	0.1
	Chemicals- HVCs	tnCO2/tn	tonnes produced	Scope 1	-19%	-35%	-52%	-68%	-82%	-87%	0.98	0.80	0.63	0.48	0.32	0.18	0.13
	Diversified chemicals	Index		Scope 1,2	-27%	-50%	-68%	-80%	-89%	-92%							
	Diversified chemicals	Index		Scope 3	-13%	-32%	-49%	-67%	-81%	-89%							
Other	Real estate	tnCO2/m2	square meter	Scope 1,2	-33%	-59%	-82%	-95%	-99%	-100%	0.039	0.027	0.016	0.007	0.002	0.000	0.000
	Real estate	tnCO2/m2	square meter	Scope 1	-16%	-40%	-67%	-88%	-97%	-99%	0.015	0.012	0.009	0.005	0.002	0.000	0.000
	Semiconductors	Index		Scope 1,2	-30%	-62%	-86%	-98%	-99%	-99%							
	Hospitality	Index		Scope 1,2	-32%	-62%	-85%	-96%	-99%	-100%							
	Household & Personal Care	Index		Scope 1,2	-22%	-53%	-79%	-96%	-98%	-98%							
	Household & Personal Care	Index		Scope 3	-16%	-38%	-62%	-81%	-93%	-96%							
	Food & beverage	Index		Scope 1,2	-24%	-55%	-80%	-97%	-99%	-99%							
	Food & beverage	Index		Scope 3	-7%	-18%	-30%	-45%	-55%	-61%							
	Food retail	Index		Scope 1,2	-26%	-58%	-82%	-97%	-99%	-99%							
	Food retail	Index		Scope 3	-8%	-19%	-33%	-48%	-58%	-65%							
	Tobacco	Index		Scope 1,2	-25%	-56%	-81%	-97%	-99%	-99%							
	Tobacco	Index		Scope 3	-10%	-22%	-36%	-52%	-61%	-68%							
	Capital goods	Index		Scope 1,2	-25%	-56%	-81%	-96%	-98%	-99%							
	Capital goods	Index		Scope 3	-15%	-34%	-54%	-72%	-85%	-92%							

Source: Goldman Sachs Global Investment Research

Exhibit 8: Table summarizing our corporate carbon intensity pathways by industry for a global net zero by 2060 scenario (GS <2.0)

Sector	Industry	Carbon intensity measure	Activity indicator	Scopes coverage	% Reduction in carbon intensity vs 2019 base						Carbon intensity value (stated units)						
					2025	2030	2035	2040	2045	2050	2019	2025	2030	2035	2040	2045	2050
Energy	Oil & Gas Integrated producers	gCO2/MJ	energy sold	Scope 1,2,3	-7%	-14%	-25%	-40%	-58%	-75%	70.2	65.6	60.7	53.0	41.9	29.4	17.8
	Oil refiners	gCO2/MJ	energy sold	Scope 1,2,3	-6%	-15%	-29%	-48%	-68%	-83%	74.8	70.1	63.9	53.1	38.9	24.2	12.9
	Gas producers	gCO2/MJ	energy sold	Scope 1,2,3	-6%	-11%	-16%	-28%	-43%	-59%	63.2	59.4	56.4	52.8	45.4	36.3	25.8
	Electric Utilities	kgCO2/MWh	energy produced	Scope 1,2	-26%	-44%	-63%	-79%	-89%	-96%	504.3	370.7	280.2	186.7	103.6	53.6	21.4
Transportation	Airlines	gCO2/pkm	fleet	Scope 1,2	-11%	-23%	-37%	-53%	-64%	-74%	110.4	98.2	85.1	70.0	51.7	39.4	28.5
	Aerospace & defence	gCO2/pkm	aircrafts sold	Scope 1,2,3	-11%	-23%	-36%	-53%	-64%	-74%	67.6	60.2	52.3	43.0	31.8	24.2	17.5
	Automotive manufacturers - LDV	gCO2/km	vehicles sold	Scope 1,2,3	-11%	-29%	-55%	-76%	-88%	-96%	175.6	156.5	124.3	78.9	42.2	20.4	7.3
	Automotive manufacturers - HDV	gCO2/km	vehicles sold	Scope 1,2,3	-8%	-18%	-36%	-68%	-94%	-97%	631.3	580.8	516.1	406.1	202.0	36.1	17.5
	Maritime Shipping	gCO2/tkm	fleet	Scope 1,2	-15%	-31%	-46%	-60%	-79%	-89%	6.9	5.8	4.8	3.7	2.7	1.5	0.8
	Logistics & Shipping	Index		Scope 1,2,3	-13%	-26%	-42%	-58%	-71%	-81%							
Basic materials	Copper	tnCO2/tn	tonnes refined	Scope 1,2	-22%	-40%	-58%	-75%	-86%	-93%	4.0	3.1	2.4	1.7	1.0	0.5	0.3
	Steel	tnCO2/tn	tonnes produced	Scope 1,2	-11%	-24%	-42%	-59%	-72%	-85%	1.81	1.61	1.37	1.04	0.74	0.50	0.27
	Cement (Construction materials)	tnCO2/tn	tonnes produced	Scope 1,2	-10%	-19%	-27%	-42%	-57%	-73%	0.62	0.56	0.51	0.45	0.36	0.27	0.17
	Aluminium (all)	tnCO2/tn	tonnes produced	Scope 1,2	-22%	-41%	-58%	-72%	-80%	-85%	10.1	7.9	6.0	4.2	2.8	2.0	1.5
	Aluminium primary	tnCO2/tn	tonnes produced	Scope 1,2	-22%	-40%	-57%	-71%	-78%	-82%	14.8	11.5	8.9	6.4	4.4	3.2	2.6
	Iron ore	tnCO2/tn	tonnes produced	Scope 1,2	-7%	-17%	-40%	-61%	-78%	-88%	0.0105	0.0098	0.0087	0.0063	0.0041	0.0023	0.0012
	Iron ore	tnCO2/tn	tonnes produced	Scope 1,2,3	-11%	-24%	-42%	-59%	-72%	-85%	1.21	1.08	0.92	0.70	0.50	0.33	0.18
	Coal mining	tnCO2/tn	tonnes produced	Scope 1,2	-16%	-34%	-50%	-68%	-81%	-89%	0.061	0.051	0.040	0.030	0.020	0.011	0.006
	Nickel	tnCO2/tn	tonnes produced	Scope 1,2	-20%	-38%	-55%	-73%	-85%	-92%	11.20	8.95	6.92	5.01	3.08	1.73	0.90
	Diversified metals & mining	Index		Scope 1,2	-18%	-36%	-54%	-70%	-82%	-89%							
	Diversified metals & mining	Index		Scope 3	-9%	-22%	-38%	-54%	-67%	-79%							
	Paper & packaging	tnCO2/tn	tonnes produced	Scope 1,2	-22%	-39%	-58%	-75%	-86%	-93%	0.8	0.6	0.5	0.3	0.2	0.1	0.1
Chemicals	Chemicals- ammonia	tnCO2/tn	tonnes produced	Scope 1	-3%	-9%	-22%	-40%	-53%	-64%	2.3	2.2	2.1	1.8	1.4	1.1	0.8
	Chemicals- methanol	tnCO2/tn	tonnes produced	Scope 1	-7%	-16%	-28%	-42%	-58%	-74%	2.1	1.9	1.8	1.5	1.2	0.9	0.5
	Chemicals- HVCs	tnCO2/tn	tonnes produced	Scope 1	-11%	-23%	-35%	-47%	-60%	-71%	0.98	0.87	0.75	0.63	0.51	0.39	0.29
	Diversified chemicals	Index		Scope 1,2	-17%	-32%	-46%	-60%	-72%	-81%							
	Diversified chemicals	Index		Scope 3	-13%	-31%	-47%	-65%	-80%	-89%							
Other	Real estate	tnCO2/m2	square meter	Scope 1,2	-26%	-44%	-60%	-77%	-89%	-96%	0.039	0.029	0.022	0.016	0.009	0.004	0.001
	Real estate	tnCO2/m2	square meter	Scope 1	-15%	-33%	-54%	-75%	-92%	-98%	0.015	0.013	0.010	0.007	0.004	0.001	0.000
	Semiconductors	Index		Scope 1,2	-19%	-35%	-55%	-73%	-86%	-93%							
	Hospitality	Index		Scope 1,2	-24%	-42%	-61%	-79%	-90%	-96%							
	Household & Personal Care	Index		Scope 1,2	-12%	-25%	-47%	-66%	-82%	-90%							
	Household & Personal Care	Index		Scope 3	-14%	-30%	-48%	-67%	-83%	-91%							
	Food & beverage	Index		Scope 1,2	-14%	-27%	-48%	-67%	-82%	-91%							
	Food & beverage	Index		Scope 3	-6%	-13%	-24%	-37%	-49%	-57%							
	Food retail	Index		Scope 1,2	-16%	-30%	-51%	-70%	-84%	-92%							
	Food retail	Index		Scope 3	-5%	-12%	-23%	-36%	-49%	-59%							
	Tobacco	Index		Scope 1,2	-15%	-28%	-50%	-69%	-83%	-91%							
	Tobacco	Index		Scope 3	-9%	-17%	-29%	-41%	-53%	-62%							
	Capital goods	Index		Scope 1,2	-15%	-29%	-51%	-69%	-83%	-92%							
	Capital goods	Index		Scope 3	-9%	-21%	-37%	-53%	-68%	-80%							

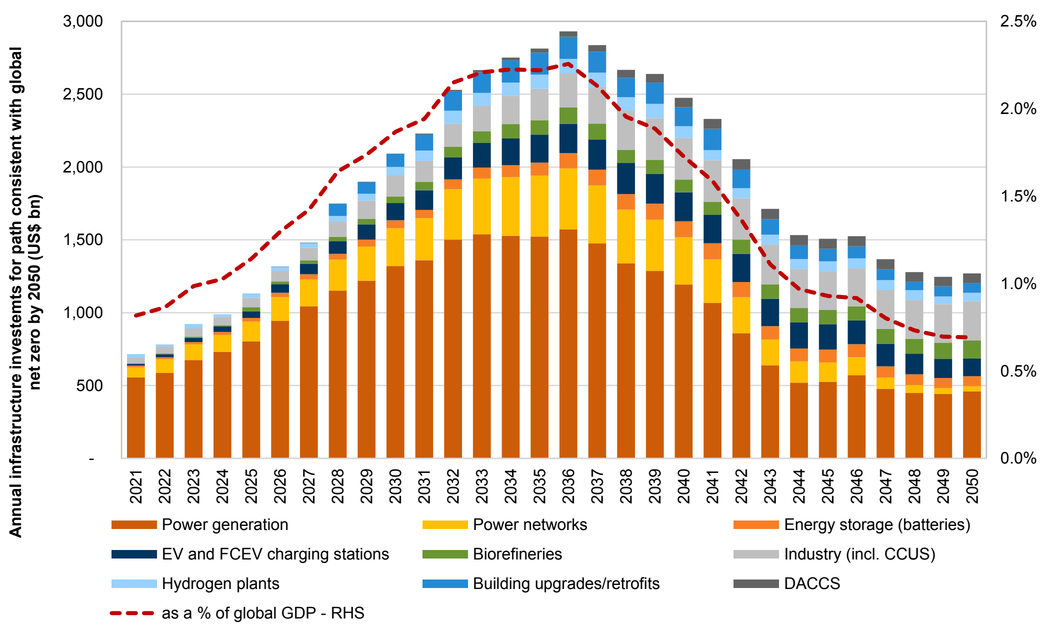
Source: Goldman Sachs Global Investment Research

Technological innovation: We expect a cumulative US$56 tn of green infrastructure investments to meet Net Zero by 2050 in a 1.5°C path, driving technological innovation throughout our Carbonomics cost curve.

In aggregate, we estimate a total investment opportunity in clean tech infrastructure of US$56 tn by 2050 in the GS 1.5° path. This figure focuses solely on incremental infrastructure investments and does not include maintenance and other end-use capex. Overall, the average annual investments in de-carbonization that we estimate over 2021-50 are c.US$1.9 tn, with the peak in the 2036 (US$2.9 tn) representing 2.3% of global GDP (vs. US$1.6 tn pa with a peak of US$2.5 tn in 2041 in the GS <2.0° scenario). We estimate that c.50% of de-carbonization is reliant on access to clean power generation, including electrification of transport and various industrial processes, electricity used for heating and more. Overall, we expect total demand for power generation in a global net zero scenario by 2050 to increase three-fold (vs. 2019) and surpass 70,000 TWh as the de-carbonization process unfolds. Based on our GS 1.5° model, power generation almost entirely de-carbonizes by 2040 (2055 under the GS <2.0° scenario). We estimate a total investment opportunity in clean tech infrastructure of US$56 tn by 2050 in the GS 1.5° path, representing c.2.3% of global GDP at peak.

Exhibit 9: We expect up to $3 tn pa in infrastructure investments will be needed to achieve Net Zero Carbon by 2050 in the more aspirational GS 1.5 path...

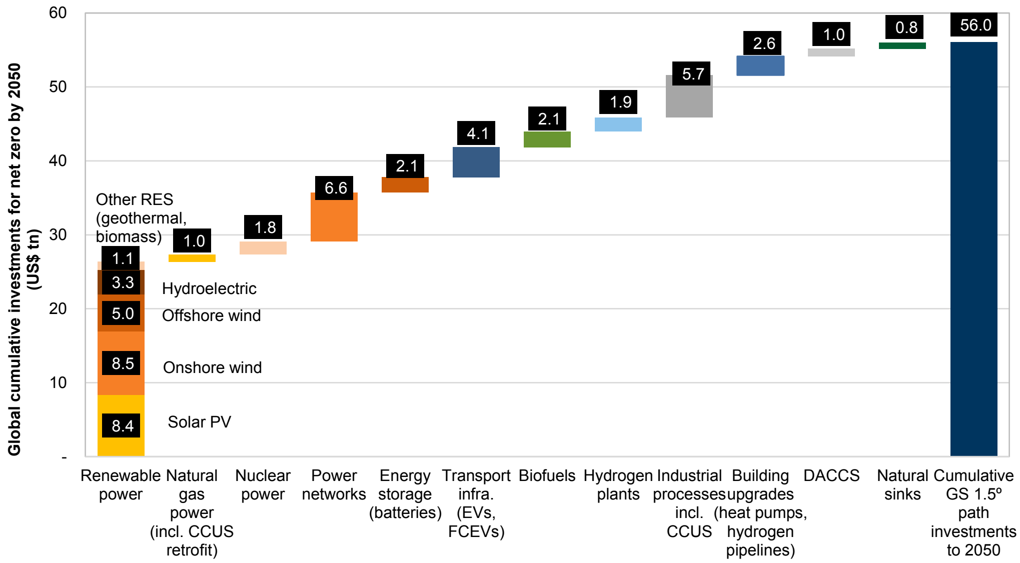
Annual infrastructure investments for GS 1.5 path to Net Zero by 2050 (US$ tn)



Source: Goldman Sachs Global Investment Research

Exhibit 10: ...as a complex ecosystem of renewable power, batteries, hydrogen, carbon capture and circular economy will be needed for Net Zero by 2050

Cumulative infrastructure investment opportunity for our GS 1.5° global net zero by 2050 model (US$ tn)



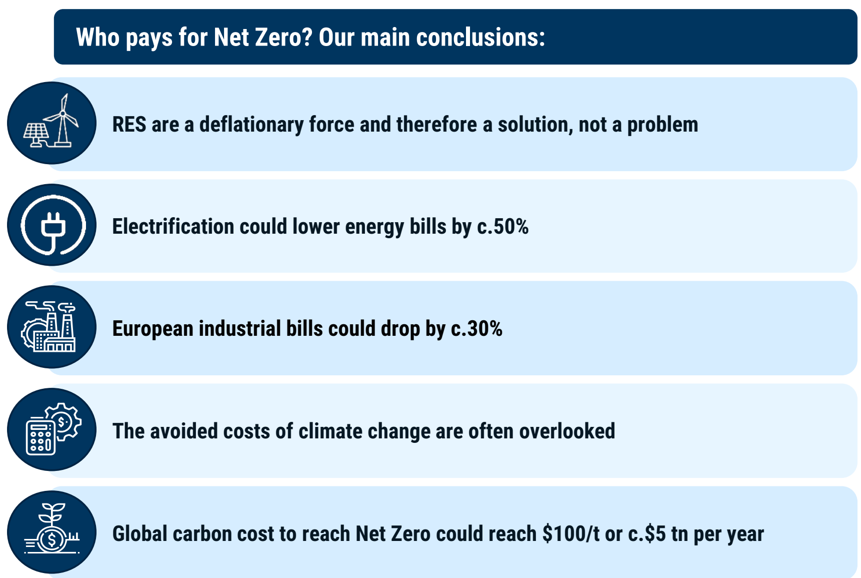
Source: Goldman Sachs Global Investment Research

Who pays for Net Zero: Our analysis shows that affordability is unlikely to derail the Net Zero journey due to five notable conclusions

As explained in a recent report (here), over the past 12 months gas prices have increased by c.450%, carbon prices have nearly quadrupled and – as a result – forward power prices have more than doubled. This has led to a c.35%-50% increase in end-user energy bills across Europe on our estimates. For a typical household, this would translate into c.€700 in incremental gas and power bills, on an annualized basis. During winter time, this could imply nearly €100 in additional costs per month in utility bills.

We analyze the costs to reach Net Zero plans (see here) and conclude that affordability is unlikely to derail the Net Zero journey. We reach five notable conclusions: (1) RES are a deflationary force to power systems and are therefore a solution, not a problem. (2) The electrification process would lower households' energy and fuel bills by c.50%, although the up-front costs would require state intervention. (3) European industrial bills could drop by c.30% and would become much more predictable. (4) The avoided costs of climate change – natural disasters of c.$250 bn pa and legacy investments in hydrocarbons of nearly $1 tn pa – are often overlooked. (5) Based on IMF data and GS estimates, the global carbon cost to reach Net Zero could reach $100/t or c.$5 tn per year.

Exhibit 11: Who pays for Net Zero? Our main conclusions



Source: Goldman Sachs Global Investment Research

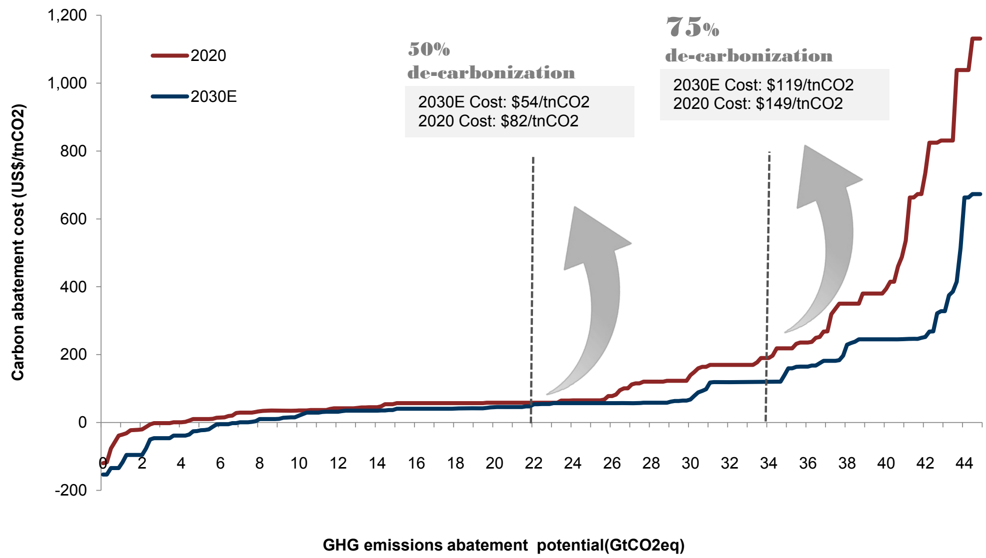
Carbon Pricing: A key driver of de-carbonization

The EU ETS, which operates in all EU countries as well as Iceland, Liechtenstein and Norway, is a powerful example of early adoption of carbon pricing, and has led to the largest reduction in carbon emissions of any major global economy over the past decade, covering c.40% of the EU's greenhouse gas emissions. Notably, China's introduction of a national carbon trading scheme this year raises the % of global emissions covered by carbon schemes to >20% for the first time in history, providing strong momentum to carbon pricing, even though the schemes remain largely uncoordinated on a global basis and price levels differ dramatically.

Our *Carbonomics Cost curve*, which we introduced in 2019, shows that higher carbon prices will be needed to achieve Net Zero, with a required carbon price of $82/$149/$268/ton at the 50%/75%/90% percentile of the abatement cost curve today. Technological innovation will however add a dynamic element to this cost curve and help to lower the cost of de-carbonization over time. Our expectations on cost deflation led by technological improvements and benefits of scale suggest that the required carbon price could fall to $54/$119/$245/ton at the 50%/75%/90% percentile of the abatement cost curve by 2030. This would be consistent with the material evolution of the cost curve that we have already witnessed since our initial assessment in 2019, and which has led to a 20%+ improvement in costs, resulting in a US$1 tn pa reduction in the global cost to reach 70% de-carbonization, highlighting the importance of ongoing clean tech innovation to achieve affordable Net Zero Carbon.

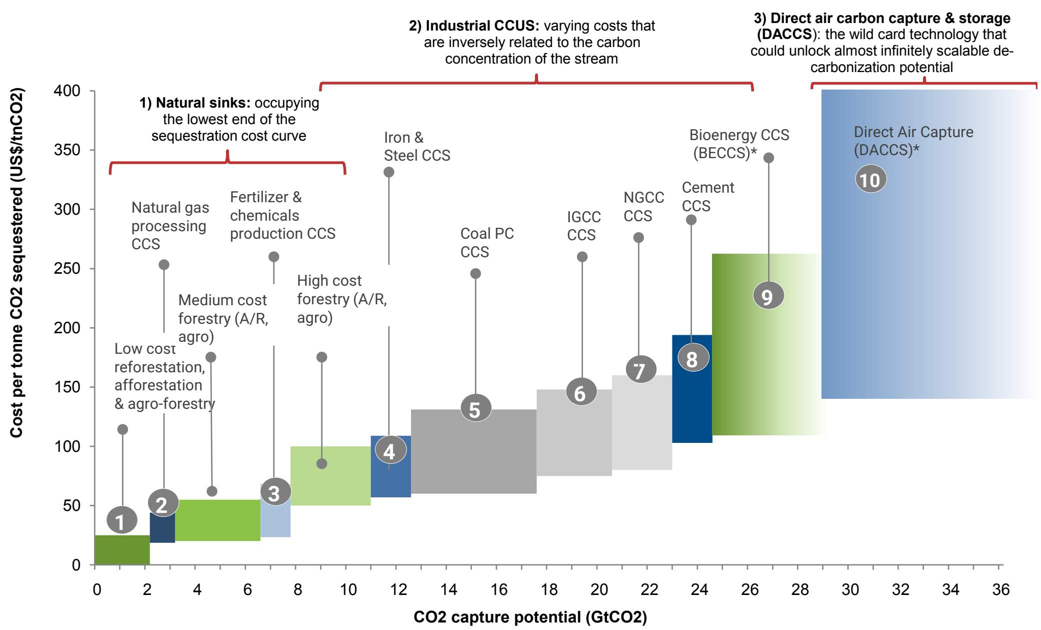
Technology-specific incentives can go a long way to incentivize investments and technological developments (e.g. subsidies for solar panels, offshore wind or EVs), as we have seen across renewable power, electric mobility and bio-fuels over the past decade, with implied carbon pricing as high as $1,000/ton in some instance Exhibit 12. However, we believe that explicit carbon schemes (such as the EU ETS) can be a more efficient, technology agnostic instrument of de-carbonization and clean tech innovation. Carbon leakage and unfair competition can however be an issue in the absence of a globally coordinated carbon pricing, hence the focus on a border adjustment to ensure a level playing field. The Carbon Boarder Adjustment Mechanism (CBAM) proposed by the EU could help to remedy the issue of carbon leakage by placing a tariff-like cost on emission-intensive imports and exports to attempt to reconcile the difference in carbon pricing between the EU and its trading partners. We believe that there is a need for more global coordination and consistency in relation to carbon pricing, and the upcoming COP-26 meetings presents an opportunity for the world's largest economies to agree on a more standardized and consistent carbon pricing framework.

Exhibit 12: We expect the cost curve to transform this decade, driven by cost deflation mostly in energy storage
Carbon abatement cost curve for de-carbonization of anthropogenic GHG emissions, based on current technologies



Source: Goldman Sachs Global Investment Research

Exhibit 13: The carbon sequestration curve is less steep vs. the conservation curve but has a higher range of uncertainty given the limited investment to date and the largely pilot nature of these technologies
Carbon sequestration cost curve (US$/tnCO2eq) and the GHG emissions abatement potential (GtCO2eq)



* Indicates technologies primarily in early development/ pilot phase with wide variability in the estimates of costs

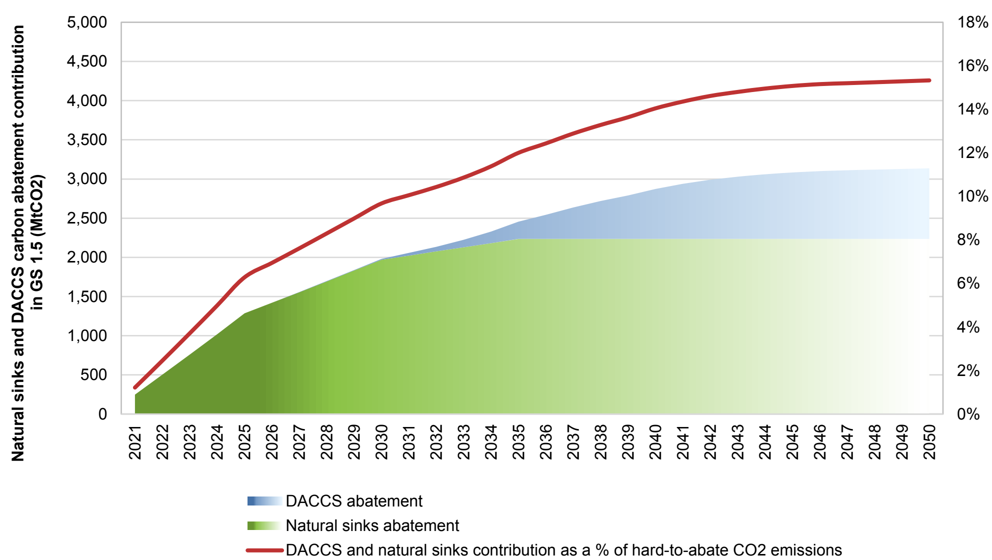
Source: IPCC, Global CCS Institute, Goldman Sachs Global Investment Research

Voluntary Carbon Credits financing carbon removal could contribute 15% of de-carbonization in harder-to-abate sectors

Carbon offsets are also a powerful instrument of de-carbonization and the only global (although poorly regulated) carbon market at present. Carbon emissions abatement alone is highly unlikely, in our view, to achieve the Net Zero by 2050 ambition, and we do believe that carbon offsets are a crucial driver of carbon removal through nature Based Solutions and Direct Air Carbon Capture. In our latest Carbonomics report, *The Path towards Net Zero*, we highlight the importance of carbon offsets in our sector pathways, indicating that the incorporation of carbon offsets could contribute around 15% to the de-carbonization of harder-to-abate sector emissions by 2050 as shown in Exhibit 14, on our estimates. We believe that discussions surrounding tighter standards, stronger supervision and better liquidity of global voluntary carbon credits could materially contribute to a cost-efficient path to Net Zero Carbon.

Exhibit 14: Natural sinks and DACCS are an important component to the global Net Zero path, contributing to c. 15% abatement of hard-to-abate CO2 emissions (defined as those with a carbon abatement cost above US$100/tnCO2 in our Carbonomics cost curve)

Natural sinks and DACCS carbon abatement contribution in GS 1.5 (MtCO2)



Source: Goldman Sachs Global Investment Research

The symbiotic relationship between carbon pricing and technological innovation

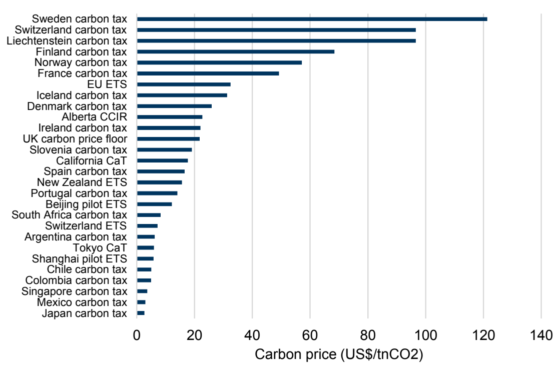
We believe that **carbon pricing will be a critical** part of any effort to move to net zero emissions, while incentivizing technological innovation and progress in de-carbonization technologies. The very steep carbon abatement cost curve calls for a growing need for technological innovation, sequestration technologies deployment and effective carbon pricing. The two approaches to de-carbonization, carbon abatement and carbon removal, are both vital in achieving net zero carbon emissions as emissions continue to overshoot the path associated with the more benign global warming paths. In the short term, we believe that **carbon prices should be sufficiently high to incentivize innovation and healthy competition between carbon abatement and carbon removal technologies**, while longer term such an equilibrium price of carbon would be expected to decline on the back of technological innovation and economies of scale.

Carbon pricing initiatives are accelerating, yet still only cover c.23% of total global emissions

At present, 57 carbon pricing initiatives are under way, covering 46 national and 28 regional governments worldwide, mostly through cap-and-trade systems. These initiatives are gaining momentum, with China, the world's largest CO_2 emitter, launching the initial phase of its own national carbon pricing scheme this July. These carbon pricing systems have shown varying degrees of success in reducing carbon emissions; together, according to the World Bank Group, all of these initiatives (including China) cover 11 $GtCO_2eq$, representing c.23% of the world's total GHG emissions.

Exhibit 15: The carbon prices associated with global carbon price initiatives (carbon taxes and ETS) show a wide regional variability...

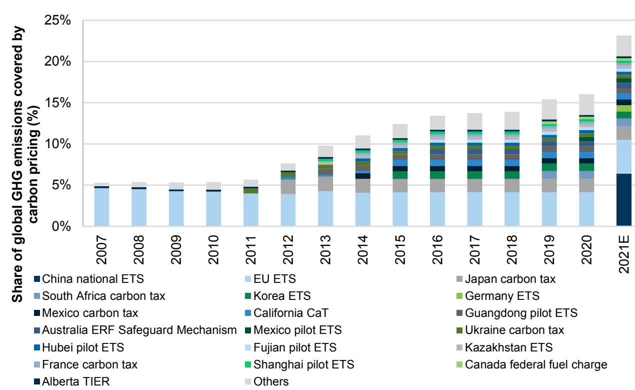
Carbon prices through taxes and ETS



Source: World Bank Group

Exhibit 16: ...with the addition of China's national ETS, the total global emissions covered by carbon pricing initiatives should reach c.23%

Carbon pricing initiatives' share of global GHG emissions covered (%)



EU includes the UK.

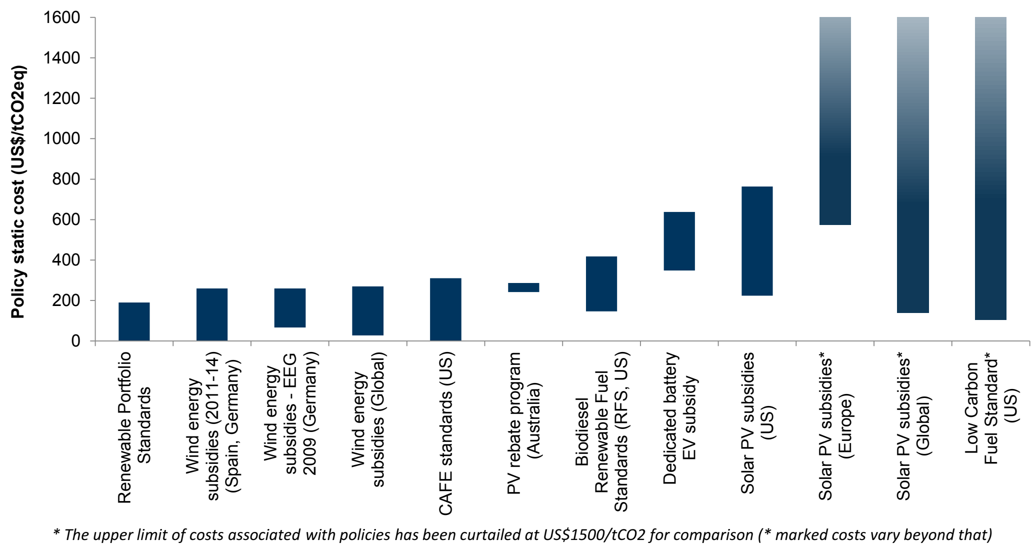
Source: World Bank Group

Governments have been successful at incentivizing specific low-carbon technologies, but efforts have been largely uncoordinated

With current emissions on a continuing upwards trajectory, a wide range of energy efficiency and low-carbon policies have been put in place in different countries over the past decade aimed at tackling climate change. Some of them have been very targeted (e.g. ethanol/wind/solar subsidies), while others have been broader (fuel standards). In aggregate, they have been successful at incentivizing clean tech developments yet they have not necessarily been a cost-efficient way of reducing carbon emissions and have only fostered technological innovation in narrow areas of the low-carbon economy. The costs associated with these policy measures encompass a very wide range, from zero to US\$1,000/tCO_2, with several of the policies implying a cost/ton CO_2 that is higher than the implied cost of alternative technologies such as sequestration. The economic studies involved in shaping the estimates presented in the exhibit below are primarily concerned with policy measures that were in force during the period 2010-14, with some of those sectors and technologies having experienced a substantial reduction in costs since then (solar and wind in particular), driven by accelerated capacity additions that unlocked the benefits of economies of scale.

Exhibit 17: A number of targeted low-carbon policies have been implemented over the past decade with a wide range of associated costs

Range of static carbon abatement cost of different past policies (US$/tnCO2eq)



Source: The Cost of Reducing Greenhouse Gas Emissions, Kenneth Gillingham James H. Stock, Journal of Economic Perspectives vol. 32, Copyright American Economic Association; reproduced with permission of the Journal of Economic Perspectives

Consumer Choice: Empowering the consumer to push for lower carbon supply chains

Today, global consumers have information available to them to understand the calorie and nutritional content of packaged food, however there is a lack of information disclosed with regard to the carbon footprint of products and services. We believe this is a missed opportunity to leverage consumer pressure on global companies to de-carbonize their value chain, finance carbon offsets and aim for a net zero carbon label. The disclosure of the calories and nutrient content on packaged food helped to increase awareness on nutrition and health, and we believe the same could hold true by putting pressure on global companies to enhance their de-carbonization strategies, finance carbon offsets and accelerate the path toward net zero.

COP-26 provides an opportunity for leading economies to lead the way in terms of climate action. We anticipate that the introduction of carbon labeling would have a positive effect on consumer choices and the impact they have on the environment. However, in order for the carbon labeling to be successfully implemented, global economies need to work together. COP-26 has a crucial role to play as it can facilitate co-ordination, co-operation and cohesion among global economies by outlining and introducing transparent, informative and standardized regulations surrounding emission disclosures and carbon removal offsets. An example of an innovative carbon labeling scheme is Foundation Earth, a pilot scheme supported by the UK Government and food and beverage companies such as M&S and Nestlé which aims to label a range of products with their carbon footprint as of Autumn 2021. In addition, Unilever has laid out plans to roll out carbon footprint labeling for a range of selected products in Europe and North America by the end of 2021.

This product-by-product disclosure would not have been technically possible a decade ago, but today it can be enabled thanks to innovation in Blockchain, Internet of Things and Big Data. These technologies have the ability to improve transparency, accessibility and accountability of data used for tracking the effects of climate change. Blockchain, in particular, offers the opportunity to track and calculate the reduction of carbon footprints across the value chain.

Carbon labeling: A catalyst for changing consumer behavior?

Labeling food and beverages with the calorie and nutritional content acts as an identity card for the products. It allows consumers to fully assess what they are consuming and the opportunity to make an informed decision on their consumption choices. However, the same cannot be said for consumers' ability to easily assess their carbon footprint impact from products and services they use. In our view, consumers should have a similar mechanism to understand the environmental impact of their consumption choices, just as they do the calorie and nutritional contents of food and beverages.

Labeling food and drinks with the nutritional information was introduced by many local and national governments as a means of encouraging consumers to opt for the healthier options with regard to food and drink consumption. Looking anecdotally at (non packaged) food labeling, a study carried out on New York fast food restaurants found that of 28% of the customers surveyed who saw calorie labeling on menus, 88% said the information had an impact on their choice. Similarly, the same study conducted on restaurants in Seattle, 45% of respondents reported that calorie labeling had an impact on their choices (Kiszko, Martinez, Abrams and Elbel, 2014). Additionally, analysis on food labelling effects on consumer behaviours and industry practises by the American Journal of Preventative Medicine, showed labels decreased the intake of calories by 6.6%, total fat by 10.6% and other unhealthy food choices by 13% (Shangguan et al., 2019).

Moreover, one notable outcome is a heightened awareness surrounding the relationship between diet and health. Labeling foods with the nutritional and calorie content has helped consumers to recognize the relationship between food and physical health, and enabled consumer to make informed decisions. The same may hold true for carbon footprint labeling on goods and services. While the introduction of carbon footprint labeling may not have an overwhelming impact on consumer choices initially, spreading awareness about the carbon footprint of products and services is a good start, while also allowing consumers to make an informed decision on the environmental impact of their consumption habits and behavior.

Notably, Unilever has announced the implementation of carbon footprint labeling on selected products in Europe and North America by the end of 2021, with the aim to label its entire product range over the next 2-5 years. Unilever hopes that introducing carbon footprint labeling on products will help to transform customer consumption habits and encourage more sustainable shopping.

Similarly, Foundation Earth is a traffic-light style innovative that will be rolled out across food production and retailing in the UK and EU, with the pilot launch in Autumn 2021. The organization is supported by many major food and beverage companies such as Sainsbury's, Nestlé and M&S as well as the UK Government. The mission of the organization is to promote more sustainable buying choices by consumers and more climate-friendly food from producers by enforcing a front-of-pack environmental score on labels. The pilot scheme will help to assess how consumers react to the climate-friendly labels.

Capital Markets Pressure: The rise of "green" investing

Capital markets pressure on de-carbonization has been on the rise in recent years. With the rise in global GHG emissions, investors are driving the climate change debate by placing pressure on corporate management to incorporate climate change into their business plans and strategies. Today >$100 tn of global assets under management have signed up to UN PRI and are implementing ESG metrics as part of their investment process. This wave of "green" investments is driving capital towards de-carbonization technologies through a divergence in the cost of capital of high carbon vs. low carbon investments. Looking at the energy sector, we estimate that the spread in the cost of capital of hydrocarbon vs. renewable developments has widened by > ten percentage points over the last five years. This is equivalent, on our estimates, to a global carbon tax of $80/ton, and is driving a historical turning point in energy investment, with global renewable power spend overtaking oil & gas developments for the first time in history.

Sustainable Investing & Financing: Unprecedented momentum

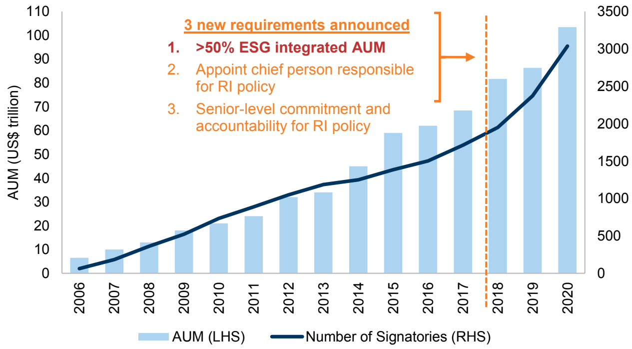
Sustainable investing is gaining momentum, potentially reaching ~US$50 tn AUM this year

Global AUM adopting ESG investing strategies continue to surge... As our GS SUSTAIN team *outline in their PM's Guide to the ESG Revolution 2*, ESG-linked investments continue to grow in both size and influence. There are now 3,000+ signatories to the PRI (Principles of Responsible Investment), representing over US$103 tn in global AUM (+20% yoy AUM growth) (Exhibit 18). Signatories were required to incorporate ESG considerations into at least 50% of their AUM by the end of 2020, suggesting that at least US$50 tn should become 'ESG aware' this year. While signatory AUM reflects growth across global markets, the SUSTAIN team also see this corresponding with trends in ESG fund flows which have consistently remained positive, adding US$135 bn in AUM ytd versus -US$422 bn in outflows for non-ESG funds (Exhibit 19) – see *ESG Nifty Fifty Series: How have ESG fund favorites changed in 2020* and *ESG's share of flows moves higher, as does passive.*

...leading to calls for improved data and more investor-relevant ESG reporting. Despite the doubling of available ESG data points from companies over the last three years, disclosures remain dominated by vague and difficult-to-compare policy pronouncement (70% of total disclosures, by our analysis), while 54% of available numeric metrics still have disclosures below 20%. The lacking data quality creates challenges for assessing corporate ESG performance and has influenced the increasing focus on ESG reporting frameworks such as SASB (Sustainability Accounting Standards Board) and TCFD (Task Force on Climate-related Financial Disclosures). Our SUSTAIN team's analysis of public filing for Global S&P 1,200 companies found the number of companies mentioning and discussing SASB has risen from 73 in 2016 to 268 as of June 2020 (+38% CAGR), while TCFD's adoption has accelerated from 12 company mentions in 2016 to over 515 as of June 2020.

Exhibit 18: PRI signatory count and AUM growth are accelerating off an already large base...

PRI signatory growth and AUM, 2006 - 2020*

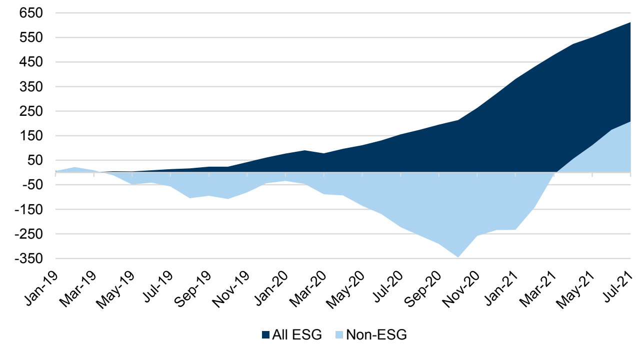


*As at June 2020

Source: PRI, Goldman Sachs Global Investment Research

Exhibit 19: ...helping fuel the consistently positive flow of AUM into ESG funds...

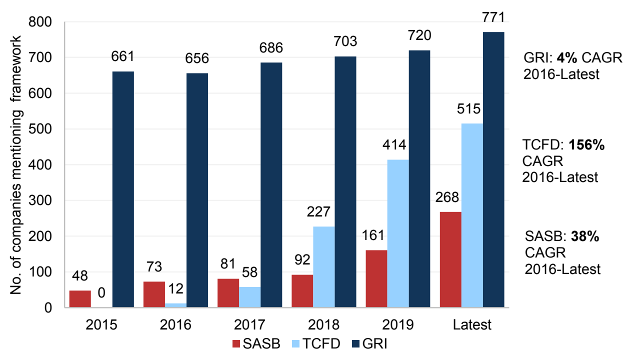
Cumulative monthly global flows for ESG and non-ESG equity funds since Jan 2019 (bn USD)



Source: Morningstar, Goldman Sachs Global Investment Research

Exhibit 20: ...and is also putting pressure on companies to report ESG data in a more investor-relevant manner

Number of S&P Global 1,200 companies mentioning SASB, TCFD and GRI in public filings from 2015 to latest*

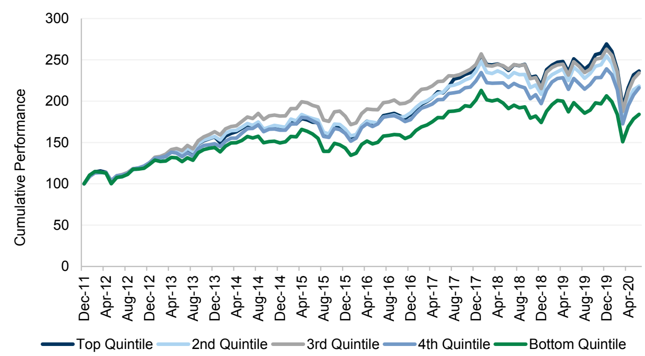


*As at June 2020

Source: Bloomberg, Company data, Goldman Sachs Global Investment Research

Exhibit 21: Bottom-quintile headline E&S companies have significantly underperformed, with the top quintile outperforming in recent years

Cumulative performance of quintiles based on SUSTAIN E&S headline percentiles (January 2012 to June 2020)



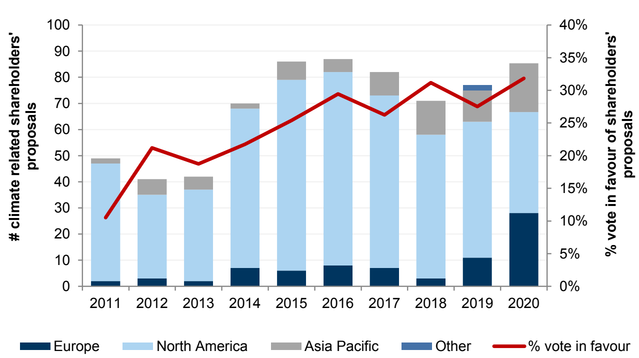
Source: Bloomberg, Refinitiv, FactSet, MSCI, Goldman Sachs Global Investment Research

Investors have emerged with a leading role in driving the climate change debate through rising engagement and shareholder proposals

With global GHG emissions on a persistent upward trajectory over the past few years, investors have emerged with a leading role in driving the climate change debate, pushing corporate managements towards incorporating climate change into their business plans and strategies. The number of climate-related shareholder proposals (as shown by data from ProxyInsight) has almost doubled since 2011 and the percentage of investors voting in favor has tripled over the same period. 2020, despite the outbreak of COVID-19, was another year of strong shareholder engagement on climate change, the most notable increase coming from Europe. Similarly, the percentage vote in favor has increased yoy, currently at c.34%. This investor pressure, however, is not uniformly distributed across sectors and shows a clear bias towards energy producers vs. energy consumers, with data since 2014 showing 50% of proposals targeting energy producers (oil & gas, utilities) while only 30% target the sectors that account for most of the final energy consumption.

Exhibit 22: Shareholders are pushing energy companies to embrace the energy transition...

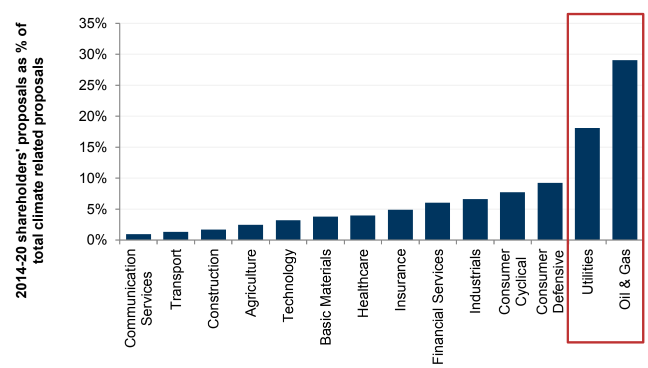
Number of climate-related shareholder proposals vs. % vote in favor



Source: ProxyInsight, Goldman Sachs Global Investment Research

Exhibit 23: ...with a targeted focus on the energy industry

% of climate-related shareholder proposals, split by industry, 2014-20



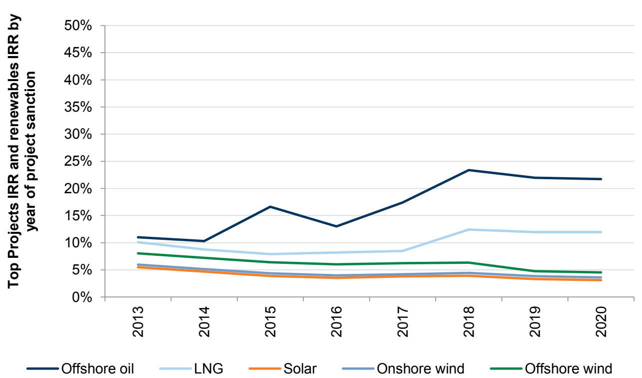
Source: ProxyInsight, Goldman Sachs Global Investment Research

The bifurcation in the cost of capital for high-carbon vs. low-carbon energy has contributed c.1/3 of the reduction in overall costs for renewable power

We note that along with the operational cost reduction that renewable energy has enjoyed over the past decade owing to economies of scale, the ongoing downward trajectory of the cost of capital for these low-carbon energy developments has also made a meaningful contribution to the overall affordability and competitiveness of clean energy. In contrast, financial conditions keep tightening for long-term hydrocarbon developments, creating higher barriers to entry, lower activity and ultimately lower oil & gas supply. This has created an unprecedented divergence in the cost of capital for the supply of energy, as shown in Exhibit 24, with the continuing shift in allocation away from hydrocarbon investments leading to hurdle rates of 10-20% for long-cycle oil & gas developments compared with c.3-5% for the regulated investments in Europe. On our estimates, long-cycle offshore oil and LNG projects' IRR premium relative to renewables implies a carbon price in the range of US$60-130/tn CO_2 (US$80/ton on average) for offshore oil and US$30-60/tn CO_2(US$40/ton average) for LNG. The capital markets are therefore currently implying a materially higher cost of carbon than the global average carbon price of US$3/tn CO_2.

Exhibit 24: The bifurcation in the cost of capital for hydrocarbon vs. renewable energy developments is widening on the back on investor pressure for de-carbonization

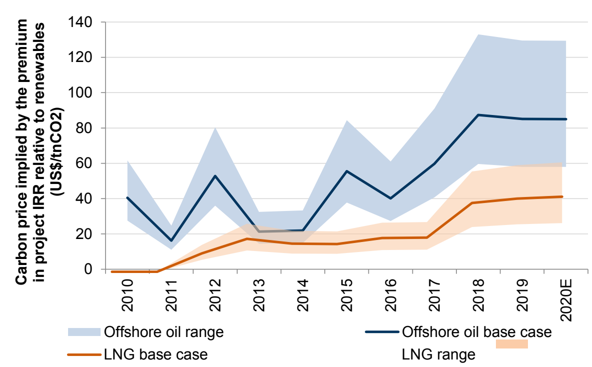
Top Projects IRR for oil & gas and renewable projects by year of project sanction



Source: Goldman Sachs Global Investment Research

Exhibit 25: The IRR project premium for offshore oil developments compared with renewables implies a carbon price range of US$60-130/tn CO2 and a range of US$30-60/tn CO2 LNG projects

Carbon price implied by the IRR premium for offshore oil and LNG projects compared with renewables (US$/tn CO2).



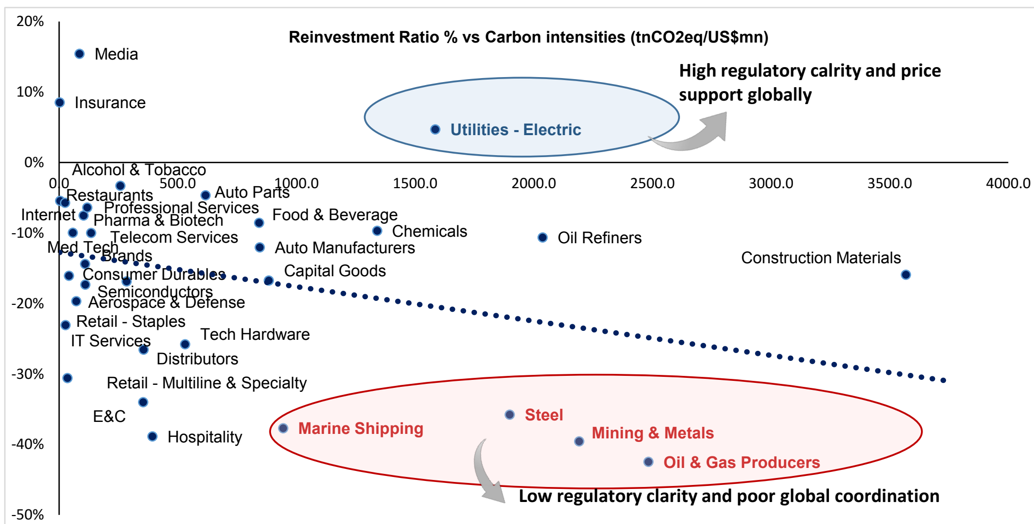
Source: Goldman Sachs Global Investment Research

Carbon-intensive sectors with low regulatory clarity are re-investing c.40% less of their cash flows in the business, leading to under-investment and future supply tightness

Uncertainty around future carbon regulation and lack of global coordination around carbon pricing are impacting investment in several sectors, mostly in energy, materials and heavy transport. On our estimates, there has been a decline in the re-investment ratio (10 year average vs. 2022E) of c.40% in Oil & Gas, Steel, Mining and Marine Shipping: global carbon intensive sectors which suffer from lack of clear policies around de-carbonization. In contrast, Electric Utilities is an example of a sector where clear de-carbonization incentives and strategies are actually leading to higher investment than in the past, as shown in Exhibit 26. We believe that ongoing lack of coordination is running the risk of severe under-investment in core parts of the 'Old Carbon Economy' that could lead to supply tightness, as we already are starting to experience in parts of the materials, oil & gas and transport industries.

Exhibit 26: Carbon intensive sectors with low regulatory clarity are structurally under-investing compared with history

Reinvestment Ratio % (2022E vs. 10 yr average) vs. Carbon intensities (Scope 1,2,3 emissions intensity per revenue (tnCO2eq/US$mn))



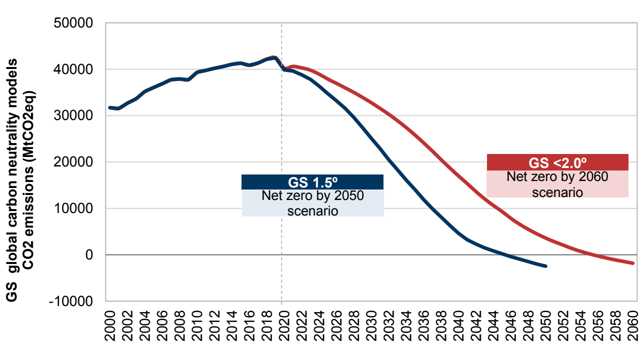
Source: Bloomberg, MSCI, Thomson Reuters Eikon, Company data, Goldman Sachs Global Investment Research

The Path to Net Zero

We have built two global paths to Net Zero carbon: one aspirational scenario consistent with a 1.5°C global temperature rise and one consistent with a rise well below 2.0°C (the 'Paris Agreement scenario')

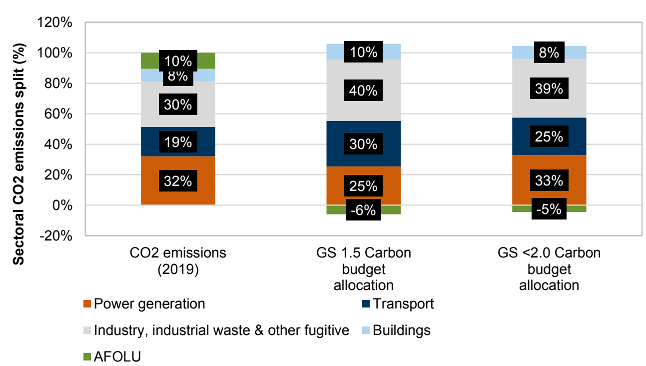
In our June 2021 report, we introduced our emissions path for global net zero carbon by 2050 which would be consistent with limiting global warming to 1.5°C, with limited temperature overshoot (**GS 1.5°**). For this scenario, we assume a carbon budget for remaining net cumulative CO_2 emissions from all sources from 2020 to be c.500 $GtCO_2$, consistent with the IPCC estimates in its Special Report on Global Warming of 1.5°C (2018) - 580 $GtCO_2$ from the 2018 base as the IPCC SR1.5 report indicates, consistent with around a 50% probability of limiting warming to 1.5°C by 2100. We also introduced a less aspirational, but in our view likely more achievable, global net zero model which is consistent with the Paris Agreement's aim to keep global warming well below 2°C (**GS <2.0°**) and which achieves global net zero around 2060. For the purpose of this analysis, we define the carbon budget for our GS <2.0° model to be near the mid-point of the range of IPCC's RCP2.6 scenario, implying a cumulative remaining carbon budget of around 750 $GtCO_2$ from 2020. For our global net zero carbon scenarios we adopt a sectoral approach, leveraging our Carbonomics de-carbonization cost curve and allocating the available carbon budget across different emitting industries on the basis of cost positioning and technological readiness.

Exhibit 27: We have constructed two global carbon neutrality scenarios: one aspirational scenario consistent with 1.5°C and one consistent with <2.0°C global warming...
GS net zero global models, CO2 emissions (incl. AFOLU)



Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research

Exhibit 28: ...adopting a sectoral carbon budget allocation approach which is largely dependent on the technological readiness and carbon abatement cost of clean de-carbonization technologies in each sector, as addressed by our Carbonomics cost curve
Sectoral CO2 emissions split (%)



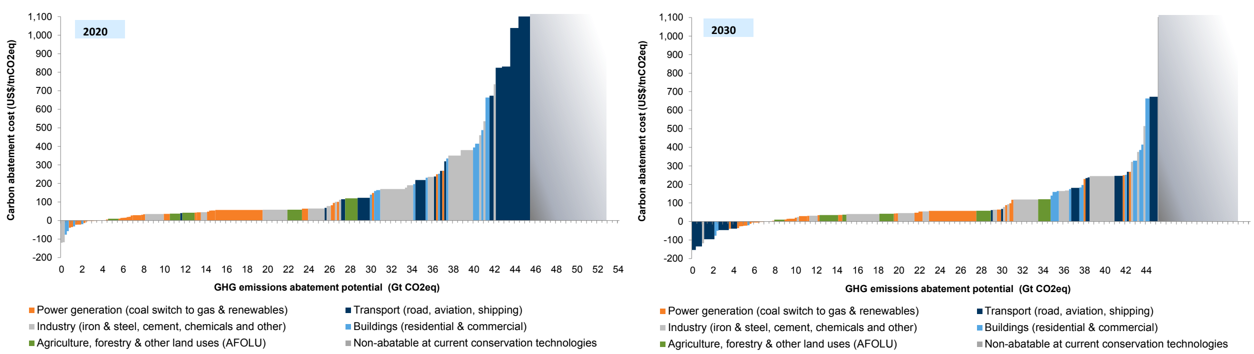
Source: Emission Database for Global Atmospheric Research (EDGAR) release version 5.0, FAO, Goldman Sachs Global Investment Research

We expect the Carbonomics cost curve to transform this decade, driven by cost deflation mostly in energy storage (batteries and clean hydrogen)

The additional carbon budget flexibility offered by the <2° scenario effectively provides an extra decade to achieve global net zero. This would provide more time for three key technologies driving the de-carbonization of transport and industry (batteries, clean hydrogen and carbon capture) to move lower on the Carbonomics cost curve before being rolled out on a giant scale worldwide. **We estimate that the upper half of the cost curve could fall by 22%/30%, respectively, by 2025/2030, driven by technological innovation and the benefits of scale,** mostly in energy storage and carbon capture technologies. **In the GS 1.5° path, power generation needs to de-carbonize by 57% by the end of this decade,** implying retirement of coal power plants by 2035 (two decades before the end of their useful life) and of gas power plants by 2045 (one decade before). This potentially disruptive and abrupt change in the power generation sector is a result of the tight carbon budget and the immaturity of de-carbonization technologies in transport and industry to be deployed at giant scale this decade. **However, under the less strict GS <2.0° path, the de-carbonization technologies in transport and industry have more time to evolve (we estimate 83% lower carbon abatement costs for the de-carbonization of transport by 2030 compared to today) and need a smaller relative allocation of the carbon budget** (25% to transport compared to 30% in the GS 1.5° path). **This allows power generation to de-carbonize at a more reasonable pace (-28% de-carbonization by 2030), avoiding the mass retirement of young power generation assets**, with a more gradual transition **and a greater role for natural gas.**

Exhibit 29: We estimate that the upper half of the cost curve can fall by c.30% by 2030, driven by technological innovation and the benefits of scale, mostly in energy storage and carbon capture technologies

2020/30E conservation carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies



Source: Goldman Sachs Global Investment Research

We expect US$56 tn pa of infrastructure investments to meet global Net Zero carbon by 2050, reaching >2% of GDP by 2033, in the 1.5° scenario

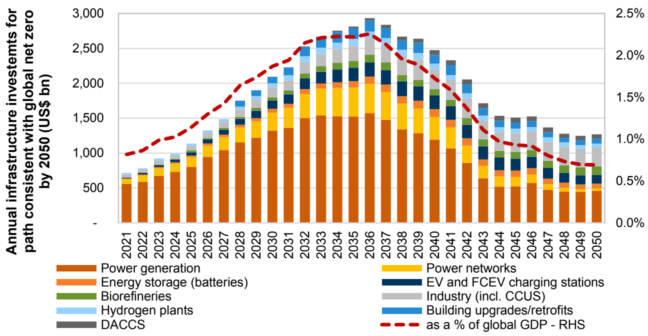
In aggregate, we estimate a total investment opportunity in clean tech infrastructure of US$56 tn by 2050 in the GS 1.5° path. This figure focuses solely on incremental infrastructure investments and does not include maintenance and other end-use capex. Overall, the average annual investments in de-carbonization that we estimate over 2021-50 are c.US$1.9 tn, with the peak in the 2036 (US$2.9 tn) representing 2.3% of global GDP (vs. US$1.6 tn pa with a peak of US$2.5 tn in 2041 in the GS <2.0° scenario). We estimate that **c.50% of de-carbonization is reliant on access to clean power generation**, including electrification of transport and various industrial processes, electricity used for heating and more. Overall, we expect **total demand for power generation** in the GS 1.5° global net zero scenario by 2050 to **increase three-fold (vs. that of 2019) and surpass 70,000 TWh as the de-carbonization process unfolds**. Based on our GS 1.5° model, power generation almost entirely de-carbonizes **by 2040** (2055 under the GS <2.0° scenario).

The de-carbonization of transport, buildings and industry will require a complex ecosystem of low carbon technologies, including energy storage (both batteries and clean hydrogen) and carbon capture alongside the supply of clean power. For light duty vehicles (LDVs) transport (primarily constituting passenger vehicles, commercial vehicles and short/medium-haul trucks), **we consider electrification the key de-carbonization technology**. For **long-haul heavy trucks**, we **consider clean hydrogen a competitive option**, owing to its faster refueling time, lower weight and high energy content. Sustainable aviation fuels (SAFs), synthetic fuels and improved aircraft efficiency are in our view all key parts of the solution to lower carbon aviation, while LNG and ammonia drive the de-carbonization of shipping and hydrogen addresses rail.

Fuel switch and efficiency govern emissions reduction in buildings, while clean hydrogen, CCUS, efficiency, circular economy and electrification set the scene for a new industrial technology revolution. We estimate that clean hydrogen can contribute to c.20% of global de-carbonization with its **addressable market growing 7-fold from c.75 Mt in 2019 to c.520 Mtpa on the path to global net zero by 2050.** We have incorporated carbon capture technologies in our GS 1.5° path for carbon neutrality by 2050, with CCUS across sectors contributing to annual CO_2 abatement of c.7.2 $GtCO_2$ by 2050. **Electrification and clean energy are likely to have an impact on total demand for natural resources, and in particular base metals** such as aluminium, copper, lithium and nickel, driven by renewables (solar panel, wind turbines manufacturing), power network infrastructure, charging infrastructure, electric vehicles and battery manufacturing. We attempt to quantify the potential impact that the path to net zero will have on the demand for each of these metals. We find that annual **green copper demand in a global net zero path by 2050 will rise by c.10 Mtpa, a c.40% increase from global copper demand in 2019. Similarly, we estimate the global average incremental annual green aluminium demand to be around 25Mtpa to 2050, c.40% of total global aluminium demand in 2019.**

Exhibit 30: In aggregate, we estimate a total investment opportunity in clean tech infrastructure of US$56 tn by 2050 in the GS 1.5° path, representing c.2.3% of global GDP at peak in 2036...

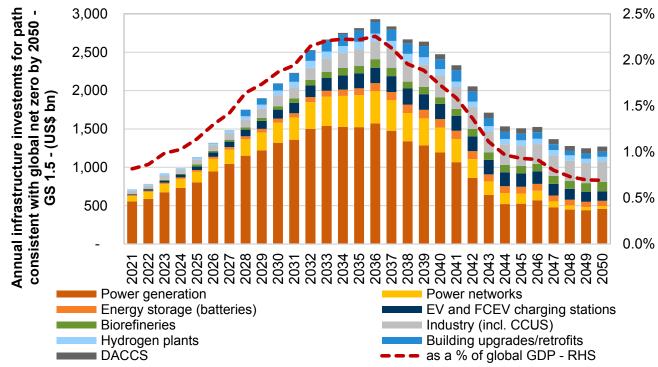
Annual infrastructure investments for GS 1.5 path to net zero by 2050 (US$ tn)



Source: Goldman Sachs Global Investment Research

Exhibit 31: ...and c.1.8% of GDP at its peak in 2040 for the GS <2.0° path

Annual infrastructure investments for GS <2.0 path to net zero by 2060 (US$ tn)



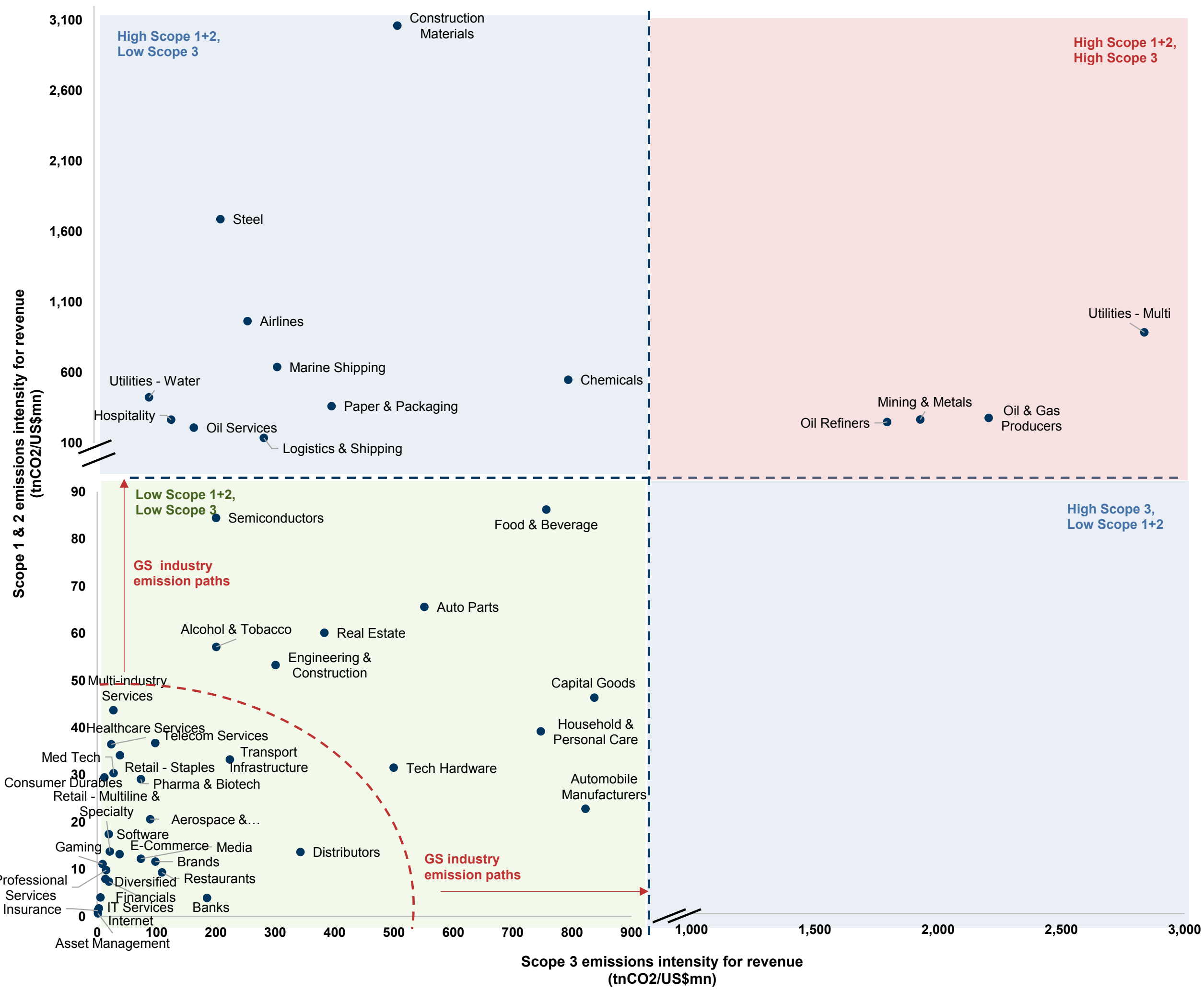
Source: Goldman Sachs Global Investment Research

We have mapped the carbon intensity reduction of 30 corporate industries in both our global net zero scenarios (GS 1.5° and GS <2.0°)

We have applied our GS 1.5° net zero by 2050 and GS 2.0° net zero by 2060 scenarios to **construct corporate emission reduction paths by industry for the highest-emitting industries globally on Scope 1 and 2 but also on Scope 3 for sectors where Scope 3 emissions are material.** This provides a tool to screen corporates against the aspirational/less aspirational net zero by 2050/2060 paths, and to assess their current emissions intensity reduction targets. We primarily formulate these corporate paths for a **carbon intensity measure**, rather than absolute emissions (to adjust for market share movements). We have mapped 30 industries (based on European listed corporates) with **high relative Scope 1 & 2 revenue emissions intensity and/or high Scope 3 revenue emissions intensity. For homogeneous industries with a defined unit of production, we show both the percentage reduction in emissions intensity and the actual intensity per unit of output (e.g. ton/MWh). For heterogeneous industries, which do not have a consistent output metric, instead of an absolute carbon intensity measure we have built an index for emissions reduction based on the current emissions split and emissions sourcing of key corporates in each sector.** Carbon offsets in the form of natural sinks and DACCS are also critical for the path to global net zero, especially for harder-to-abate sectors, in the absence of further technological innovation. We estimate that natural sinks and DACCS' contribution to the de-carbonization of harder-to-abate sector emissions (defined as the CO_2 emissions with a carbon abatement cost above US\$100/tnCO_2 in our cost curve) is around 15% by 2050.

Exhibit 32: We construct emission reduction pathways for 30 corporate industries with high Scope 1 & 2 and/or high Scope 3 emissions intensity per revenue

Scope 1 & 2 emissions intensity for revenue (y-axis) vs. Scope 3 emissions intensity for revenue (x-axis) for corporates listed in Europe



Source: Bloomberg, MSCI, Thomson Reuters Eikon, Company data, Goldman Sachs Global Investment Research

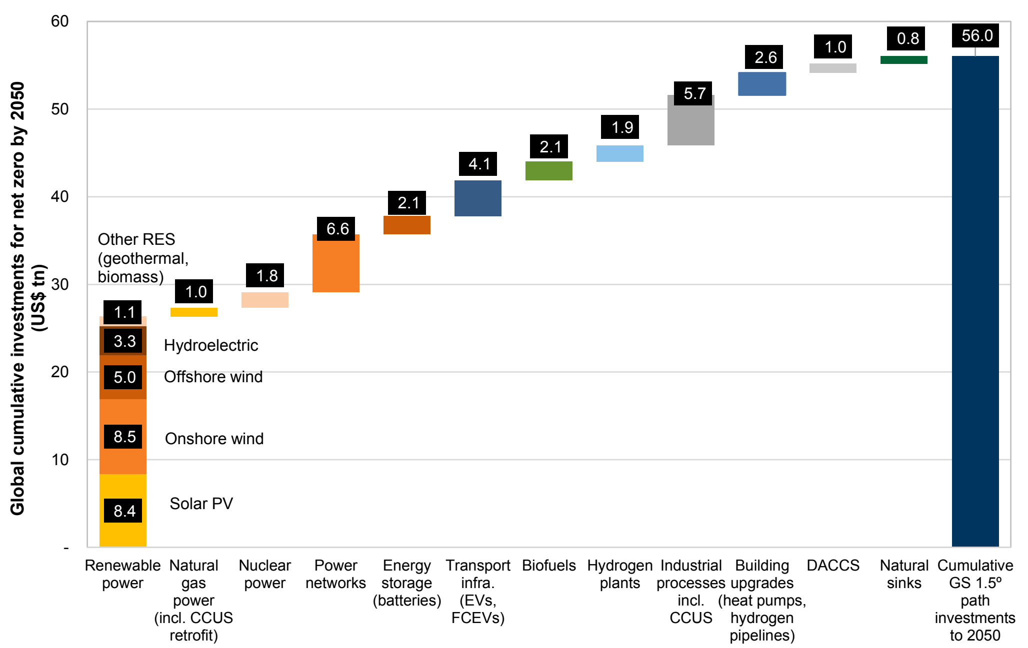
Fostering a profitable transition through technological innovation: The Investment Path (GS 1.5° scenario)

A global path to net zero by 2050 (GS 1.5°) has the potential to transform not only the global energy ecosystem but also the economy and society's standard of living. Exhibit 33 shows the wide range of investment opportunities associated with what we believe are the key infrastructure milestones required to achieve net zero emissions by 2050. These include, among others, the increasing uptake of renewable energy, bioenergy, an increasing focus on infrastructure investments for networks and charging stations that will enable a new era of electrification, an upgrade and/or retrofit of industrial plants (the cleanest available alternative technology), retrofitting of buildings and other existing heating infrastructure enabling greater uptake of cleaner fuels such as electrification and/or clean hydrogen, and finally a greater focus on carbon sequestration (natural sinks and carbon capture).

In aggregate, we estimate a total investment opportunity around US$56 tn by 2050 in a scenario consistent with the GS 1.5° path to net zero we have outlined above, which **implies an average annual green infrastructure investment opportunity of c.US$1.5-2 tn**. We note that this figure focuses solely on **incremental infrastructure investments** and does not include maintenance and other end-use capex.

Exhibit 33: We estimate that in aggregate a c.US$56 tn investment opportunity across sectors on the path to global net zero by 2050

Cumulative investment opportunity across sectors for our GS 1.5° global net zero by 2050 model (US$ tn)



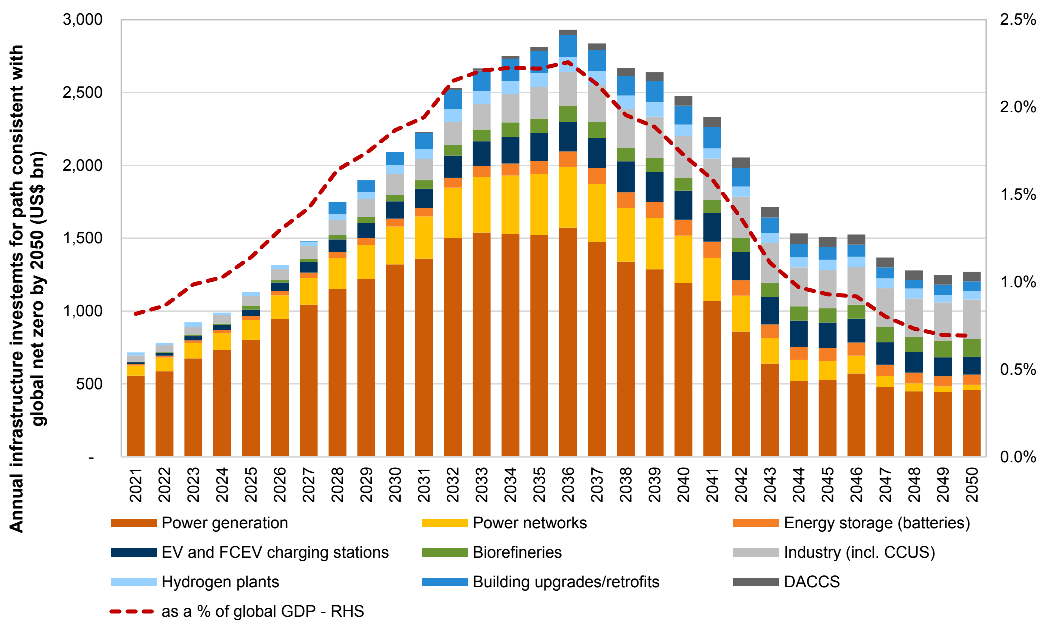
Source: Goldman Sachs Global Investment Research

The global path to net zero by 2050 requires, on our estimates, green infrastructure investments peaking at $3 trn in the mid 2030s, representing c.2.5% of global annual GDP

As highlighted in Exhibit 33, we estimate a total investment opportunity of c.US$50-60 tn by 2050 in a scenario consistent with the path to net zero and 1.5°C global warming, but we would not expect this to be evenly distributed annually to 2050. Instead, we anticipate an annual de-carbonization investment profile similar to that shown in Exhibit 34, with an acceleration of investments to 2035-40, the years when we expect investments to peak, driven largely by the initial infrastructure expansion required for power networks, charging networks, the massive expansion of renewable power, buildings upgrades and heating pipeline infrastructure to accelerate the penetration of electrification and clean hydrogen, and fuel substitution in transport and industry. Overall, the average annual investments in de-carbonization that we estimate over 2021-50 are c.US$1.9 tn (compared with <US$1 tn spent on power generation in 2019), with the peak in the 2030s (c.US$2.9 tn) representing >2% of global GDP.

Exhibit 34: We expect an annual investment profile similar to the one presented in the exhibit here, for a path consistent with global net zero by 2050, with investments peaking in the mid 2030s, representing up to c.2% of global GDP (US$ 2010 PPP)

Annual infrastructure investments for GS 1.5 path to net zero by 2050 (US$ tn)



Source: Goldman Sachs Global Investment Research

Energy Costs and Affordability: Who pays for Net Zero?

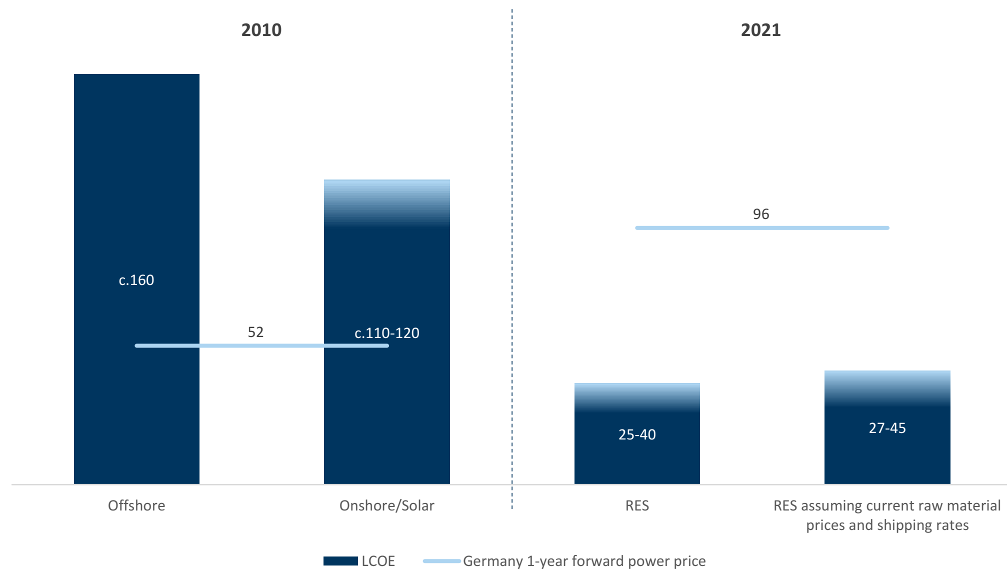
We respond to a question we frequently receive from investors: who pays for Net Zero? Over the past few weeks, the question has become more central to the debate in the industry owing to the spike in commodities prices and energy bills. As explained in a recent report (here), over the past 12 months gas prices have increased by c.450%, carbon prices have nearly quadrupled and – as a result –forward power prices have more than doubled. This has led to a c.35%-50% increase in end-user energy bills across Europe on our estimates. For a typical household, this would translate into c.€700 in incremental gas and power bills, on an annualized basis. During winter time, this could imply nearly €100 in additional costs per month in utility bills.

We analyze the costs to reach Net Zero plans (see here) and conclude that affordability is unlikely to derail the Net Zero journey. We reach five notable conclusions: (1) RES are a deflationary force to power systems and are therefore a solution, not a problem. (2) The electrification process would lower households' energy and fuel bills by c.50%, although the up-front costs would require state intervention. (3) European industrial bills could drop by c.30% and would become much more predictable. (4) The avoided costs of climate change – natural disasters of c.$250 bn pa and legacy investments in hydrocarbons of nearly $1 tn pa – are often overlooked. (5) Based on IMF data and GS estimates, the global carbon cost to reach Net Zero could reach $100/t or c.$5 tn per year.

Affordability a misconception due to the past; renewables are a deflationary force

Ten years ago the electricity produced from RES was expensive and became a burden for consumers; in Germany – the most extreme case – RES subsidies currently account for c.20%-25% of end-user bills. Yet following a significant cost reduction – wind and solar costs have dropped by 60% and 80%, respectively – and the recent strength in commodities (power prices have more than doubled in about a year), RES are now a key deflationary force in power systems.

Exhibit 35: Wind/solar is very competitive compared to European forward power prices
LCOE (Levelized Cost of Electricity) and German merchant forward power price (€/MWh)

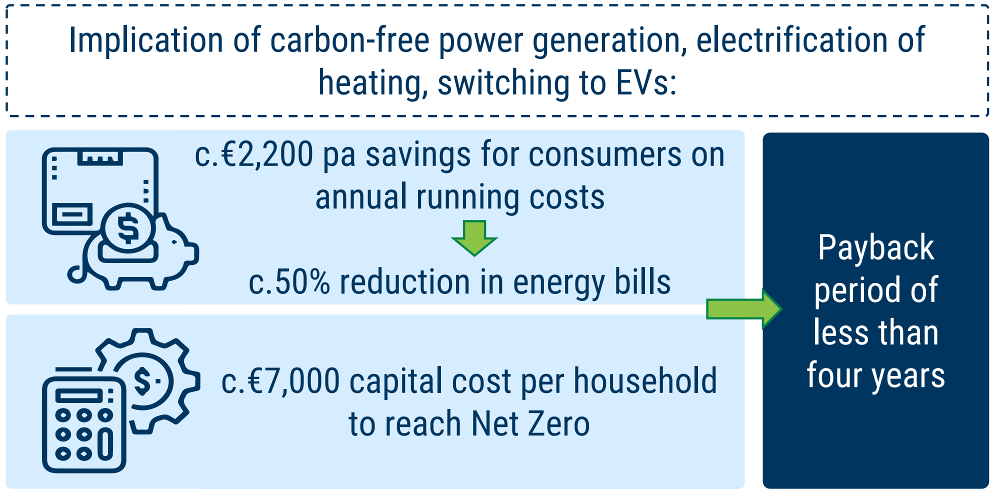


Source: Goldman Sachs Global Investment Research

Households energy bills would halve, but up-front costs require state support

Following the c.50% increase in power and gas bills over the past year (see here for details), we estimate that energy bills (power, gas and petrol) cost a typical European household some €4,400 per year, or more than €350 per month on average. We estimate reaching Net Zero by 2050 – implying carbon-free power generation, the electrification of heating, switching to electric vehicles – would save consumers nearly €2,000 pa vs. current bills and €2,200 pa vs. a business as usual 2050 forecast. Put differently, the electrification process could lead to a c.50% reduction in energy bills for European households. However, to achieve these savings households would have to spend c.€7,000 in up-front capital costs, we estimate – a significant amount for the majority of families. Capital costs would mostly fund the purchase of an electric vehicle and the installation of a new heating system relying on heat pumps. If up-front costs were to be covered by state incentives (c.€1.6 tn to 2050, or about €50 bn per year for Europe would be required, we estimate), the drop in energy bills would "repay" up-front costs in less than four years.

Exhibit 36: Costs incurred by the government and savings by households imply a payback period of less than four years



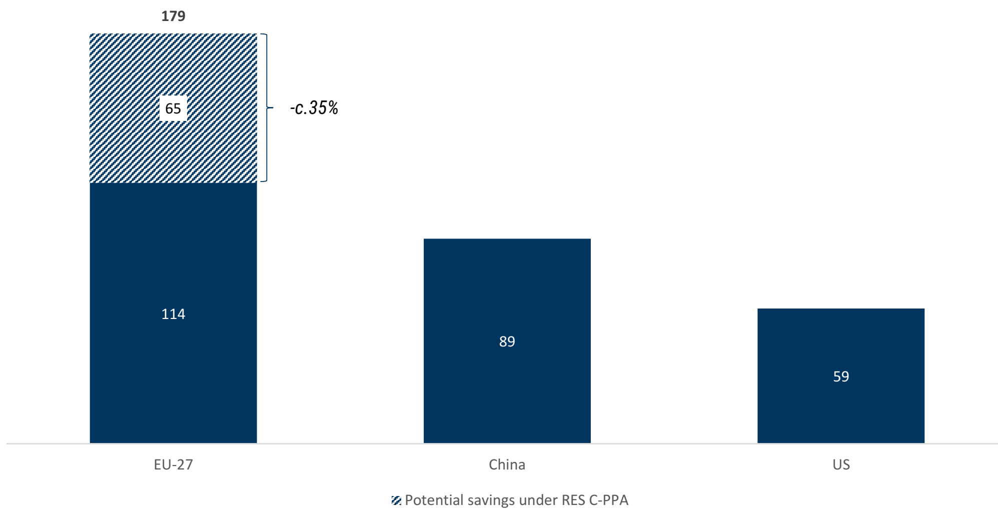
Source: Goldman Sachs Global Investment Research

Lower (and more predictable) costs for industrial customers

Currently, industrial electricity bills in Europe are about three times as high as the tariffs paid by equivalent companies in the US and c.100% higher than in China. In the most electricity-intensive European industries (e.g., construction, chemicals, pulp & paper) electricity represents 5%-15% of operating costs; thus, expensive power provides a meaningful competitive disadvantage.

The European marginal system is based on hourly bids, where thermal plants set prices for about 70%-75% of the hours despite producing less than 20% of the total annual output. In such a system currently power prices are c.€100/MWh. Currently RES (wind, solar, hydro, other) generate about 40% of the European annual needs, and this is set to exceed 70% by 2030. As the cost of generating electricity from wind/solar is 2x-5x cheaper than any thermal equivalent, a widespread use of Renewables Corporate PPAs (Power Purchase Agreements) would lead to meaningful savings for European companies, and narrow the electricity bills gap by c.35%, we estimate.

Exhibit 37: We estimate a c.35% decrease in European industrial electricity prices under a C-PPA vs. current prices
Industrial electricity prices (€/MWh): EU, China and US, 2021E

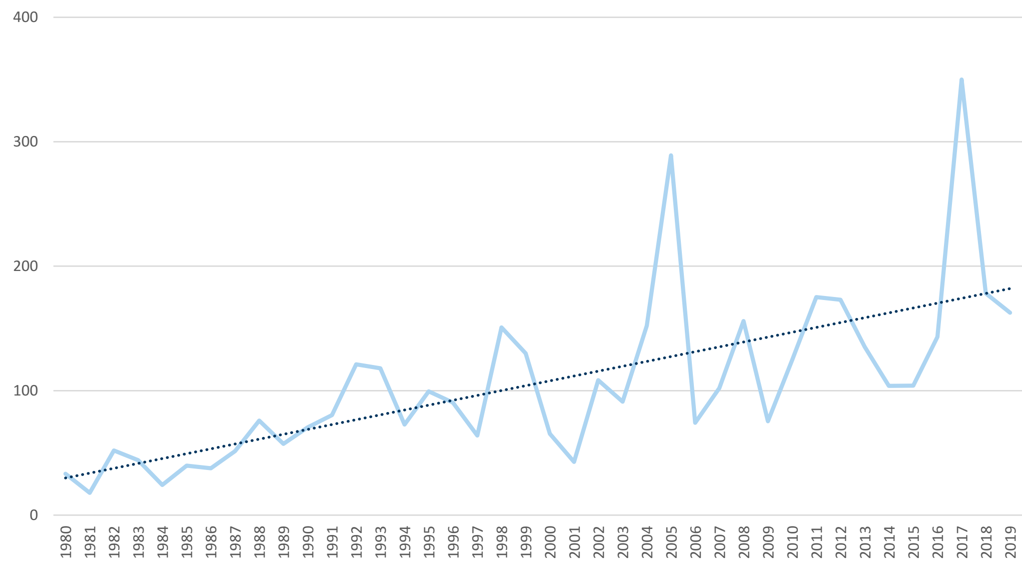


Source: Bloomberg, Goldman Sachs Global Investment Research

"Climate inaction" costs often overlooked

Data by Munich Re show that costs related to natural disasters approach c.$250 bn per annum globally, some +600% higher than in the 1980s, in real terms. The recent IPCC report on climate change urged for immediate action to avoid a "climate catastrophe" and talked about "code red for humanity", following the higher frequency in extreme weather episodes.

Exhibit 38: Global losses from weather-related disasters have increased by 600% since the 1980s in real terms
Global losses from weather disasters (real, $ bn)

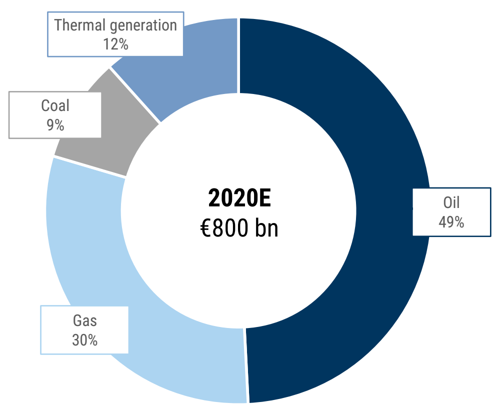


Source: Munich RE, Goldman Sachs Global Investment Research

Legacy hydrocarbon costs

Data by the IEA show that, each year, investments in oil, gas, coal and thermal generation amount to about €800 bn per year globally. For Europe (c.15% of global hydrocarbon consumption), this figure would imply >€5 tn in investments in legacy (dirty) activities over the coming 30 years. This figure is not too different to the c.€6 tn in investments in clean energy investments (renewables, power grids) to 2050 that we estimate are needed to fully decarbonize energy systems and comply with the EU Green Deal Net Zero requirements.

Exhibit 39: Investments in oil, gas, coal and thermal generation amount to about €800 bn per year
Global annual legacy investments breakdown (€ bn)



Source: IEA, Goldman Sachs Global Investment Research

Carbon costs at $5 tn pa globally to reach Net Zero

Currently, the world emits about 32 bn tonnes of carbon per annum (c.50 bn tonnes GHG, expressed in carbon equivalent terms), based on 2020 data by the IEA (here). Reaching the Paris Agreement goals of keeping global temperature increases below 2 degrees vs. pre-industrial levels (ideally to +1.5) would imply – according to the IPCC – a two-thirds reduction in carbon emissions, to c.10 bn tonnes per year. Separately, the IMF estimates that to reach Paris Agreement goals carbon should be priced at $75/t, implying a global cost of c.$4 tn per annum. Considering the incremental efforts to reach Net Zero and the higher carbon costs related to storage, green hydrogen and carbon capture, usage and sequestration, the average carbon cost to reach Net Zero could exceed $100/t, implying at least $5 tn in carbon costs to reach Net Zero.

Exhibit 40: Carbon costs at $5 tn pa globally to reach Net Zero

Goal	Carbon Costs	Total Costs
Paris Agreement	$75/t	c.$3.8 trn pa
Net Zero	At or above $100/t	At least $5 trn pa

Source: IMF, Goldman Sachs Global Investment Research

Capital costs to decarbonize Europe imply €45/t cost, net of legacy investments

As presented in our previous research (see here), we estimate the cost for EU Clean Energy Infrastructure and Grants under the EU Green Deal at €10 tn. These include privately funded investments in clean energy (c.65%) as well as subsidies to support the electrification process and more nascent technologies such as green hydrogen and CCUS (Carbon Capture, Usage and Storage). Translated into a cost of carbon per year, such capital costs would imply a carbon price of c.€80/t. Yet we believe this analysis could be misleading. Indeed, once deducting the expected investments in hydrocarbons and legacy technologies – which would drop to broadly zero in a fully decarbonized world – the net cost of the Green Deal would broadly halve, implying a net carbon cost per year of c.€45/t just from capital costs.

Exhibit 41: We estimate a carbon cost of c.€45/t to fully decarbonize Europe under the EU Green Deal
Carbon cost in Europe's full decarbonization scenario, GSe (€ tn, € bn, bn tonnes, €/ton)

Current EU GHG emissions	4.2 bn tonnes
EU Green Deal Capex/Grants	€10 trn
Gross carbon cost to reach net zero	c.€80/ton
Imported cost of hydrocarbons	c.€4.3 trn
Green Deal Net Capex 2021-2050	€5.7 trn
Extra Capex per year	€190 bn
Net Carbon cost to reach Net Zero	**c.€45/ton**

Source: Goldman Sachs Global Investment Research

Disclosure Appendix

Reg AC

We, Michele Della Vigna, CFA, Alberto Gandolfi, Zoe Stavrinou, Ajay Patel, Mafalda Pombeiro, Emma Burns and Bepul Shahab, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

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The Future of Mobility

Artificial Intelligence

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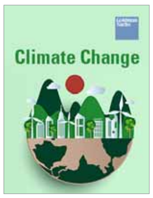
5G: From Lab to Launchpad

Climate Change



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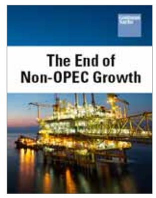

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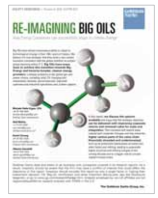
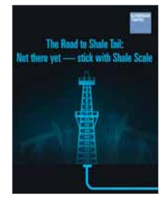


The Rise of Renewables

Shale Scale to Shale Tail



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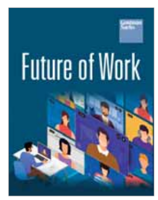
The Genome Revolution

Digital Health

The Future of Finance

Future of Work



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Space

Factory of the Future

eSports: From Wild West to Mainstream

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The Chinese Consumer

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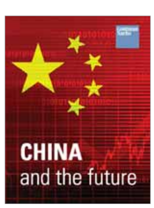
New China, Old China



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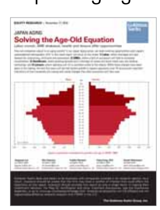

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