Net-Zero Scenarios: What Will the Energy Landscape Look Like?

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INTRODUCTION

NET-ZERO SCENARIOS: WHAT WILL THE ENERGY LANDSCAPE LOOK LIKE?

An increasing number of countries have committed to reach net-zero carbon emissions, usually between 2050-70. Any remaining emissions of carbon dioxide or other greenhouse gases would be cancelled out by increased forestry or other methods to remove atmospheric CO_2.

What are realistic scenarios for reaching net-zero by mid-century? What are the key features of each? What are the conditions for them to be realised, and what are the environmental, technological, economic and political implications?

Sustainability Report

This research paper is part of a 12-month series published by The Al-Attiyah Foundation every year. Each in-depth research paper focuses on a prevalent sustainable development topic that is of interest to The Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available online to all Foundation members.

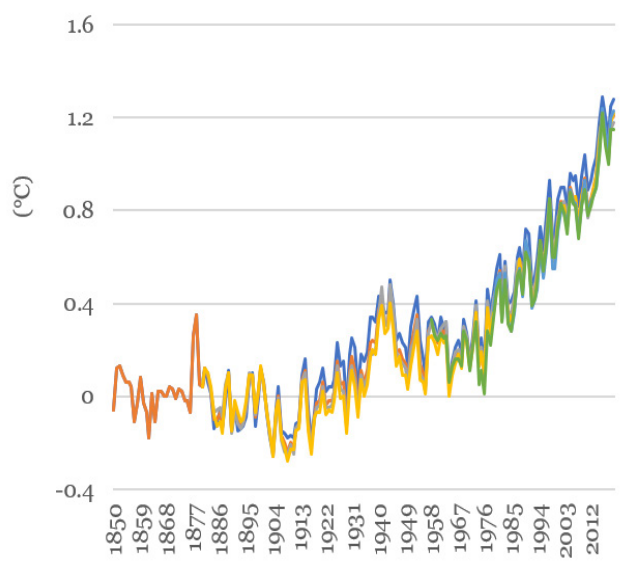
EXECUTIVE SUMMARY

- Reaching net-zero emissions is akin to achieving "climate neutrality". In the lead-up to the 26th Conference of the UNFCCC in November 2021, several new countries have committed to net-zero pledges.
- Any assessment of net-zero scenarios must be reconciled with the Sustainable Development Goals (SDGs).
- Unlike climate-only pathways, socioeconomic-based pathways can offer crucial insights into how future societal choices will affect GHG and CO_2 emissions, and therefore, how the climate goals of the Paris Agreement could be met in a sustainable way.
- The IPCC's Shared Socioeconomic Pathways (SSPs) provide a consistent set of assumptions of population, economic activity, and urbanisation as inputs to energy, land use, and ultimately climate impacts.
- Most climate neutral approaches to mitigating emissions en route to net-zero are technically and commercially mature. For new technologies, the market design and price formation are important to leverage capital in innovation.
- Nearly all climate scenarios to a 1.5°c future include some degree of (temporary) "overshooting", which would have to be mitigated through offsets and/or carbon sinks.
- Policy makers and academics can benefit from scenario modelling by working to build a real-time framework that updates GHG historical and future projections, including any uncertainties.

ADOPTION OF NET-ZERO TARGETS

Achieving net-zero emissions' targets has become an explicit goal of many climate and energy-related policies around the world, especially in the wake of the Intergovernmental Panel on Climate Change (IPCC) 6th assessment report (AR6), published in August 2021[i]. Under the 2015 Paris Agreement, countries agreed to limit global warming to well below 2°c above pre-industrial levels (by 2100), ideally to 1.5°c by mid-century; however, the world is not close to be on track to meet either. Current warming (1.2°c[ii]) has already resulted in damaging climate impacts, from melting glaciers and snow caps, to heat waves and intense storms, highlighting the urgency of minimising temperature increases.

Figure 1 Temperature Difference from Pre-industrial Conditions, 1850-2020[iii]



Meeting the Paris Agreement's temperature goals will require reaching net-zero carbon dioxide (CO_2) emissions between 2044 and 2050 for a 1.5°c future[iv], with total greenhouse gas

(GHG) emissions reaching net-zero between 2063 and 2068[v]. If net-zero is reached in the earlier part range, say by the early 2040s for CO_2 emissions, the risk of overshooting the target temporarily could be mitigated. Reaching the target at the end of the range means global temperatures will most likely surpass 1.5°c for some time before net-negative emissions are achieved and temperatures eventually drop.

In case of the 2°c goal, CO_2 emissions need to reach net-zero between 2070-2085, with total GHG emissions reaching neutrality by 2100[vi], for a 50-66% likelihood of limiting warming to 2°c. This further highlights the need to cap temperatures below 1.5°c before the first half of the century concludes.

The EU, and many other countries, such as UK, Norway, Iceland, Canada, New Zealand, Costa Rica and others, have made net-zero commitments, generally for 2050 or earlier (for instance, 2040 for Iceland). The administration of President Biden in the USA has set a net-zero goal no later than 2050. In the lead-up to the 26th Conference of the UNFCCC (COP26), that was held in November 2021, several new countries made or reiterated net-zero pledges. These include Bahrain (2060), Saudi Arabia (2060), the UAE (2050), China (2060), India (2070), Brazil (2050, up from an earlier 2060), Russia (2060), and Australia (2050).

Currently, more than 82 countries accounting for 73.9% of global GHG emissions, have communicated net-zero targets, although only 13 countries, representing 10.2% of global GHG emissions, have embedded these into a legal framework.

Net-zero targets are expected to be set and enshrined in government policy and domestic laws and regulations. Detailed strategies for achieving the targets, particularly covering

short-term actions up to 2030 or 2035, should be integral part of a country's nationally determined contribution (NDC).

Companies are also setting net-zero targets, which cover their direct Scope 1 emissions, and/or Scope 2 emissions from their purchase of electricity and heat, or also their supply-chain emissions (Scope 3). Amazon aims to be net-zero by 2040, Microsoft to be 'carbon-negative' by 2030 and to have offset all its historic emissions by 2050, and Google claims to have been 'carbon-neutral' since 2007 and plans to be 'carbon-free' by 2030.

Figure 2 Share of net-zero targets in law, policy, and pledges, from 82 countries[vii]

Table 1 shows a list of the countries with net-zero targets beyond 2050. Apart from China, all targets are high-level political pledges, which puts a question mark over their realisation.

However, not all countries need to achieve net-zero emissions at the same time. Wealthier, higher-emitting countries need to achieve climate neutrality much quicker than low-emitting countries, especially if equity-related considerations are taken into consideration.

Table 1 Countries with net-zero targets beyond 2050 include some of the largest GHG emitters in the world[viii]

Country	Net-zero Target Year	Type of Target	Share of Global GHG Emissions
Bahrain	2060	Political Pledge	0.1%
China	2060	Policy	23.9%
India	2070	Political Pledge	6.8%
Russia	2060	Political Pledge	4.1%
Saudi Arabia	2060	Political Pledge	1.3%
Turkey	2053	Political Pledge	1.0%
Nigeria	2060	Political Pledge	0.7%
Kazakhstan	2060	Political Pledge	0.6%
Ukraine	2060	Political Pledge	0.5%

WHAT ARE THE CURRENT MAJOR NET-ZERO SCENARIOS?

Current net-zero emissions' mitigation pathways exist at both national (for countries who have announced explicit net-zero goals in law) and global levels. There are many studies that have assessed these scenarios, but most do not fully evaluate the trade-offs necessary to reconcile the scenarios with the UN Sustainable Development Goals (SDGs).

Table 2 Major global net-zero scenarios with key features

Organisation	Type	Net-Zero Scenario(s)	Key Features	Generation Mix 2050
Bloomberg New Energy Finance (BNEF)	Consultancy	• BNEF Green Scenario	• High electrification of end-use economy complemented by green hydrogen • 30% drop in energy-related emissions by 2030 relative to 2019 to reach net-zero in 2050 • 75% drop in energy-related emissions by 2040 relative to 2019 to reach net-zero in 2050	85% Renewables, 10% Fossil, 5% Nuclear
IEA / (coupled with IIASA Greenhouse Gas-Air Pollution Interactions and Synergies Model and Global Biosphere Management Model)	International Energy Platform	• Net-Zero Emissions by 2050 (NZE)	• NZE shows what is needed for the global energy sector to achieve net-zero CO2 emissions by 2050 • Requires corresponding GHG emissions reductions from outside the energy sector to limit global temperature rise to 1.5°C, but not included in scenario • Energy efficiency, wind and solar provide ~50% of emissions savings to 2030 • Electrification, hydrogen, CCUS provide >50% of emissions savings between 2030 and 2050	67% Renewables, ~20% Fossil, ~13% Nuclear
DNV	Consultancy	• Energy Transition Outlook	• Shows the gap with ambitions to achieve net-zero by 2050 • Solar and wind becoming highly competitive but low-carbon fuels and CCUS lack support	82.5% Renewables, 13.2% Fossil, 4.3% Nuclear
BP	Private Enterprise	• Net Zero Scenario (Net Zero)	• Policy measures, increase in carbon prices, sector specific measures to reduce carbon emissions from energy use to >95% by 2050, reinforced with the policy measures embodied in the BP Rapid Transition Scenario (Rapid, which causes carbon emissions from energy use to fall by ~70% by 2050)	20% Fossil, 60% Renewables, 10% Hydro, 10% Nuclear

WHAT ARE THE CURRENT SCENARIOS?

Network for Greening the Financial System (NGFS) / (PIK, IIASA, UMD-produced transition pathways)	International Platform	• Net Zero 2050 • Divergent Net Zero 2050	• Net Zero 2050: stringent climate policies + innovation; jurisdictions like US, EU, Japan reach net-zero for all GHGs • Divergent Net Zero: Divergent policies lead to higher costs across sectors to quickly phase out oil use; net-zero achieved in 2050	Net Zero 2050: 68% Renewables and Biomass, 30% Fossil, 2% Nuclear
IPCC	International Platform	• Representative Concentration Pathways (RCPs) • Shared Socioeconomic Pathways (SSPs)	• Net Zero: RCP 1.9 limits global warming to below 1.5°C, requires very strongly declining emissions • SSP1-1.9: SSP1 (Sustainability (Taking the Green Road)) emphasises more inclusive development that respects perceived environmental boundaries. When coupled with the RCP radiative forcing 1.9, SSP1-1.9 presents as the most likely scenario to achieve net-zero CO2 emissions and very low GHG emissions by 2050	~ Varied ~

Used most widely to assess net-zero pathways

Used to assess net-zero pathways primarily for the energy sector

Table 2 highlights some of the major global net-zero scenarios. These are developed by a variety of government and state-level research organisations, private enterprises, energy agencies, and international platforms.

Bloomberg NEF's Green Scenario, the IEA's NZE, and BP's Net Zero highlight what is needed to bring energy-related emissions to net-zero, on the assumption that non-energy sector emissions will simultaneously be brought to net-zero as well.

Socioeconomic measures can help analyse behavioural changes in consumption patterns, as well as preferences of companies to switch to low carbon energy sources. Unlike climate-only pathways, socioeconomic-based pathways can offer crucial insights into how future societal choices will affect CO_2 and other GHG emissions, and therefore, how the climate goals of the Paris Agreement could be met.

Until the IPCC's 5th Assessment Report (AR5), the Representative Concentration Pathways (RCPs) were widely used for modelling a variety of global and national-level climate mitigation pathways and scenarios.

In 2021, the IPCC used the Shared Socioeconomic Pathways (SSPs) as important inputs for its latest climate models in its 6th Assessment Report (AR6). These socioeconomic pathways offer five future paths that the world could take, by offering a broader view of a "business as usual" (BAU) world without implementation of climate policies. By providing a consistent set of assumptions of population, economic activity, and urbanisation as inputs to energy, land use, and ultimately climate impacts, the SSPs highlight the futures under which mitigating and adapting to climate change would be easier compared to others.

The SSPs vary considerably in their assumptions about economic growth, inequality, trade, dependence on fossil fuels, and material consumption. For example, SSP1 (Sustainability – Taking the Green Road) assumes medium economic growth, moderate international trade, low growth in material consumption, low-meat diets, and an emphasis on renewable energy and energy efficiency. SSP5 (Fossil-fuelled Development – Taking the Highway), on the other hand, assumes high economic growth, high international trade, high material consumption, meat-rich diets, and a strong emphasis on the use of fossil fuels.

Other characteristics, such as GDP, which plays a key role in analysing the varying challenges to mitigation and adaption, also differs between both SSP1 and SSP5, even though it is characterised as "high"[xii].

WHAT ARE THE CURRENT MAJOR NET-ZERO SCENARIOS?

Table 3 Shared Socioeconomic Pathways in the IPCC Sixth Assessment Report[ix]

SSP	Description	Input with Radiative Forcing (RCPs)	Combined Climate Impact Scenario	Estimated Warming (2041-2060)
SSP1: Sustainability – Taking the Green Road	• This future poses low challenges to mitigation and low challenges to adaptation • Global population peaks mid-century • Emphasis on human well-being • Environmentally friendly technologies and renewable energy • Strong and flexible institutions on global, regional, and national level	RCP1.9, RCP 2.6	**SSP1-1.9** • Very low GHG emissions • CO2 emissions cut to net-zero around 2050 **SSP1-2.6** • Low GHG emissions CO2 emissions cut to net-zero around 2075	1.6°C 1.7°C
SSP2: Middle of the Road	• This future poses moderate challenges to mitigation and moderate challenges to adaptation • Population growth stabilizes toward the end of the century • Current social, economic, and technological trends continue • Global and national institutions make slow progress toward achieving sustainable development goals	RCP4.5	**SSP2-4.5** • Intermediate GHG emissions • CO2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2°C
SSP3: Regional Rivalry – A Rocky Road	• This future poses high challenges to mitigation and high challenges to adaptation • Population growth continues with high growth in developing countries • Emphasis on national issues due to regional conflicts and nationalism • Economical development is slow and fossil fuel dependent • Weak global institutions and little international trade	RCP7.0	**SSP3-7.0** • High GHG emissions • CO2 emissions double by 2100	2.1°C

Included in the IPCC AR6

SSP4: Inequality – A Road Divided	• This future poses low challenges to mitigation and high challenges to adaptation • Population growth stabilizes toward the end of the century • Growing divide between globally connected, well-educated society and fragmented lower income societies • Unrest and conflict become more common • Global, regional, and national institutions are ineffective	**RCP6.0**	**SSP4-6.**[x] • High GHG emissions • CO2 emissions peak by 2040 and slowly decline thereafter	
SSP5: Fossil-fuelled Development – Taking the highway	• This future poses high challenges to mitigation and low challenges to adaptation • Global population peaks mid-century • Emphasis on economic growth and technological progress • Global adoption of resource and energy intensive lifestyles • Lack of environmental awareness	**RCP8.5**	**SSP5-8.5** • Very high GHG emissions • CO2 emissions triple by 2075	2.4°C

By the end of the century, GDP under SSP1 reaches US$ 280 billion, and US$ 1,000 billion under SSP5 "[xiii].

The major consideration being that under SSP5, fossil-fuelled development results in rapid technological change and human development, globalising markets, and placing a stronger emphasis on production and consumption. In contrast, SSP2, SSP3, and SSP4 have intermediate levels of technological development, which impact their levels of GDP, although SSP2 (often characterised as a "world that continues the historical experience") manages to catch up with SSP1 towards the end of the century "[xiv].

Education is another key characteristic that determines the outcome of the SSP when

WHAT ARE THE CURRENT MAJOR NET-ZERO SCENARIOS?

Figure 3 Future annual emissions of CO_2 across the IPCC AR6's 5 illustrative scenarios[xi]

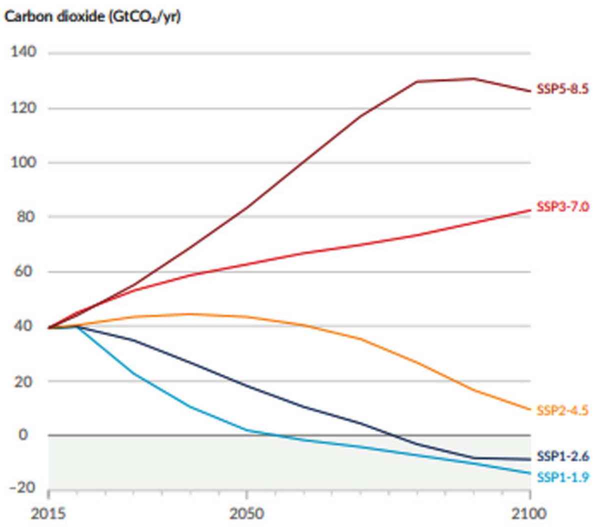
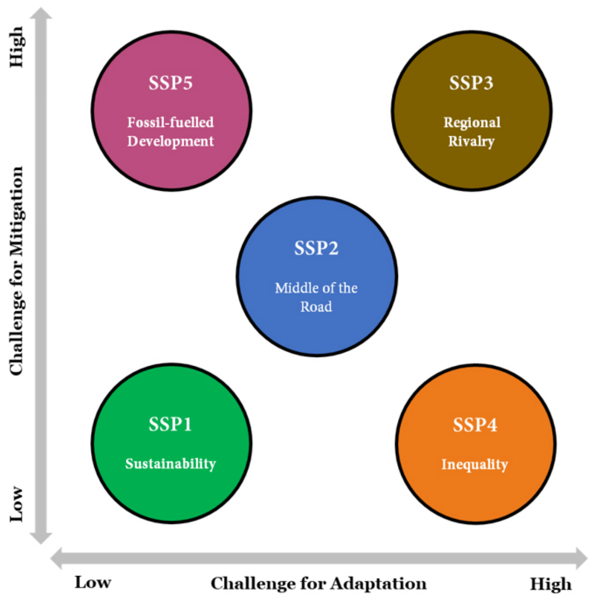


Figure 4 Ranking matrix of the 5 SSP scenarios



combined with radiative forcing (see Table 3). Higher educational attainment results in lower fertility of the human population and higher social inclusion. The "progressive" scenarios SSP1 and SSP5 therefore have substantially lower population projections due to high educational attainment. SSP3, wherein regional rivalry and nationalism is high, results in lower educational attainment and therefore the highest population projection amongst all five futures. SSP4 is characterised by an unequal distribution of educational attainment between rich and poor households / regions.

WHAT ARE THE COMPONENTS OF THE NET-ZERO SCENARIOS?

Almost all net-zero scenarios are comprised of the climate neutral components, shown in Table 4.

Most of these climate neutral approaches to mitigating emissions en route to net-zero are technically and commercially mature. Others are more immature, such as hydrogen in transport. Agricultural waste reduction is relatively straightforward but can be socio-politically complicated due to differing social systems, cultural practices, and limited capital. Almost all of the net-zero scenarios place renewable energy as the backbone of the energy transition, led by solar PV and wind capacity, massive electrification of end uses, a rapid phase-out of fossil fuels, and an unprecedented scale-up of disruptive and emerging technologies, such as electric vehicles, biofuels, hydrogen, and low-carbon codes for buildings.

However, several differences exist. For example, the extent of energy efficiency improvements in the power generation sector, and the reduction of final energy demand varies considerably across all the scenarios. The role of new hydropower, small modular nuclear reactors, biofuels, and disruptive technologies scale-up also lack a systemic definition, which makes their role in the transition somewhat unclear, considering the high inertia of the existing energy system.

Finally, it is very hard to include completely disruptive new technologies that could nevertheless play a role (positive or negative) by 2050. These include technologies that might increase emissions, if not mitigated, notably hypersonic passenger flight and space tourism.

WHAT ARE THE COMPONENTS OF THE NET-ZERO SCENARIOS?

Table 4 Incidence of key climate neutral components in major net-zero scenarios[xv]

Component	Subcomponent	Major net-zero Scenarios					
		BNEF Green Scenario	IEA NZE	DNV Net Zero	BP Net Zero	NGFS Net Zero	IPCC SSP1-1.9
Power Generation	Renewables	●●●●	●●●●	●●●●	●●●●	●●●●	●●●●
	Nuclear	●●	●●●	●	●●	●	●
	Hydropower	●●	●●	●●●	●●	n/a	●●
	Hydrogen	●●	●●●	●●	●●	n/a	n/a
	Energy Efficiency	~	●●	●●●●	●●	●	~
	Energy Storage	~	●●	●●●●	●	●●●	~
Industry	Hydrogen	●●	●●●●	●●	●●●●	n/a	n/a
	Circular Economy	●		●	●	~	~
	Low-carbon electrification	●	●●●	●●●	●●●	●●	n/a
	CCUS		●●●	●	●●●	~	●●
Transport	Electric Vehicles	●●●	●●●	●●●	●●●	n/a	~
	Biofuels	●	●●	●●	●●	n/a	n/a
	Hydrogen	●	●●	●●	●●	n/a	n/a
	Modal Shifts			●●		~	
Buildings	Efficiency	●	●●	●●●●	●	~	●
	Green codes		●●	●●	~	n/a	~
	Distributed renewables			●●	~	n/a	~
	Electrification	●●	●	●●●●	●	~	●
Agriculture	Waste reduction	~	~	n/a	~	●	●●
	Methane capture	~	●	n/a	●	●●	~
	Shifting cultivation	~		n/a	~		n/a
Non-CO2 GHGs	Methane	~	n/a	n/a	●	●	●
	Nitrous Oxide	~	n/a	n/a	n/a	●	●
	HFCs	~	n/a	n/a	n/a	~	●

Table 5 Key indicators that need more focus in the net-zero scenarios[xvi]

Indictors	Supply	• Biofuels • Power-to-X Capacity • Material flow needs
	Demand	• Zero-emission vehicles • Electrification of final energy • Building heating systems • Consumer behaviour
	Cost and Emissions	• CCUS • Afforestation • Natural carbon sinks • Investment cost • Finance gaps
Assumptions	Achievability Limits	• How fast sectors can grow • How much can be electrified • How easily climate-neutral fuels can be supplied • Consumers' role in technology uptake • Impact of carbon budgets • Limits of financing
	Technology Trade-offs	• Electrification versus the use of green hydrogen or derived fuels • Natural gas with CCUS versus upscaling renewables and electricity storage • Public transport versus private EVs

On the low-carbon side, breakthrough technologies could include the 'hyperloop' for mid-range high-speed travel; nuclear fusion; direct solar hydrogen generation; low-cost ocean energy (wave, current, tidal and thermal); CO_2 mineralisation; and battery-electric short/mid-range aviation.

Market design and price formation are a challenge in any net-zero, marginal cost environment and have little or no coverage in most scenarios. Getting the market design and price formation right is important in order to leverage capital in innovation, particularly for new and disruptive technologies like hydrogen, or advanced renewables.

WHAT ARE THE GAPS AND CHALLENGES IN ACHIEVING THE SCENARIOS?

Table 5 provides a summary of indicators and assumptions that require more focus in developing, modelling, and exacting climate change scenarios. These can be regarded as "gaps" in existing scenarios. While commonalities can increase confidence in the future trajectory of technologies, especially mature ones, such as solar PV, wind and increasingly now electric vehicles, consensus can change over time, which can alter policy. For example, CCUS for power generation, biomass, and nuclear dominated most climate change scenarios 15 years ago, whereas today hydrogen plays a larger role and CCUS has been refocused on industry. Focussing on variations in emissions between policy and non-policy-driven scenarios can provide important insights into achievability limits and technology trade-offs, especially in the heavy industry, transport, and buildings sectors.

Because the climate scenarios are designed to focus on larger-scale trends, they can lack focus on societal dynamics and political economy factors that can drive national emissions reduction strategies. Another important facet in modelling is the role of consumers. Consumer choice can affect the pace of deployment of low-carbon products, efficiency improvements in power, and transport.

Social acceptance of new technology infrastructure and design and potential negative behavioural change can result in bottlenecks/challenges that may not be considered by the scenarios. These include community opposition to infrastructure, developing a skilled workforce at the pace required to meet the energy transition, building out supply chain capabilities, ensuring regulators can review and permit investment proposals at the scale and pace needed,

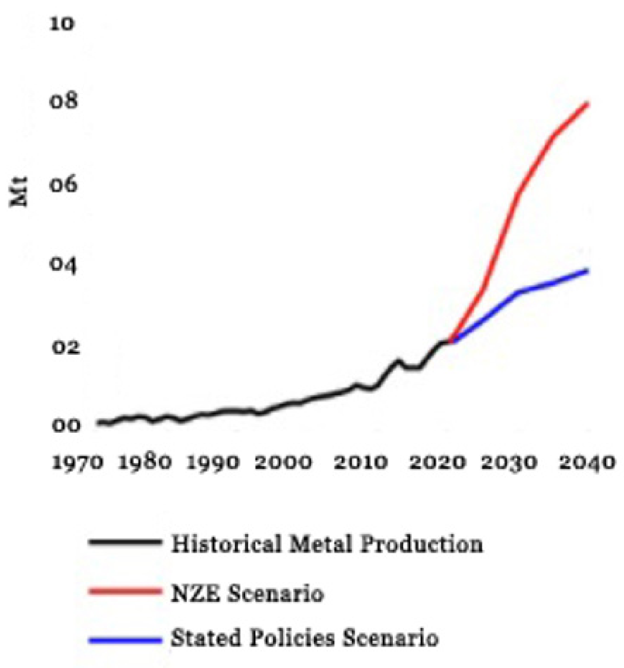
Figure 5 Climate action must progress much faster to achieve net-zero goals[xviii]

	Carbon-neutral approach to help halve emissions by 2030	Required ramp-up from current levels
	Renewable Energy	6x
	Electric Vehicles	22x
	Afforestation / Tree Cover	5x
	Phase-out of coal-fired power plants	5x
	Use of low-carbon fuels	8x
	Electrification of industry	1.5x

lowering upfront cost premiums for new technologies, and the need to mitigate risks with capital to accelerate project timelines to align with a 1.5°c future.

Even though many of the carbon-neutral approaches considered in net-zero scenarios are relatively well understood, their adoption will need to accelerate to reach 2030 and 2050 goals. Merely halving current emissions by 2030 would require ramping up renewables by a factor of 6, electric vehicles by a factor of 22, afforestation by a factor of 5, phasing-out of fossil fuel-based power generation by a factor of 5, the use of low-carbon fuels by a factor of 8, and electrification of industry by a factor of 1.5[xvii].

Figure 6 Renewable energy capacity growth, 2010-2020[xxi]



Climate neutral technologies will also require more critical minerals and precious metals than fossil fuel-based technologies to reach climate goals. This could substantially boost demand for metals like copper, nickel, cobalt and lithium [xix] for renewable energy technologies, electric

Figure 7 Historical nickel production and IEA energy transition scenarios[xxii]

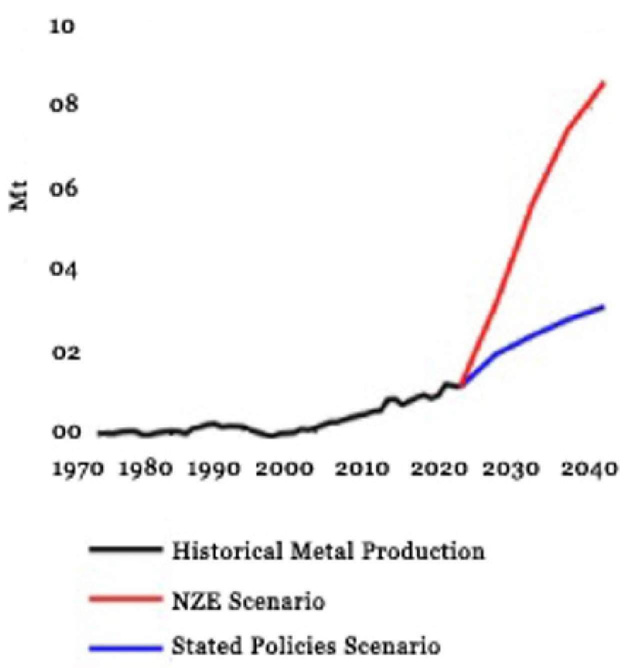
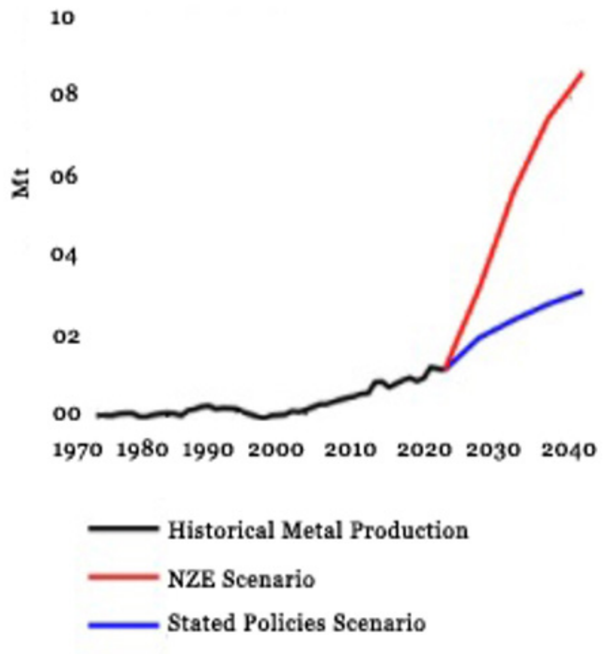


Figure 8 Historical cobalt production and IEA energy transition scenarios[xxiii]



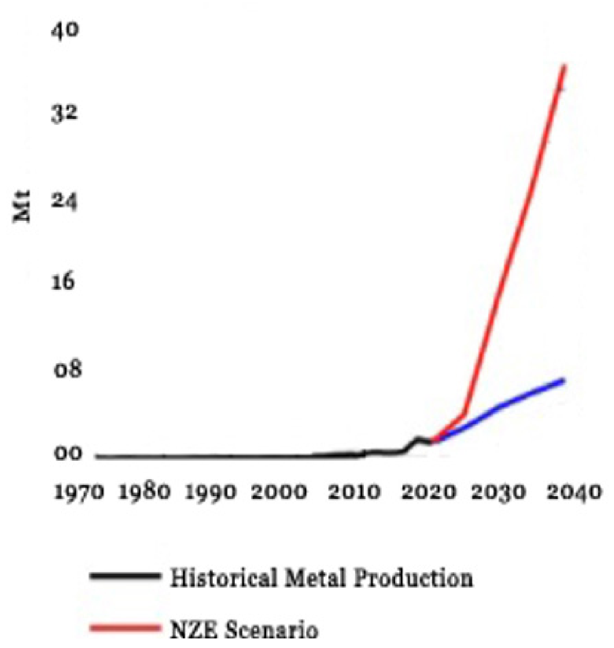
vehicles, hydrogen production, and CCUS. On the supply side, producers will have to act quickly to provide "energy transition metals" as governments and corporates shift increasingly to carbon neutrality.

A fast-paced transition, like the IEA's NZE, implies soaring demand for metals towards a net-zero future. In this scenario, the total consumption of lithium and cobalt increases by a factor of >6, driven by clean energy requirements and batteries. Copper increases twofold and nickel fourfold[xx]. This rapid pace of increase itself will face practical, political, environmental and community obstacles.

Scenario modelling requires the pursuit of near-term action along with long-term objectives to avoid locking in carbon-intensive, non-resilient infrastructure and technologies. This can be done through coordinated policy action between countries to develop inter- and intraregional scenarios that consider the unique social, cultural, environmental, and ecological facets of similar

WHAT ARE THE GAPS AND CHALLENGES IN ACHIEVING THE SCENARIOS?

Figure 9 Historical lithium production and IEA energy transition scenarios[xxiv]



ecosystems. Developing regional models can help countries cut costs in the short and long-term by investing in infrastructure that does not need to be phased out later, designing consistent policies, and providing leverage to the private sector to invest in climate neutrality.

IMPLICATIONS FOR LEADING OIL AND GAS PRODUCERS

- Net-zero scenarios require rapid decarbonisation and mitigation of GHG emissions to be achieved on-schedule.
- All net-zero scenarios will result in a significant reduction of global oil and gas demand, as well as future investment and financing for fossil fuels.
- The transition towards cleaner sources of energy is already underway, and the better-prepared oil and gas giants are already diversifying their operations to include greener portfolios..
- Alongside diversification, many oil and gas companies will begin to cease Exploration and Prospecting (E&P) activity and run existing assets down before returning cash to investors.
- Oil and gas companies need to adopt emission reduction pathways and embark on trajectories of decarbonisation that are compatible with national and global net-zero targets.
- Oil and Gas companies should not only focus on the emissions directly produced by their operations, but also cover in their decarbonisation plans, the emissions generated by the sale of hydrocarbons and their entire supply chain.
- Hydrocarbon producers can secure offsets well in advance (as prices will likely rise) and partner with developers of carbon geoengineering projects, and with countries with high potential, such as those with large forest covers.

CONCLUSION

Even though net-zero scenarios can differ from each other in terms of inputs and assumptions, the common goal remains the same: world emissions need to be abated to avoid 1.5°c warming, and they need to be abated fast. This requires a policy, technology, and behaviour shift across the board. Climate neutral approaches like renewables, fuel-switching, energy efficiency, LULUCF regulations, afforestation, and waste management practices can all exert significant downward pressure on emissions.

Existing infrastructure, particularly in energy, power, and industry, can last for decades, particularly in countries that are heavily dependent on fossil fuels. This can have a major impact on global mid-century targets. Decision makers must address this by establishing near-term and medium-term milestones for their countries towards future net-zero aspirations, including by scaling up their 2030 emission reduction targets as part of their NDCs.

Near-term actions rely on established technologies or at least those now entering commercial viability, such as EVs. However, achieving net-zero would require many more new technologies, such as hydrogen, to be rapidly developed and expanded at competitive cost.

Policy makers and academics can benefit from scenario modelling by working to build a real-time framework that regularly updates GHG historical and future projections.

Developing inter and intraregional scenarios that consider the unique social, cultural, environmental, and ecological facets of similar ecosystems can help countries avoid locking in carbon-intensive, non-resilient infrastructure and technologies. Regional models can help countries cut costs in the short and long-term by investing in infrastructure that does not need to be phased out later, designing consistent policies, and providing leverage to the private sector to invest in climate neutrality.

Finally, to ensure successful implementation, net-zero pathways should be compatible with political, technological and financial realities. They also have to support achieving the Sustainable Development Goals (SDGs), in order to get buy-in from stakeholders and the wider society. Governments, campaigners and companies with net-zero goals have to be very careful not to overlook or compromise other key achievements in human welfare.

APPENDIX

i. The Working Group I contribution to the IPCC's AR6, Climate Change 2021: The Physical Science Basis, was published in August 2021. Other contributions by the IPCC's other two Working Groups and a Synthesis Report will be released in 2022.
ii. World Meteorological Organisation, "2020 was one of the three warmest years on record", January 2021, https://public.wmo.int/en/media/press-release/2020-was-one-of-three-warmest-years-record
iii. https://flo.uri.sh/visualisation/4457649/embed
iv. With CO2 emissions reduced by at least 50% from 2019 levels by 2030.
v. IPCC, "Mitigation Pathways Compatible with 1.5C in the Context of Sustainable Development", Table 2.4, Chapter 2, P119, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf
vi. World Resources Institute, https://www.wri.org/insights/net-zero-ghg-emissions-questions-answered
vii. https://www.climatewatchdata.org/net-zero-tracker
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ix. IPCC, "Climate Change 2021 The Physical Science Basis, Summary for Policymakers", 2021, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf; https://climateanalytics.org/media/gmd-13-3571-2020.pdf for SSP4-6.0
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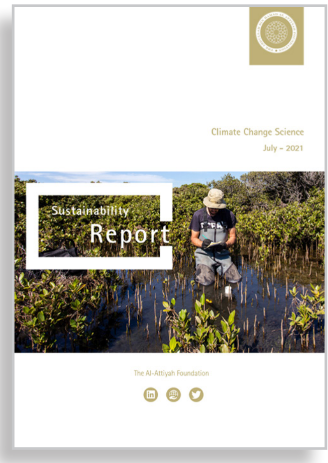

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