The Inevitable Policy Response 2023

IPR 2023 Policy Forecast and Forecast Policy Scenario Summary Results

September 2023

INEVITABLE POLICY RESPONSE

IPR was commissioned by the PRI[1] and is supported by world class research partners and leading philanthropies, financial institutions, & NGOs

1. Principles for Responsible Investment
2. The conclusions of the report are solely those of Energy Transition Advisers and Theia Finance Labs

Commissioned by PRI

In 2018, the Inevitable Policy Response was commissioned by PRI to advance the finance industry's knowledge of climate transition risk & support investor efforts to incorporate climate risk & opportunities in portfolio assessment

PRI Principles for Responsible Investment

A Climate Research Consortium

This report was produced by Energy Transition Advisers and Theia Finance Labs[2]

NGO partners include Carbon Tracker, Climate Bonds & Planet Tracker

Energy Transition Advisors ETA

THEIA FINANCE LABS

Strategic Partners

In 2021, leading financial institutions joined the IPR as Strategic Partners to provide more in-depth industry input, and to further strengthen its relevance to the financial industry

FitchRatings, BNP PARIBAS ASSET MANAGEMENT, quinbrook infrastructure PARTNERS, TEMASEK, apg

Core philanthropic support

The IPR is funded in part by the Gordon and Betty Moore Foundation through The Finance Hub, which was created to advance sustainable finance, and the ClimateWorks Foundation striving to innovate and accelerate climate solutions at scale

THE FINANCE HUB, GORDON AND BETTY MOORE FOUNDATION, climateworks FOUNDATION

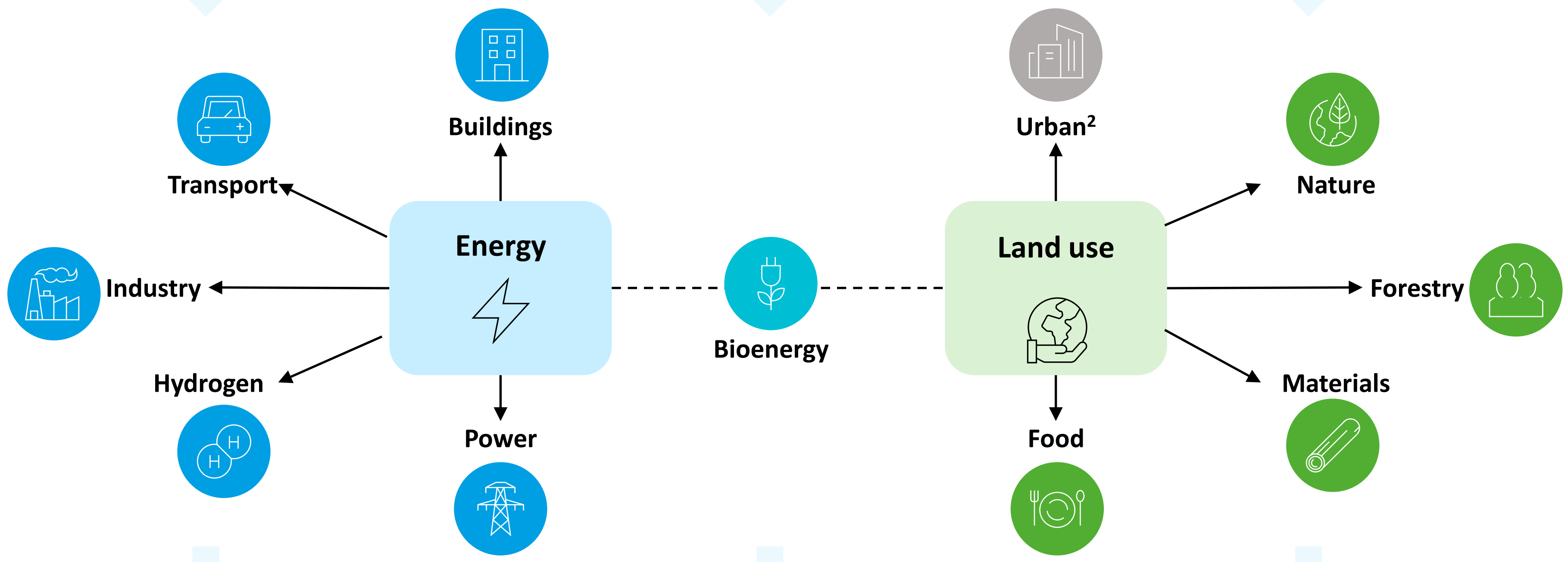
IPR offers a range of applications to help financial institutions navigate the climate transition

Policy Forecast

IPR produces **>300 high-conviction policy forecasts** covering 21 countries and 10 policy areas across energy and land use

Policy forecasts feed into a fully **integrated climate and nature scenario model** that elicits the impact of the forecasted policies on the energy, land use, and nature systems up to 2050, tracing detailed effects on all emitting sectors[1]

Modeling



Value drivers

IPR's integrated scenario model outputs detail value drivers across energy and land use. See Value Driver Visualizer

Applications

Fitch Ratings, Morning Star, Paris Agreement Capital Transition Assessment (PACTA), Planetrics, *tilt* (Climate data for SMEs)

1. IPR also develops a '1.5°C Required Policy Scenario'(1.5°C RPS) building on the IEA NZE by deepening analysis on policy, land use, emerging economies, NETs and value drivers. The RPS scenario is also run through the model and can be used by those looking to align to 1.5°C. 2. Urban areas are not modelled in detail in IPR

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IPR has developed global, policy-based forecasts of forceful policy responses to climate change and implications for energy, agriculture and land use

Please see the IPR Home Page for further details

Scenario	Policy Forecast Details	Open Access Database
IPR 2023 Forecast Policy Scenario (FPS) • Models impact of forecasted policies on the real economy	IPR FPS 2023 Summary Report IPR 2023 Policy Forecast IPR FPS 2023 Detailed Energy Results IPR FPS 2023 Detailed Land Use and Nature Results IPR 2023 Bioenergy Report	IPR FPS 2023 Value Drivers IPR Scenario Explorer
IPR 1.5°C Required Policy Scenario (RPS) • Required policies to align to a **1.5°C objective** building on the IEA's Net Zero scenario and deepening analysis on policy, land use, emerging economies and value drivers	IPR 1.5°C RPS Energy and Land Use System Results including Policy Details	IPR RPS 2021 Value Drivers
IPR Forecast Policy Scenario + Nature (FPS + Nature) • First integrated climate and nature scenario for use by investors	IPR 2022 FPS + Nature detailed results	IPR FPS + Nature Value Drivers

IPR has published a set of publicly available outputs from the FPS and 1.5°C RPS that offer significant granularity at the sector/country level, allowing investors to assess their own climate risk across 4,000+ variables

Disclaimer: This is not intended to constitute policy advice, financial advice or any specific advice.

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The Inevitable Policy Response has begun…

The Inevitable Policy Response is now under way, but there is plenty of work left to do

Nearly 90% of OECD policy announcements are now consistent with the IPR FPS, although implementation and legislation remain key. This number drops to 40% for the non-OECD, partly driven by their longer decarbonization runway, highlighting the crucial policy gap for the next decade as policies ratchet through 2030.

Despite progress, the 1.5°C low overshoot goal no longer appears feasible.

Only 3% of global policies forecasts (based on their relative importance to emissions) are currently consistent with the IPR Required Policy Scenario (1.5°C low overshoot).

Given policy trends, global net zero only slightly delayed, affirming the IPR forecasts

Advanced Economies (AEs) reach near-zero CO_2 emissions by 2050 and Emerging Market and Developing Economies (EMDEs) reach net zero by the 2060s, consistent with the outcome of our policy pulse survey across sustainability professionals and experts. Of course, these outcomes still require significant policy action.

Just Transition & broader sustainability considerations become key guardrails in the policy transition

Social aspects of the transition inform future land use - as the role of nature conservation increases in parallel – and phase outs of fossil fuels. Just Transition elements will likely play a growing role in the policy landscape.

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….Driving a high conviction forecast of temperatures peaking at 1.7-1.8°C by the 2040s…

Our high conviction forecast sees temperatures peak at 1.7°- 1.8°C

Building on 300+ forecasts across 10 policy levers and 21 countries, +100 expert surveys, and the tracking of hundreds of policies, IPR FPS 2023 presents a *high-conviction* forecast that the Paris Agreement "well below 2°C goal" will be met (1.7° - 1.8°C peak by 2040s).

The high conviction forecast provides extra runway for emerging markets

Emerging markets have roughly 10-15 years extra runway to net zero in the forecast, implying a slower policy transition. Despite the extra time, we still expect policies to ratchet over the next decade.

Expected best case ambition by 2100 may see temperatures drop

We expect that climate impacts and risk of tipping points will drive policymakers to not accept temperature stabilization at 1.7-1.8°C and thus to maintain the Paris Agreement goal of making efforts to 1.5°C with a best case outcome through Direct Air Carbon Capture & Storage (DACCS) of 1.6°C by end of century and the potential to stabilize temperatures at 1.5°C by 2120s.

NETs are key to temperatures declining towards 1.5°C

While we assume scaling of nature-based solutions in land, our 1.7-1.8°C forecast does not require technology based negative emissions technologies. However, pushing the temperature curve down further while avoiding geoengineering will only be achievable with DACCS. We expect OECD governments to pioneer DACCS development.

Land becomes the crucial challenge for ensuring temperature stabilization

Land becomes the crucial battleground for reaching climate goals over the next decades – both as a carbon sink (~3 Gt pa) as well as the growing share of land emissions – with beef and lamb reaching >20% of global GHG emissions by 2050, despite only representing ~10% of caloric intake.

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Challenges remain for achieving the forecast

Roughly 50% of the policy gap we identify to achieve our forecast is linked to coal power in India and China. Our forecast assumes some degree of 'economic stranding'. However, relative to our evidence base and expert survey, we don't see a more pessimistic view extending the time horizon of coal by more than 5-10 years.

The forecast requires some countries (e.g. Russia, Saudi Arabia) currently not globally supportive of the climate agenda to take action on climate. More than 10% of the policy gap is linked to Russia alone. However, we generally take a very conservative view (Russia does not reach net zero until post 2065) and don't expect the related emissions contributions by the second part of the century to impact climate outcomes.

Ending deforestation needs significant acceleration. We forecast an acceleration of policy ambition around deforestation following the election of Lula in Brazil and shifting dynamics in Indonesia. Some of our forecasts are roughly 5-10 years more 'ambitious' than the expert and pulse feedback survey.

Advanced Economies accelerated policy, but they start from a position of significant historic emissions and policy ambition remains misaligned with the IPR Required Policy Scenario delivering 1.5°C low overshoot. The overall policy window across AEs and EMDEs remains ambitious given the lack of accelerated action towards 1.5°C. This points to AEs tackling historic emissions via DACCS, seeking to stabilize long-term temperatures below 1.7°C.

Despite these challenges, we consider our forecast overall to represent a realistic ambition to reach Net Zero AE 2050 and EDMEs 2060s. Potential policy backsliding across these areas by 5-10 years would have at most 0.1°C impact from a temperature perspective.

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Despite these challenges, IPR policy forecasts are high conviction driven by a comprehensive evidence base of surveys, policies, markets, and expert judgements

Input

IPR 2021 policy forecast

IPR 2021 forecast

The starting point for this analysis

Climate policy forecasts covering energy and land use across the G20 plus Nigeria and Vietnam

Robust evidence base

Three core types of evidence inform the IPR policy forecasts

Barriers and drivers of policy

Analysis of drivers and barriers of policy action, including live policy tracking

Assessment of the current social, technological, and economic conditions

Policy gap analysis vs IPR 2021

Assessment of existing policy relative to IPR 2021 forecasts, including policy gaps

Expert survey

Market assessment through survey of >100 leading experts in national climate policy covering 12 countries

Forecast process

Assessment of evidence by IPR Consortium

Initial decision rule

Decision rules were used to interpret IPR evidence base and derive policy forecasts

IPR Consortium expert judgment

IPR Consortium reviewed all evidence in detail to finalise policy forecasts

Output

IPR 2023 policy forecast

IPR 2023 forecast

The output point of the analysis

Climate policy forecasts covering energy, land use, and nature across the G20 plus Nigeria and Vietnam

Supplementary evidence

Policy pulse survey

Climate survey of >100 participants of sustainability professionals

Climate impacts

Physical impacts of climate change, notably heat stress and extreme weather events

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Our forecast maps the key implications for financial institutions of the projected decarbonization pathway…

NET ZERO CO_2 IN 2050 FOR ADVANCED ECONOMIES

Net zero 2050 targets focused on activities in Advanced Economies are consistent with our forecast. However, net zero 2050 appears unlikely for Emerging Market Developing Economies and more policy action is needed to accelerate progress to net zero in the 2060s.

CLEAN ENERGY BOOM

A combination of a dramatic increase in clean energy incentives and market trends mean the low-carbon transition remains a central investment thesis for financial institutions, with total investment across the energy sector doubling between 2025 and 2050. Clean power and electrified transport drive 76% (21GtCO_2) of emission reductions to 2050, thanks to policy driving rapid cost reductions. Zero-emission vehicles (ZEVs) reach almost 90% of the car fleet by 2050.

INDUSTRY DECARBONIZATION BEGINS

Deep industrial decarbonization at scale begins by the 2030s, thanks in large part to a shift toward clean hydrogen, industrial CCS and a variety of other recycled and bio-based materials. Next generation industrial processes steadily replaces older, high carbon processes, spearheaded by steel, cement and chemicals. Over 10% of primary energy is used to produce green hydrogen by 2050.

EFFICIENCY AND BUILDINGS IN TRANSITION BY 2030

Increased efficiency of both building envelopes and electrical heat pumps reduce emissions from 2030. New net zero buildings only account for 28% of 2050 stock, meaning retrofits are critical to decarbonization.

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…and the tremendous investment opportunities for nature- and technology-based solutions for capturing emissions

NATURE BECOMES KEY

Incentives for negative emissions and biodiversity restoration drive large-scale growth in high-integrity Nature Based Solutions (NBS), converting millions of hectares of low- or no-productivity land into natural investable sources for carbon removal.

LAND SCARCITY A CHALLENGE

Land scarcity becomes a critical bottleneck for delivering both on climate goals and nature objectives. When considering sustainability guardrails (nature, social, etc.), only 300mha of land is available for bioenergy, of which only approximately 50mha is sufficiently economically attractive to develop for bioenergy when considering costs and the existing carbon captured by the land (estimated using a "carbon payback period".

BIOENERGY IS CONSTRAINED BY POLICY "GUARDRAILS" AND COSTS.

This leaves limited investment opportunities in Bioenergy with Carbon Capture and Storage (BECCS) and aviation and pulp and paper. In the medium- to long-term, we forecast that bioenergy will likely be replaced by other low-carbon solutions across its other applications (e.g. shipping, power).

DACCS IS THE FUTURE

Direct air carbon capture and storage (DACCS) becomes the crucial negative emissions technology in the long-run, both given its more flexible land requirements and cost competitiveness relative to BECCS. FPS forecasts 0.6Gt of DACCS by 2050, predicated on near-term demonstration DACCS sites, which move the technology along the learning curve in the 2030s and reduce costs to as low as $150/tCO_2$.

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While we identify growing consensus around our forecast in terms of Net Zero, the temperature implications remain poorly understood and uncertain

The relationship between temperature outcomes and net zero is poorly understood and highly complex. While our high-conviction forecast is largely mirrored across the evidence base (pulse, expert survey, policy ambition), our survey of sustainability professionals suggest a significant gap between their expectations of net zero and temperature outcomes. **We recommend investors focus on forecasts impacting sector trends leading to Net Zero outcomes.**

Uncertainty remains around temperature forecasting. The uncertain relationship between GHG emissions and temperature outcomes means that our 1.7-1.8°C forecast is achieved at ~50-66% probability given various methodologies. However, our forecast causes temperature to peak at 2°C or below with a 90% probability, suggesting 2°C warming increasingly as a “worst case outcome.”

A 1.7-1.8°C forecast may seem ambitious, but we consider a 2.5°C future overly pessimistic. A 2.5°C future would imply effectively flat emissions for another 40 years before the Inevitable Policy Response kicks in and net zero not being reached until the next century, 40-50 years later than announced net zero targets across >75% of global emissions. Even some policy backsliding likely still implies temperatures peaking below 2°C.

There is also uncertainty around the social & climate tipping points. While the temperature forecasts considers some feedback loops (e.g. permafrost thawing), the IPCC does not expect significant climate feedback loops to materialize below <2°C. Our forecast reflects this while recognizing the significant remaining uncertainty around climate feedback loops. Moreover, social tipping points may create a dramatically different policy dynamic with significant economic implications, but also implications for policy more broadly, including the social acceptance of geoengineering, and the ability to deliver the required investment to decarbonize EMDEs.

How does the IPR 2023 Forecast Policy Scenario (FPS) achieve the Paris Agreement?

The FPS predicts concerted policy action in response to rising climate impacts, leading to net zero CO_2 emissions by 2060 and net zero GHG emissions by 2080, which is consistent with Article 4 of the Paris Agreement

Temperatures are expected to peak between 1.7°C and 1.8°C, which is consistent with the "well below 2°C" objective of the Paris Agreement in Article 2.1

IPR forecasts that average global temperatures will breach the 1.5°C, the lower limit in the Paris Agreement, in the 2030s, leading to impacts on social and natural systems and increasing systemic risks for investors

In light of these risks, policy efforts are forecast to continue "pursuing efforts" to achieve the lower temperature limit of the Paris Agreement, with the potential of achieving the 1.5°C goal by the 2120s through carbon removals

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The IPR 2023 forecast provides an update to IPR 2021, covering 21 major economies accounting for 74% of global CO_2 emissions

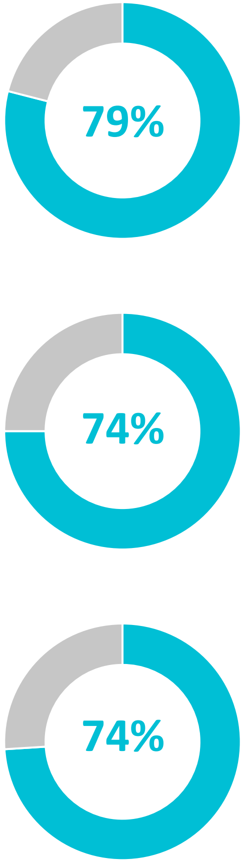
New for IPR 2023

IPR policy forecasts cover G20 countries plus Nigeria and Vietnam…

… And covers policy across all major energy and land use sectors…

- Power
- Transport
- Buildings
- Industry
- Agriculture
- Land use
- Nature

… With IPR countries accounting for



79% of global economic activity

74% of global energy use

74% of global CO_2 emissions

Source: GPD, energy use, emissions. Latest available data was used.

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IPR 2023 forecasts higher climate policy ambition across 10 policy levers covering energy, land use, and nature

Net zero

- Interim emissions target
- Net zero CO_2 long-term target

Carbon pricing

- Carbon taxes
- Emission trading systems
- Carbon border adjustment mechanisms (CBAMs)

Clean power

- Targets for a fully decarbonised electricity system
- Renewable capacity auctions
- Renewable subsidies
- Nuclear power targets and and strategies

Low-carbon buildings

- Prohibiting regulations for fossil heating systems
- Purchase subsidies for low-carbon heating systems
- Thermal efficiency regulations for buildings
- Minimum energy performance standards for new appliances

Low-carbon agriculture

- Subsidies for low-emissions practices and technologies
- Emissions regulation including via tax or cap-and-trade systems
- Farmer education and technical assistance programs

Coal phase-out

- Regulations prohibiting coal build
- Emissions performance standards
- Electricity market reforms

Zero emissions vehicles

- ZEV consumer subsidies Targets to fully decarbonise the new sales of road vehicles
- Manufacturer ZEV obligations

Clean industry

- Emissions performance standards for industrial plants
- Subsidies for new or retrofit clean industrial processes

Forestry

- Incentives for reforestation and afforestation
- Penalties for deforestation, supported by consumer pressure
- Mandates to ensure deforestation free supply chains

Nature-based solutions

- Land protection and restoration policy
- Nature incentives for landowners to protect biodiversity hotspots and habitats
- Voluntary biodiversity credit markets

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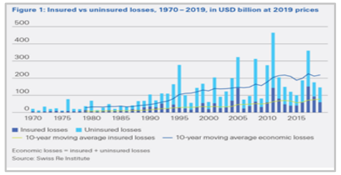
The drivers of policy momentum make an inevitable and forceful policy response more likely…social tipping points are key

Changes in physical & monetary costs

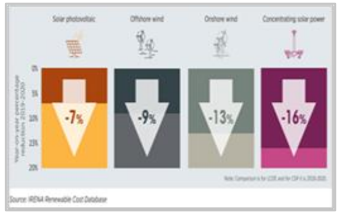
Extreme weather events

Increase in wet-bulb globe temperature

Uninsurable world



Cheaper renewable energy



Increased pressure from society, markets & regulators

Financial markets pressure for net zero

Civil society advocating for 1.5C

Financial regulator interventions

Pressure for global institutions to support EDMEs transition

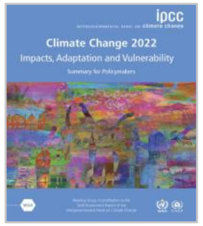
Changes in geopolitics, energy security and research

US IRA impact on industrial policy

Impacts on security

Improved climate collaboration

New climate research



Ratchet pressures increase the likelihood that governments will strengthen policy by 2025, and again to 2030 and beyond

Paris Ratchet process triggers a cumulating policy response into 2025, 2030, and beyond

2021	2023	2025	2028	2030
Countries communicate their updated or 2nd round of climate pledges	Global Stocktake (GST) on climate, mitigation, and finance	**2025 Ratchet** Countries submit their 3rd round of climate pledges (NDCs)	Second Global Stocktake (GST) on climate, mitigation, and finance	**2030 Rachet** Countries submit their 4th round of climate pledges (NDCs)

Policy announcements are expected to continue in 2023 -2025, with continued acceleration in 2028-2030. Recognition of Overshoot grows from 2025

COP28 UAE

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Over 50% of IPR 2023 forecasts have policy in place that is confirmatory or supportive of the forecast

Existing policy developments are assessed against the IPR's 2023 forecasts...

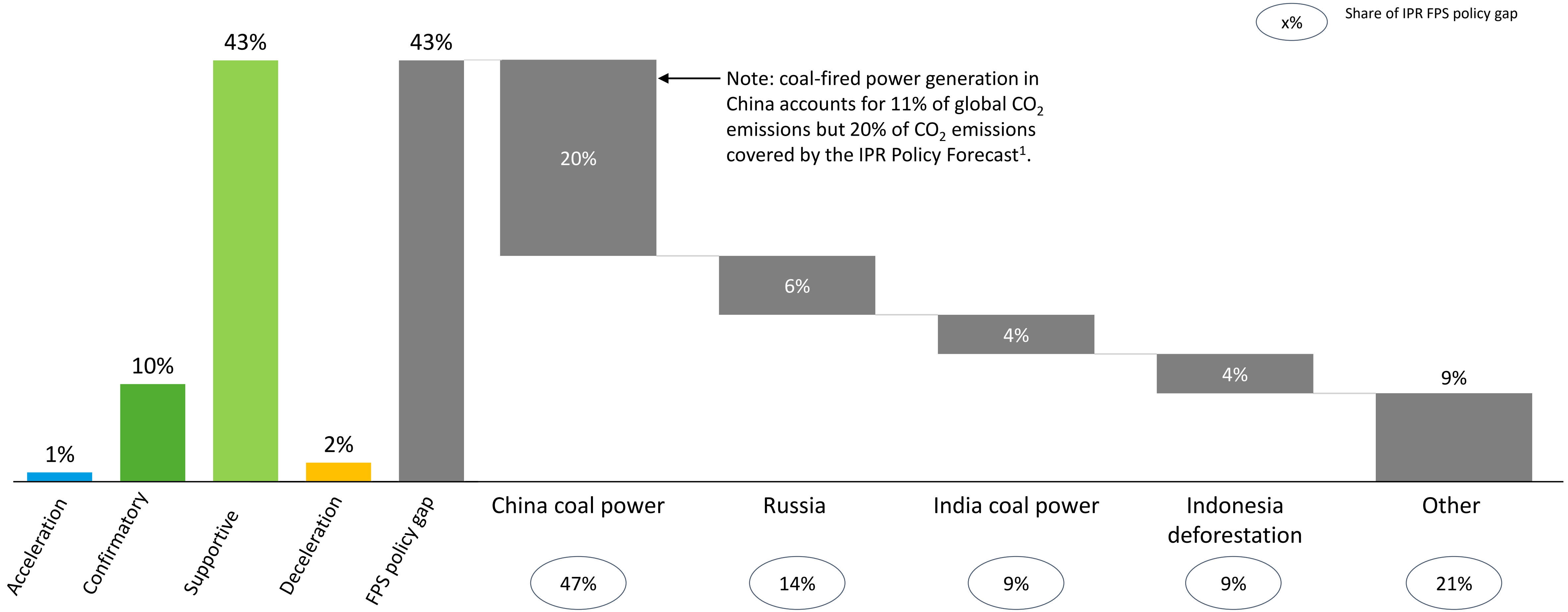
...With over 50% of forecasts having policy in place that is confirmatory or supportive of the forecast and ~40% of forecasts having a policy gap

	Policy gap assessment categories	... By number of policy forecasts, %...	... By CO_2 emissions share of policy forecasts[1], %
Accelerating beyond FPS towards IPR's 1.5°C RPS	**Acceleration** Policy announced or legislated/implemented that addresses the specific IPR forecast and sets a target date that is earlier than forecast in 2023	4%	1%
Consistent with IPR's 1.8C FPS	**Confirmatory** Policy announced or legislated/implemented that addresses the specific IPR forecast and is in line with what was forecast in IPR 2023	22%	10%
	Supportive Policy announced or legislated/implemented that moves in the direction of forecast but does not definitively meet it	37%	43%
Decelerating away from FPS towards a 2°C outcome	**Deceleration** Policy announced or legislated/implemented that addresses the specific IPR forecast but sets a target date that is later than forecast in 2023	1%	2%
	FPS policy gap No policy announced	35%	43%

1. Weighted by CO_2 emissions covered by IPR's policy forecasts.

China's coal-fired electricity fleet contributes nearly half of the gap to be addressed in IPR's 2023 policy forecast

Breakdown of IPR policy forecasts with no existing policy announcements to meet them, weighted by CO_2 emissions[1]



1. Weighted by CO_2 emissions covered by IPR's policy forecasts. IPR policy forecasts do not cover all CO_2 emissions and therefore the percentage breakdowns shown will likely be higher than if this analysis was done for all countries and sectors, covering all global emissions. For example, coal-fired power generation in China accounts for 11% of global CO_2 emissions but 20% of emissions covered by IPR policy forecasts.

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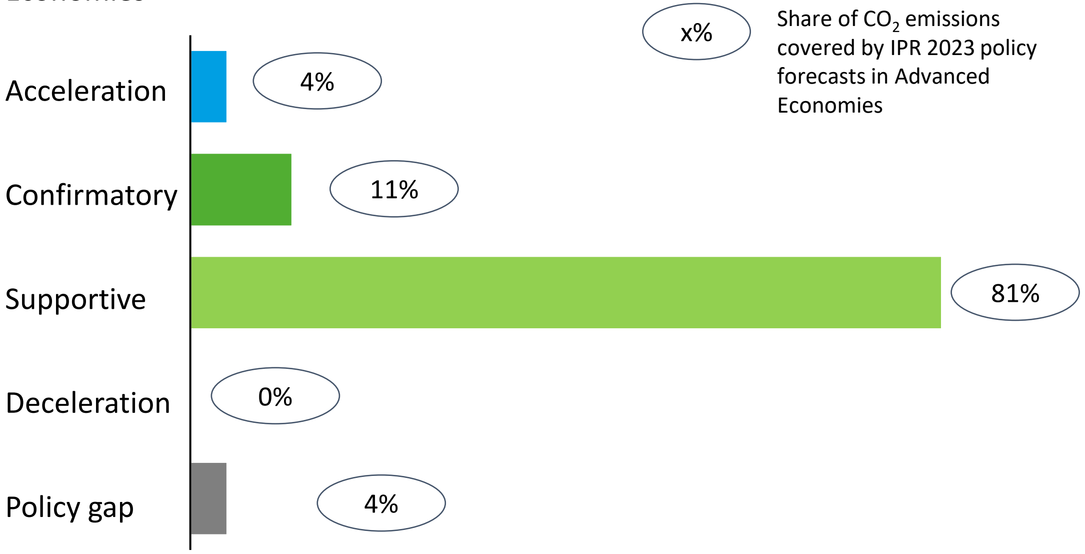
Advanced Economies have closed nearly all the policy gaps…

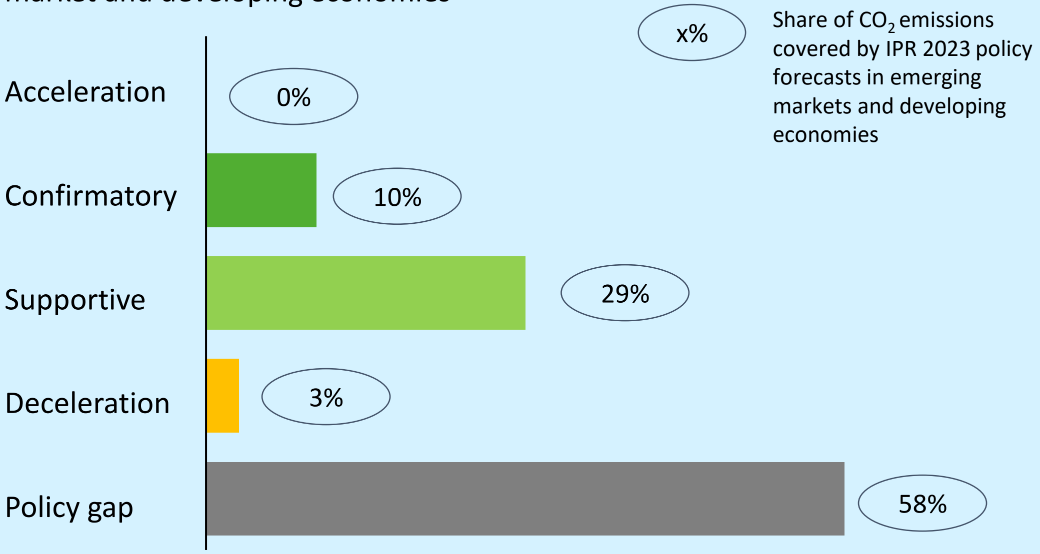
Policy forecasts relative to existing policy announcements[1], IPR Advanced Economies



- >90% of CO_2 emissions in IPR Advanced Economies (AE) are covered by existing climate policy that meets, or moves in the direction of meeting, IPR's Forecast Policy Response (FPS)
  - 4% accelerates beyond FPS towards IPR's 1.5°C Required Policy Response (RPS)
  - 11% is confirmatory of FPS, of which ~40% is legislated, while 81% moves in the direction of meeting it, of which ~30% is legislated
- 4% of CO_2 emissions in IPR AE are not covered by existing climate policy that aims to reduce them

…But the key challenge is in Emerging Markets & Developing Economies

Policy forecasts relative to existing policy announcements[1], IPR emerging market and developing economies



- 39% of CO_2 emissions in IPR emerging market and developing economies (EMDE) are covered by existing climate policy that meets, or moves in the direction of meeting, IPR's FPS
  - 10% meets the forecast (confirmatory), of which ~15% is legislated, while 29% moves in the direction of meeting it, of which ~25% is legislated
- 58% of CO_2 emissions in IPR EMDE are not covered by existing climate policy that aims to reduce them

1. Weighted by CO_2 emissions covered by IPR countries and policy forecasts. The % of emissions is based on those covered by the IPR policy forecast and therefore excludes some such as aviation & shipping

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While some sectors have significant climate policy, such as power and LDVs, others have many gaps, such as coal phase out and HGVs

Policy gap assessment relative to IPR 2023 forecast[1]: FPS policy gap | Acceleration | Confirmatory | Supportive | Deceleration

		Economy wide		Power			Buildings	Transport		Industry	Agri	Land use		Nature	
	Country[2]	Net Zero CO_2 emissions	Carbon price	New coal phase out	All coal phase out	Clean power	Zero-carbon heating	Light duty vehicles	Heavy duty vehicles	Industry decarb.	Low-carbon agriculture	Net deforestation [3]	Deforestation free supply	Protection[4] & restoration	Nature incentives
Advanced Economies	US	Announced	Policy gap	Legislated	Announced	Announced	Legislated	Announced	Announced	Legislated	Legislated	Announced	Policy gap	Announced	Legislated
	Japan	Legislated	Announced	Policy gap	Announced	Announced	Announced	Announced	Policy gap	Announced	Legislated	Policy gap	Policy gap	Legislated	Policy gap
	Germany	Legislated	Legislated	Legislated	Announced	Announced	Announced	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated
	South Korea	Legislated	Legislated	Announced	Announced	Announced	Policy gap	Announced	Policy gap	Announced	Announced	Policy gap	Policy gap	Legislated	Policy gap
	Canada	Legislated	Legislated	Legislated	Legislated	Announced	Announced	Announced	Announced	Legislated	Legislated	Legislated	Policy gap	Announced	Legislated
	Australia	Legislated	Legislated	Policy gap	Policy gap	Announced	Policy gap	Announced	Policy gap	Legislated	Legislated	Legislated	Policy gap	Announced	Announced
	UK	Legislated	Legislated	Legislated	Legislated	Announced	Announced	Announced	Announced	Legislated	Legislated	Legislated	Legislated	Announced	Legislated
	Italy	Legislated	Legislated	Announced	Announced	Announced	Announced	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated
	France	Legislated	Legislated	Legislated	Legislated	Legislated	Announced	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated	Legislated
Emerging Markets & Developing Economies	China	Announced	Legislated	Policy gap	Policy gap	Announced	Announced	Announced	Policy gap	Announced	Legislated	Announced	Policy gap	Legislated	Legislated
	India	Announced	Announced	Announced	Policy gap	Announced	N/A	Policy gap	Policy gap	Legislated	Policy gap	Announced	Policy gap	Legislated	Policy gap
	Russia	Announced	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Legislated	Policy gap
	Indonesia	Announced	Announced	Announced	Announced	Announced	N/A	Announced	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Legislated	Policy gap
	Saudi Arabia	Announced	Policy gap	N/A	N/A	Announced	N/A	Policy gap	Policy gap	Announced	N/A	Announced	Policy gap	Announced	Policy gap
	Brazil	Announced	Announced	Policy gap	Policy gap	Announced	N/A	Policy gap	Policy gap	Policy gap	Announced	Announced	Policy gap	Legislated	Announced
	Turkey	Announced	Announced	Policy gap	Policy gap	Announced	Policy gap	Policy gap	Policy gap	Announced	Policy gap	Announced	Policy gap	Legislated	Policy gap
	South Africa	Announced	Announced	Announced	Announced	Announced	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Legislated	Announced
	Mexico	Policy gap	Legislated	Policy gap	Policy gap	Policy gap	N/A	Announced	Policy gap	Policy gap	Policy gap	Announced	Policy gap	Legislated	Legislated
	Vietnam	Announced	Announced	Announced	Announced	Announced	N/A	Announced	Announced	Announced	Announced	Announced	Policy gap	Legislated	Legislated
	Argentina	Announced	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Announced	Policy gap	Policy gap	Policy gap	Announced	Policy gap	Legislated	Legislated
	Nigeria	Legislated	Policy gap	Policy gap	Policy gap	Announced	N/A	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Policy gap	Legislated	Policy gap

1. Based on major announcements and developments tracked in IPR 2021 Policy Forecast Detailed resource (March 2021) and 2022 and 2023 QFTs
2. Countries in each bucket (AE and EMDE) are ranked in order of CO_2 emissions, European Commissions Emissions Database

2. End of deforestation is defined as reduction in average annual deforestation by more than 95% versus the 1990-2020 level, alongside a net increase in forest cover
4. Policy gap assessment is shown for land protection only

INEVITABLE POLICY RESPONSE

The potential implications of climate action on achieving a just transition are used to inform IPR's policy forecasts

IPR's policy forecasts incorporate just transition impacts across policy areas

Just transition impacts of existing policy announcements

Climate policies with greater positive just transition impacts are likely to be more effective at achieving their goals

Employment impacts

A large domestic manufacturing sector of fossil fuel products, which accounts for a high share of employment, is likely to act as a barrier to the phase out of such products

Health impacts

A high level of air pollution, which causes negative health impacts, is likely to accelerate the phase out of highly polluting industries such as coal-fired power generation

Land

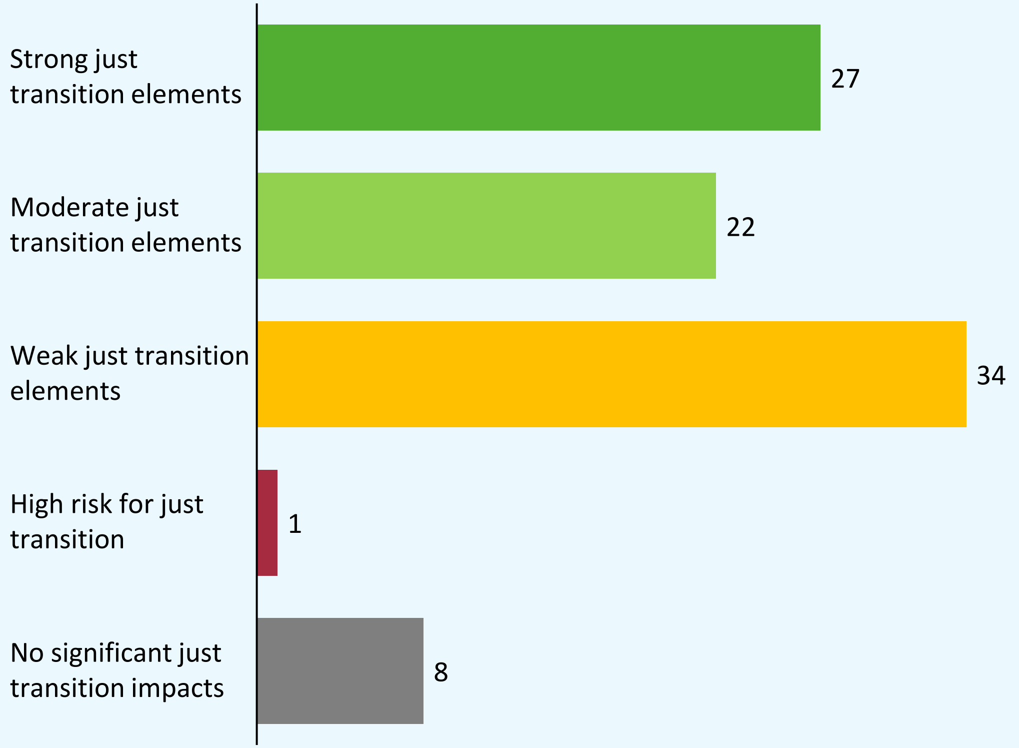
Increased land constraints (e.g., land required for urban areas or food production) act as a barrier to reducing environmentally harmful practices such as deforestation

Institutional capacity

Higher institutional capacity increases the ability of the state to support and/or compensate indigenous and rural communities to shift away from CO_2 -emitting activities and maintain living standards

Scoring deep dive: ~90 climate policy developments have been scored against just transition impact categories over the past 12 months[1]

Number of policies in each just transition impact category



1. Assessments of just transition elements completed by researchers at the LSE, building on Chan, Tiffanie; Higham, Catherine; Muller, Sabrina; Setzer, Joana; and Robins, Nick (2022). 'An assessment of Just Transition elements in the Inevitable Policy Response'. Available at: https://www.lse.ac.uk/granthaminstitute/publication/an-assessment-of-just-transition-elements-in-the-inevitable-policy-response/.

INEVITABLE POLICY RESPONSE

(1/2) IPR 2023 Top 10 Policy Forecasts

Timing	**1.**	IPR policy announcements carry on over the next decade, with continued announcements to 2025 following the Paris Agreement's first Global Stocktake, and continued acceleration to 2030 and beyond in the harder-to-abate sectors.
Economy wide	**2.**	India achieves net zero CO_2 emissions by 2065, accelerating 5 years ahead of its existing net zero by 2070 target (India contributes 7% of global CO_2 emissions). • The acceleration is driven by India's exposure to climate change and falling low-carbon technology costs
	3.	Several non-OECD countries achieve net zero emissions later than their current targets given slow decarbonisation progress to date. • Turkey and Vietnam reach net zero by 2060 and South Africa beyond 2065 despite all having targets between 2050-55 (each country contributes 1% of global CO_2 emissions) • Russia reaches net zero beyond 2065 despite a target of 2060 (Russia contributes 5% of global CO_2 emissions)
	4.	Low-carbon incentives play an increasingly important role in facilitating the climate transition as countries continue to respond to the US Inflation Reduction Act. • Carbon prices are expected to have a stronger role in enabling the transition in advanced economies compared to the emerging market and developing economies
Power	**5.**	China ends the construction of new unabated coal-fired electricity generation by 2030 and end all unabated coal generation by 2045[1], but keeps ~400GW of unabated coal plants in reserve and retrofit ~100GW with CCS (China coal-fired electricity contributes 11% of global CO_2 emissions). Unabated coal phase out is driven by China's economy-wide net zero target, the decreasing relative costs of alternative power sources and CCUS retrofit.
Nature	**6.**	Land protection reaches 30% of national land area by 2035 in North America and China, and by 2030 in Europe, as nature and biodiversity policy accelerates following COP15. The Kunming-Montreal Global Biodiversity Framework targets 30% of global land and marine areas to be protected by 2030.

1. Definition for ending unabated coal generation: actual policy and anticipated policy signals deliver 97% of dispatched power generation from sources other than unabated coal. Coal is abated when installed with CCS with a capture rate of 90% or equivalent

INEVITABLE POLICY RESPONSE

(2/2) IPR 2023 Top 10 Policy Forecasts

Road transport	**7.**	The sale of new cars and vans with CO_2 emissions mostly ends by 2040,[1] driven by global automotive OEMs decarbonising, EV technology improvements and cost falls, and increasing policy momentum to meet national net zero targets (cars and vans contribute 8% of global CO_2 emissions). • Europe and China stop selling cars and vans with CO_2 emissions by 2035 • The US and India end the sale of cars and vans with CO_2 emissions by 2040
Industry	**8.**	Industry achieves deep decarbonisation (>97% for fuel combustion and >80% for process emissions) [2] after economy-wide net zero, with iron and steel, chemicals, and cement decarbonising after light industry has electrified (industry contributes 23% of global CO_2 emissions). • Europe begins decarbonising heavy industry in the 2020s, with steel moving quicker than chemicals and cement, as low-carbon incentives and the phase out of EU ETS free allowances, drive scaled deployment of low-carbon heavy industry in the 2030s and 2040s • The US delivers heavy industry decarbonisation primarily through low-carbon incentives, e.g., the IRA, on a similar timeline to Europe • Heavy industry decarbonisation spreads globally with a 5-10 year lag to the US and Europe, as high low-carbon incentives and national carbon pricing are more widely adopted and CBAMs incentivise global decarbonisation to protect export market shares
Carbon removals	**9.**	Policy delivers significant DACs deployment from 2040 through primarily market incentives as climate change impacts increase and the cost of DACs falls. There is a limited role for BECCS in the climate transition given technology costs as well as land constraints resulting from guardrails for avoiding nature displacement, deforestation, food competition, irrigation, and use of land unsuitable for bioenergy.
Land use	**10.**	Global net deforestation ends[3] by 2030-35 (land use change contributes 10% of global CO_2 emissions). • Brazil ends net deforestation by 2030 in line with existing policy ambition and due to ratchet pressures of hosting COP30 in 2025, and Indonesia also ends net deforestation by 2030 given recent falls in deforestation levels and expected ratchet pressures at COP30 in the Amazon (both countries each contribute 25% of CO_2 emissions from land use change) • Deforestation-free supply chain mandates from Europe and North America reinforce domestic pressures to end deforestation

1. Forecast definition: policy ends the sale of 97% of new cars and vans with CO_2 emissions. (I.e., 97% of sales are ZEVs). ZEV = BEV, PHEV, FCEV.
2. Deep decarbonisation is defined as full deployment of the best available technology. According to the IEA Net Zero by 20250 report deployment of such technology is expected to deliver ~93% emissions reduction across industry. This equates to a reduction in emissions of ~97% for fuel combustion and ~80% for industrial processes – IEA.
3. End of deforestation is defined as a reduction in average annual deforestation by more than 95% versus the 1990-2020 level alongside net increase in forest cover.

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INEVITABLE POLICY RESPONSE

(1/3) IPR 2023 Top FPS Model Results – System wide and energy

Net Zero	**1. Advanced Economies reach near-zero CO_2 emissions by ~2060** with substantial emissions in Emerging and Developing economies. They still emit ~9 $GtCO_2$ in 2050 mainly from industry. Even easier-to-decarbonize sectors like power and transport do not do so fully until the 2060s
Temperature	**2. Temperatures peak at 1.7 – 1.8 degrees in the 2040s, falling to 1.6 – 1.7 degrees by 2100,** due to deployment of ~ 5Gt per annum of land and technology-based removals from 2050. Warming breaches 1.5 degrees in 2033 but could return to below 1.5C around the 2130s, provided emissions remain constant from 2100
Peak fossil use	**3. All fossil fuels decline following a mid-2020s plateau.** • Coal, oil and gas demand decline by 66%, 62% and 52% respectively between 2019 and 2050
NETs	**4. Negative Emissions Technologies (NETs) play a significant role in bending the temperature curve.** • 1 Gt of BECCS is deployed to 2050 • The FPS includes 0.6Gt of direct air carbon capture and storage (DACCS) by 2050 and 5 Gt by 2080, predicated on near-term demonstration DACCS sites, which move the technology along the learning curve in the 2030s and reduce costs to as low as $150/$tCO_2$
Power	**5. China acts on coal and rapid renewables deployment enables 85% of global power generation to be carbon free by 2050.** • By 2045, China retires 60% (800GW) of its unabated coal fleet, fits 100GW with carbon capture and storage (CCS) and keeps the “economically stranded” remainder in reserve. • Renewables account for around 85% of global electricity generation by 2050 • Most AEs achieve clean power by 2040, while unabated fossil remains in some EMDEs in 2050
Transport	**6. Road transport decarbonises 90%, while shipping and aviation account for 70% of sector emissions by 2050 despite having shifted to 50% zero carbon fuels.** • By mid-century Sub-Saharan Africa (SSA), India and other EMDEs make up 45% of ZEV sales, enabling ZEVs to constitute almost 90% of the global car fleet by 2050
Industry, buildings	**7. Industry and buildings see decarbonisation driven by technology and increased efficiency.** • Scrap becomes the crucial decarbonisation lever in steel, with hydrogen (H_2) becoming important towards 2050, while cement decarbonisation remains slow, driven mostly by carbon capture and storage (CCS) • Fossil fuels remain a core feedstock for chemical production, although electrification and hydrogen help to decarbonize industrial heating • In the FPS, increased efficiency of both building envelopes and electrical heat pumps reduce emissions from 2030. New net zero buildings only account for 28% of 2050 stock, meaning retrofits are critical to decarbonisation

INEVITABLE POLICY RESPONSE

(2/3) IPR 2023 Top FPS Model Results – Land Use and Nature

Demand for land	**1. Population and income growth drive demand for food, energy and materials, increasing demand for productive uses of land.** • Global food demand increases by 21%, as income and population growth increase food demand in EMDEs. Increasing demand for housing could drive demand for timber in construction, driving the expansion of commercial forest plantations
Land conservation and restoration	**2. Climate and nature action drive demand for land conservation and restoration, restricting the potential for agricultural land and plantation expansion onto natural land.** • Increasing nature action leads to the protection of an additional 980 Mha of natural vegetation, stabilizing biodiversity intactness to 2020 levels by 2050 • By 2050, action to halt deforestation reduces emissions by ~1.8 $GtCO_2$ /yr., while other policy and market incentives helps capture an additional ~3.8 $GtCO_2$ /yr
Emissions from land sector	**3. Increasing GHG costs in the agricultural sector, coupled with behavioural shifts and technological innovation stabilize emissions from methane and nitrous oxide emissions from agricultural production.** • Behavioral shifts and innovation drives consumers away from emission-intensive proteins, leading to a peak in ruminant meat production by 2035, towards alternative proteins and poultry meat • Innovative agricultural practices and inputs increases nitrogen fertilizer uptake efficiency, reducing nitrous oxide emissions from fertilizer use • Technical mitigation of on-farm emissions from agriculture (e.g., through feed additives) become key to reducing methane emissions from livestock production, particularly emissions from enteric fermentation
Land use products	**4. The transition impacts key land use products:** - **Food:** Real food prices continue to decline relative to 2020, as diet shifts and food waste reductions decrease pressure on agricultural production. Diet shifts reduce demand for livestock products and feed crops, while food waste reductions make the overall agricultural system more efficient and stabilize total caloric demand to 2020 levels - **Materials:** Timber production grows by 22%, to respond to an increasing demand for sustainable construction materials. The growth affects all regions, particularly current market leaders such as Europe and the US

INEVITABLE POLICY RESPONSE

(3/3) IPR 2023 Top FPS Model Results - Bioenergy

Sustainability considerations for bioenergy

1. Bioenergy competes for scarce land in a system increasingly asked to provide more food, materials, urban space, and natural ecosystems.

- Bioenergy is costly for the land system to produce, but can help the energy system decarbonize by delivering both low carbon energy and negative emissions when used with carbon capture and storage (CCS)
- Because there are many competing demands for a fixed amount of land, bioenergy can displace other uses. This opportunity cost can be partially quantified using a carbon payback period
- To be useful in the energy system, biomass must be either lower cost or more sustainable than other decarbonization technologies
- Policymakers may increasingly introduce sustainability guardrails for sourcing biomass. Feedstocks that avoid nature displacement, deforestation, food competition, and irrigation will likely be most secure

Bioenergy without CCS

2. Bioenergy without CCS is likely to be outcompeted by lower carbon alternatives in most energy system applications.

- Aviation and the pulp & paper industry are notable exceptions - a lack of cleaner alternatives and very inexpensive self-supply of waste and residues make unabated bioenergy cost competitive through 2050
- There are ~30 EJ of potential supply of waste and residue feedstocks that minimally compete for land – shifting to these widely available feedstocks supports bioenergy's role in transport through the 2030's

Bioenergy with CCS (BECCS)

3. Bioenergy with carbon capture and storage (BECCS) in industry and power is costly but offers negative emissions. ~1 $GtCO_2e$ of BECCS removals may outcompete direct air capture (DACCS) depending on achievable biomass yields.

- There are 567 Mha that meet basic land sustainability guardrails
- Between 310 and 396 Mha of that land has a carbon payback period (CPP) below 15 years, implying bioenergy could be a more efficient store of carbon than re/afforesting that land instead

Overall bioenergy outlook

4. As a result, bioenergy use only grows modestly in the updated IPR FPS 2023.

- Biomass production shifts away from unsustainable 1G crops towards waste and residues. Demand shifts away from road transport and unabated power, towards aviation and BECCS
- This contrasts with other prominent transition outlooks, many of which expect a larger role for bioenergy

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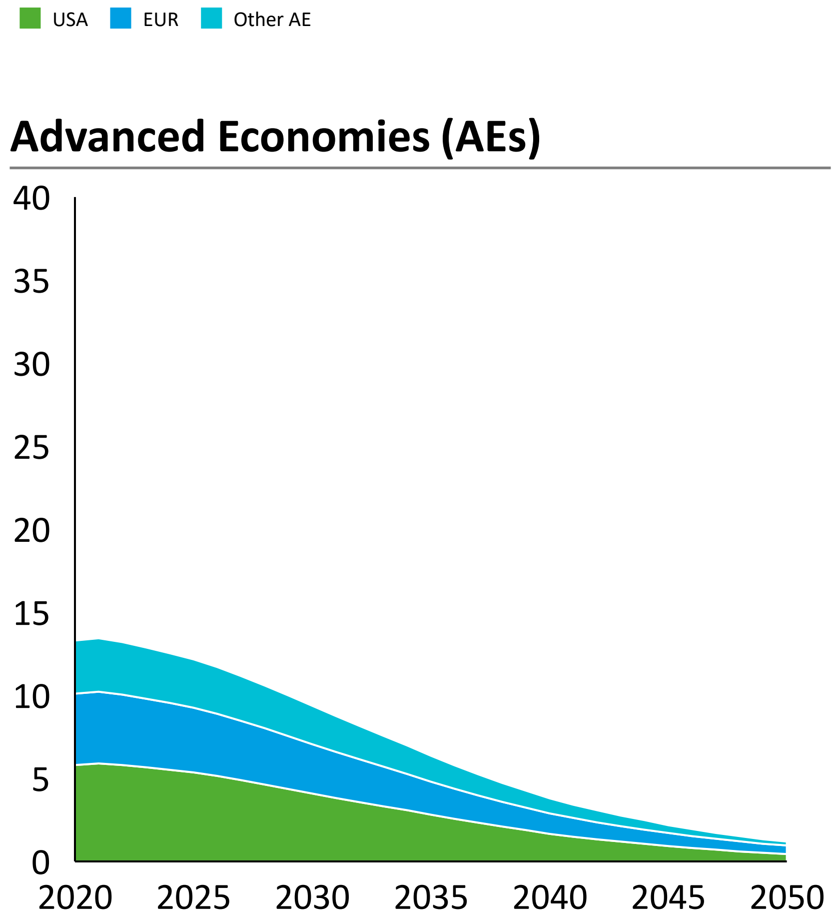
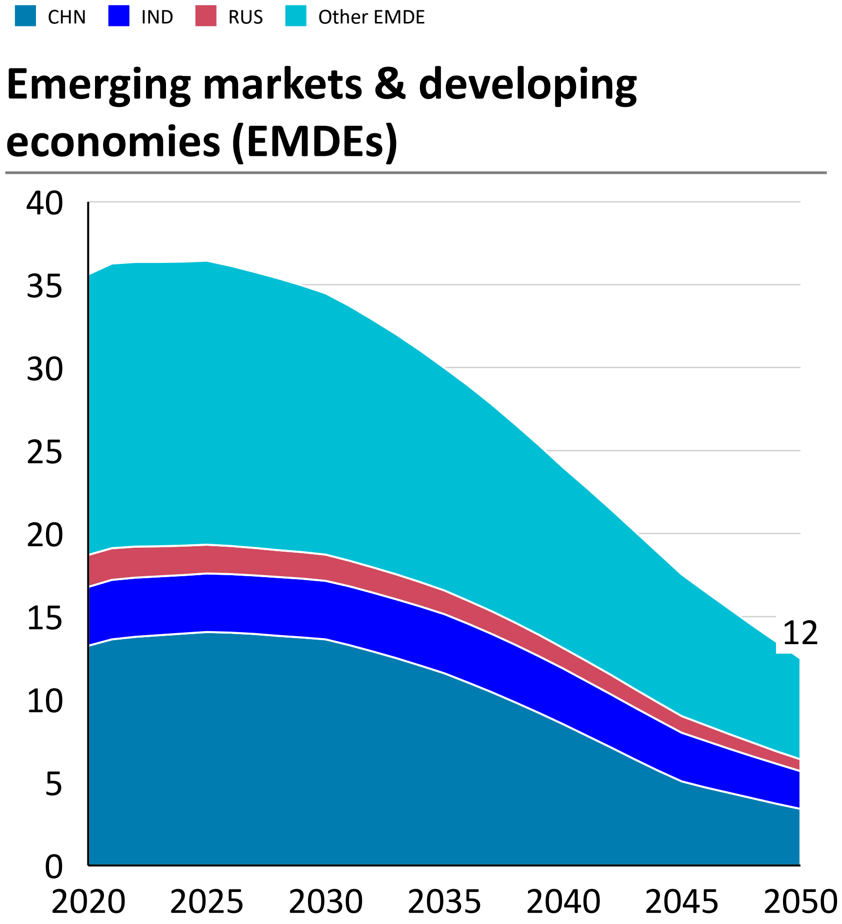
Advanced Economies reach near-zero GHG emissions by 2050, with substantial emissions in Emerging and Developing Economies

Energy and Land GHG emissions[1] by region, $GtCO_2e$/year





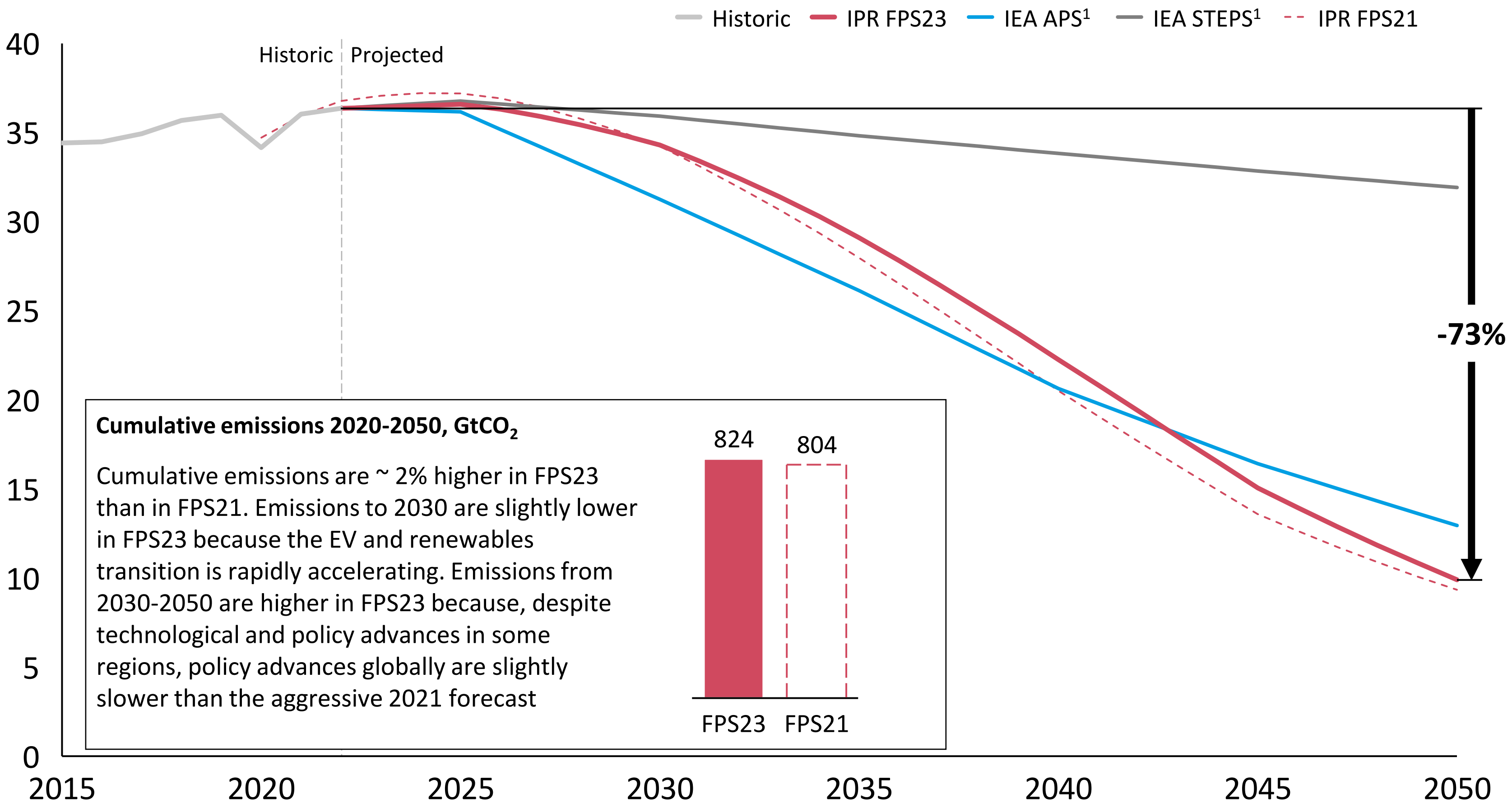
1. Emissions on a production basis. Includes carbon removals from BECCS but not DACCS

- Except for the uptick in emissions following the recovery in activity post-COVID, **AEs see GHG emissions fall rapidly** to near-zero by 2050. **AEs could reach net-zero energy** emissions with CO_2 removals from DACCS (not shown)
- In EMDEs, **emissions continue to grow throughout the 2020s** due to growing population and incomes. **They still emit 12 $GtCO_2e$ in 2050** mainly from industry. Even easier-to-decarbonize sectors like power and transport do not do so fully
- Emissions reductions in both AE and EDME land systems are driven by NBS

INEVITABLE POLICY RESPONSE

Energy system emissions plateau in the early 2020s but fall about 75% by 2050 in the FPS 2023

Global energy-related CO_2 emissions, $GtCO_2$/year



1. IEA data published in 5-year intervals and 2025 data unavailable, linear interpolation may not reflect differences with IPR

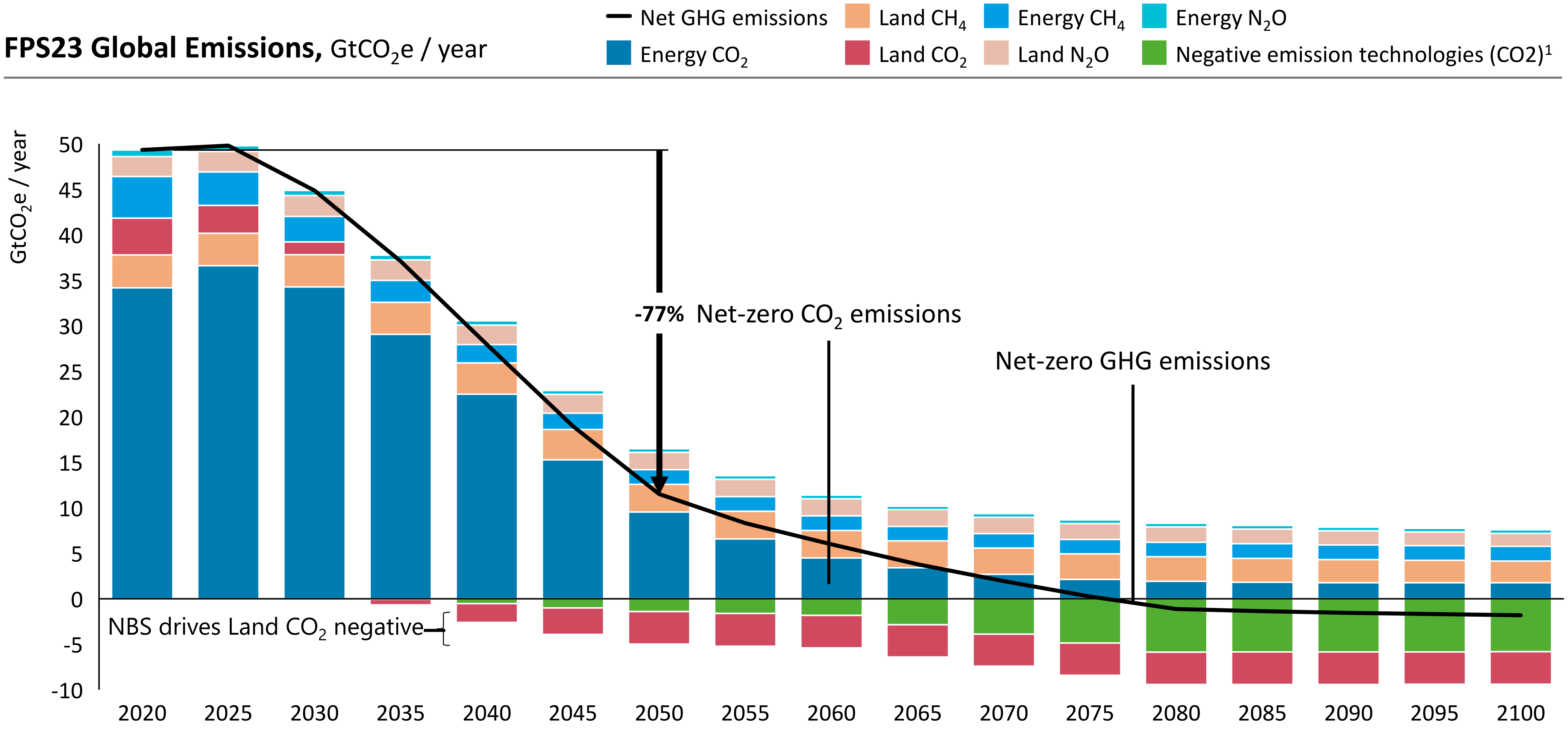
Source: IEA World Energy Outlook (WEO) 2022

- In the early 2020s, **energy-related CO_2 emissions in the FPS plateau**, following a similar pathway to IEA scenarios
- Although emissions are higher than APS through the 2030s, FPS23 is a slightly lower temperature scenario than APS. Decarbonization policies push the FPS23 trajectory lower then APS by the 2040s and FPS 2023 may also have higher land carbon sequestration from land
- As **policies ratchet up further, emissions fall below the IEA APS** level in the early 2040s, driven in part by a significant ramp up in emissions removals to around 5Gt p.a. by 2050. Emissions fall a total of 73% between 2022 and 2050

INEVITABLE POLICY RESPONSE

Greenhouse gas emissions drop 80% by 2050 and reach net-zero by 2080, but only because negative emissions technologies remove 6 $GtCO_2$ per year by 2080

FPS23 Global Emissions, $GtCO_2e$ / year

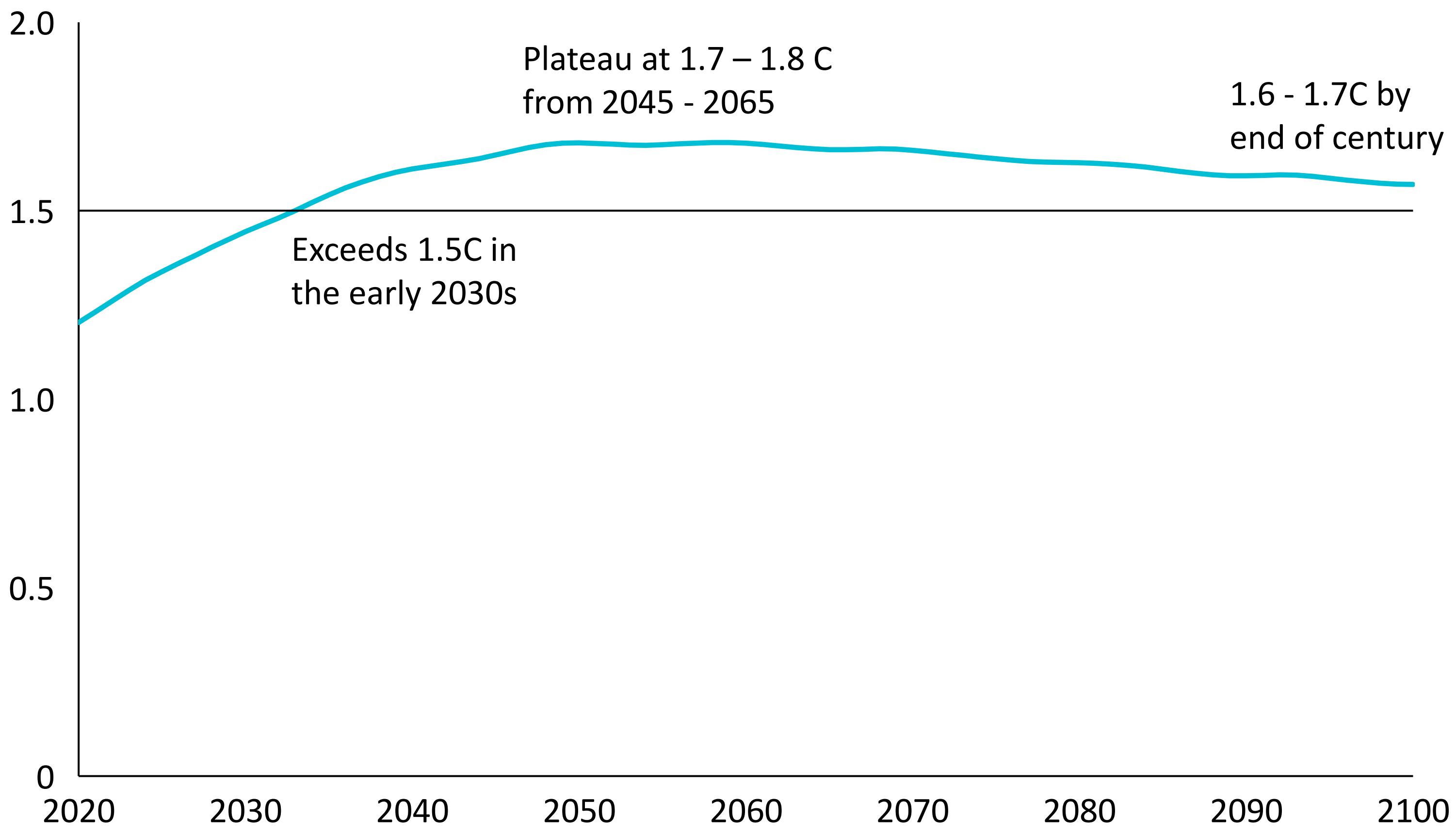


1. Direct air carbon capture and storage (DACCS) and Bioenergy with carbon capture and storage (BECCS)

INEVITABLE POLICY RESPONSE

FPS 2023 forecasts peak temperatures of 1.7-1.8C around 2045, dropping to 1.6-1.7 C by 2100 if DACCS continues

Surface temperature anomaly, degrees C above pre-industrial reference period[1]



1. The pre-industrial reference period is 1850 to 1900, defined in Kelvin. Temperature anomalies in Kelvin and Celsius are equivalent.
2. Based on MAGICC 7
3. Assuming only impact of continuation of DACCS levels

IPR FPS 2023 forecasts[2]

- An exceedance of 1.5C in the early 2030s
- Peak temperatures of 1.7 - 1.8C around 2045 - 2065
- A decline to 1.6 – 1.7C by 2100 and 1.5C by 2130[3], based on direct air carbon capture and storage (DACCS) deployment estimates
- Net-zero CO_2 emissions around 2060 and net-zero GHG emissions around 2080
- Overall likelihood of staying below 2°C warming is at >90%

INEVITABLE POLICY RESPONSE

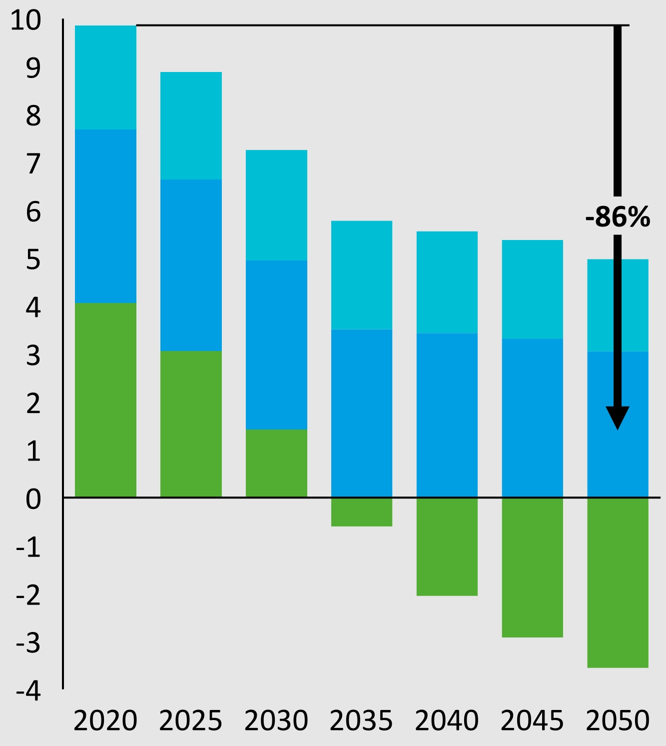
Add tracker

Carbon sequestration drives emission reductions in the land use sector, while mitigation policies in the agriculture sector stabilize other GHG emissions

Nitrous Oxide | Methane | Carbon Dioxide

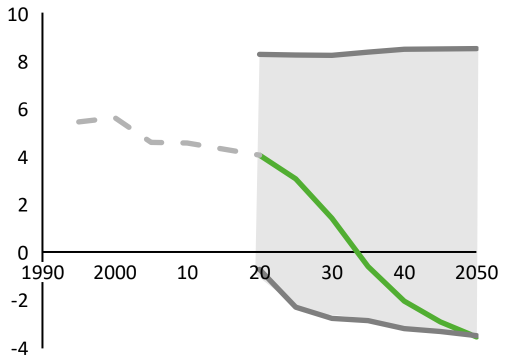
Historical values | IPCC C4 Max/Min | FPS 2023

FPS 2023: Global AFOLU Emissions, Gt CO_2eq



Global AFOLU Emissions by GHG, Gt CO_2eq

Net-CO_2 from Land[2]



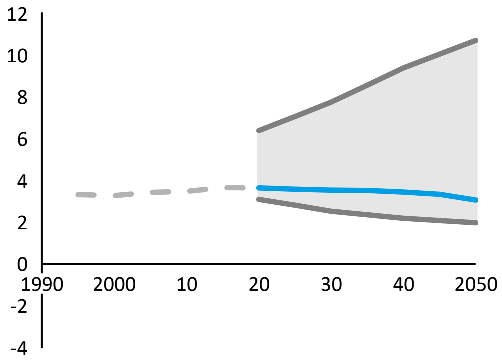
Emissions Drivers:

- Expansion of agricultural land onto natural land
- Sequestration from forest restoration, causing emissions to become negative

Mitigation Levers:

- These changes are driven by carbon pricing, A/R[1] policies, conservation and regulation against deforestation

Methane



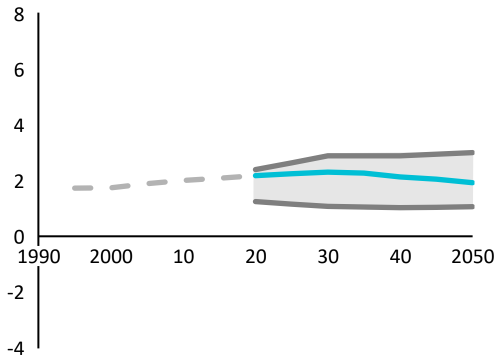
Emissions Drivers:

- Most methane emissions come from beef production (enteric fermentation)

Mitigation Levers:

- Growing emission costs incentivize producers to invest in technical mitigation (e.g., feed additives)
- Demand side shifts reduce production of emission intensive products

Nitrous Oxide



Emissions Drivers:

- Nitrogen-based inorganic fertilizers are the main source of nitrous oxide emissions

Mitigation Levers:

- A shift to sustainable agricultural practices decouple productivity growth and fertilizer use, reducing emissions

1. Afforestation and reforestation
2. This encapsulates both land use change and changes in carbon density on the same land use type (e.g., land may not change use, but may have negative emissions due to the growing of trees that sequester over time) as well as sequestration from nature-based solutions

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INEVITABLE POLICY RESPONSE

Energy system executive summary (1/2)

System-level results and key findings

- Energy system emissions plateau in the early 2020s and fall about 75% by 2050 in the Forecast Policy Scenario (FPS)
- Advanced Economies (AEs) reach near-zero emissions by 2050 while emissions fall by 60% in Emerging and Developing Economies (EMDEs)
- Clean sources grow to over 60% of the energy mix by 2050 and global peak oil occurs in the mid 2020s. Demand for oil as a fuel declines significantly from 2030 but, the use of oil as a feedstock for chemicals continues
- Energy system policies have remained similar to those in FPS 2021 – none have changed in a way that shifts our projected timeline by more than 5 years
- Power and transport drive 76% (21GtCO_2) of emission reductions to 2050 while industry is latest to decarbonize. In the FPS, zero-emission vehicles (ZEVs) reach almost 90% of the car fleet by 2050
- ~5 GtCO_2 are captured by 2050 in FPS 2023, a third of which is from negative emissions technologies
- Clean hydrogen becomes a major energy source, with demand from steel and chemicals, synfuels for shipping and aviation, and flexible power generation
- Bioenergy grows moderately to 2050, with a shift toward sustainable feedstocks fulfilling demand in aviation and biomass energy with carbon capture and storage (BECCS)
- A range of other highly uncertain but disruptive trends could shift the world to a future unlike that modelled in the FPS

Energy system executive summary (2/2)

Power

- Decarbonization of power generation, led by Advanced Economies, is a critical enabler of lower emissions in final energy consumption
- In the FPS, the remaining fossil fuel generation is dominated by emerging markets and developing economies (EMDEs), where policy trajectories result in slower phase down relative to Advanced Economies (AEs)
- By 2045, China retires 60% (800GW) of its unabated coal fleet, fits 100GW with carbon capture and storage (CCS) and keeps the "economically stranded" remainder in reserve
- Wind and solar account for around 70% of global electricity generation by 2050. They are complemented by nuclear and hydropower which generate over 15% of electricity
- In the FPS, most AEs achieve clean power by 2040, while unabated fossil remains in some EMDEs in 2050

Transport

- In the FPS, road transport decarbonises 90%, while shipping & aviation account for 70% of sector emissions by 2050 despite having shifted to 50% zero carbon fuels
- China and Advanced Economies currently dominate zero-emission vehicle (ZEV) sales, but by the mid-century Sub-Saharan Africa (SSA), India and other EMDEs make up 45% of sales
- In the FPS, ZEVs therefore reach almost 90% of the car fleet by 2050

Industry

- Scrap becomes the crucial decarbonisation lever in steel, while virgin steel is increasingly produced with hydrogen (H_2). Cement begins to decarbonize at scale in the 2030s, with a combination of zero carbon clinker and CCS
- Fossil fuels remain a core feedstock for chemical production, although electrification and hydrogen help to decarbonize industrial heating
- Policy support enables green H_2 build-out, with blue H_2 only competitive in certain regions with favourable conditions

Buildings

- In the FPS, increased efficiency of both building envelopes and electrical heat pumps reduce emissions from 2030
- New net zero buildings only account for around 30% of 2050 stock as large scale retrofitting of existing buildings takes place steadily to 2050
- Efficient electric heat pumps replace fossil heating systems from the 2020s to provide 60% of building heat by 2050, with bioenergy and hydrogen playing a role

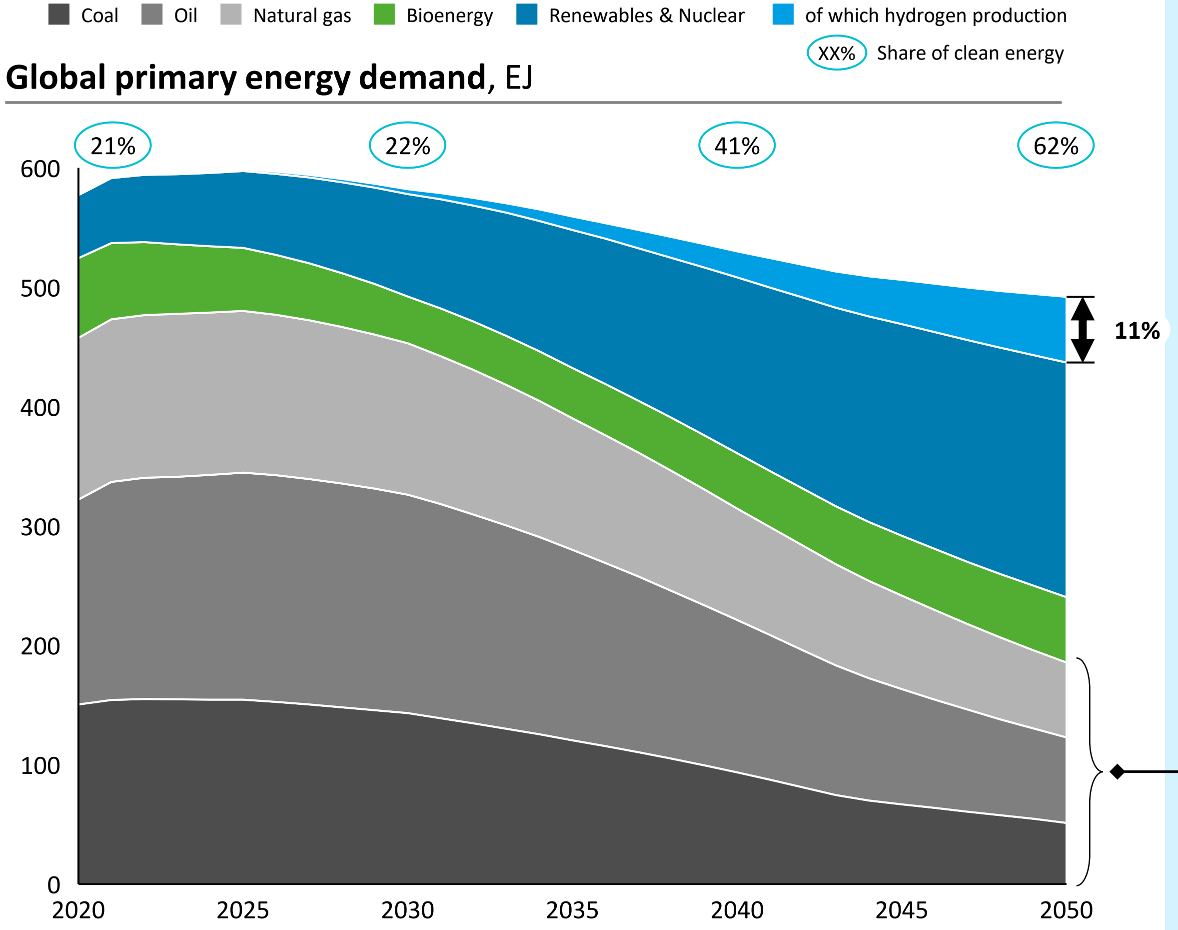
Bioenergy & Removals

- FPS23 covers bioenergy used in transport and buildings, as well as bioenergy with carbon capture and storage (BECCS) used in power and industry to provide negative emissions
- Bioenergy is a long-term decarbonisation option in aviation and some niches uses, while the need for removals in the FPS justifies expensive bioenergy with carbon capture and storage (BECCS)
- The FPS includes 0.6 Gt of direct air carbon capture and storage (DACCS) by 2050, predicated on a significant cost reduction as removals ramps up

INEVITABLE POLICY RESPONSE

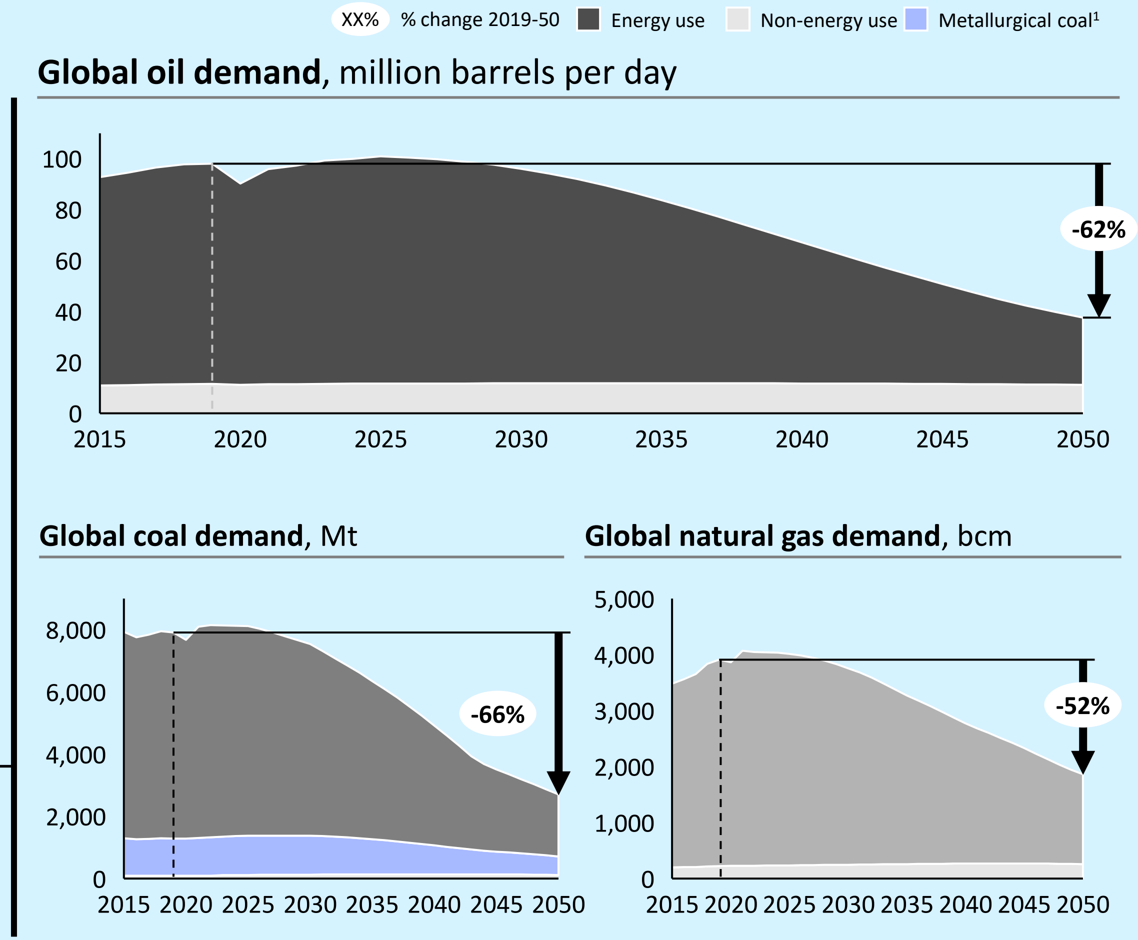
Clean sources grow to over 60% of primary energy demand by 2050…

~ 10% of primary energy is used to produce green hydrogen



…while global peak oil could occur as soon as 2025

All fossil fuels decline following a mid-2020s plateau



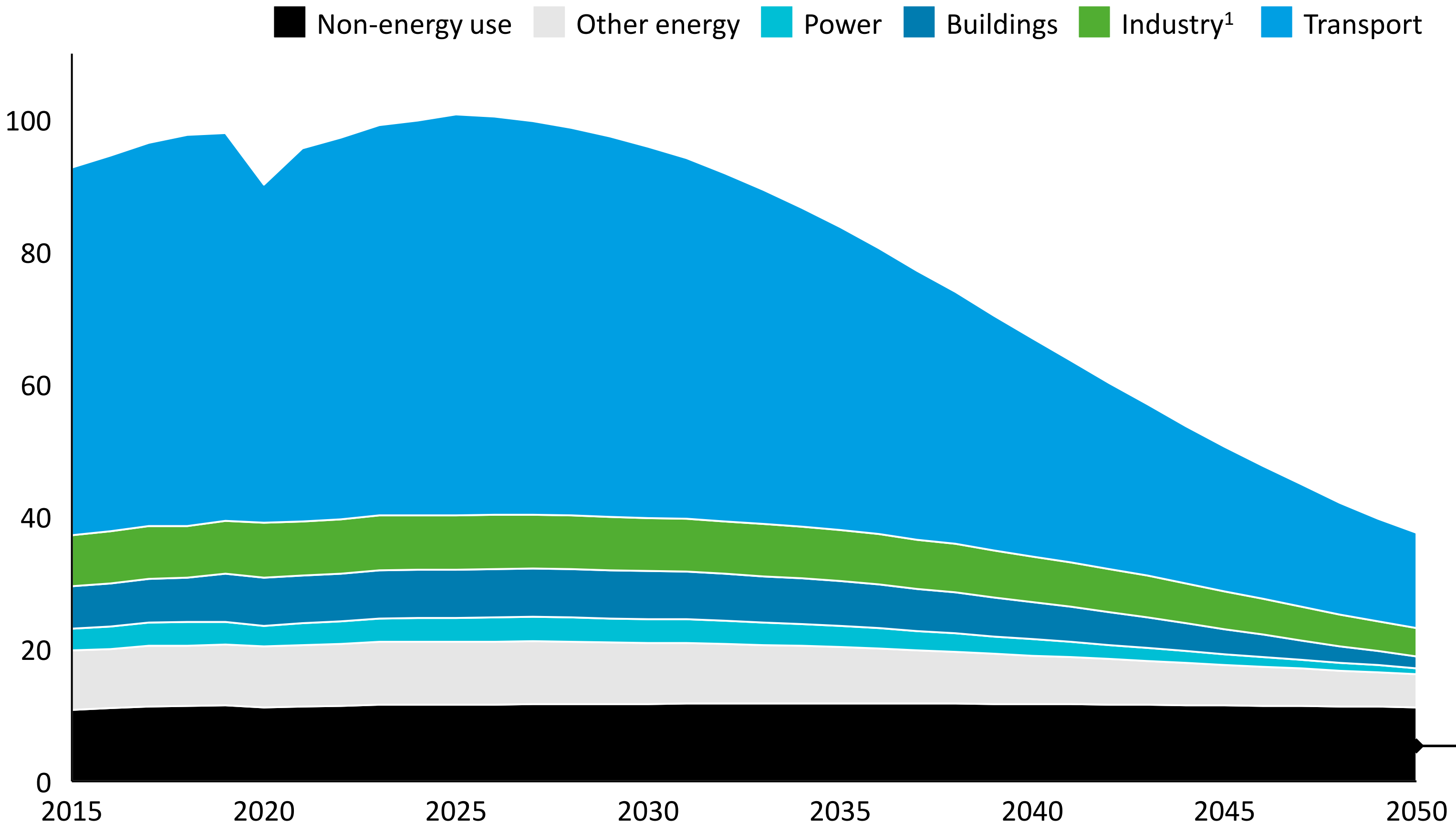
1. Metallurgical – or coking – coal is used in the production of steel, and acts as both a fuel for high temperature process heat and as a reactant in the reduction of iron ore

INEVITABLE POLICY RESPONSE

Oil demand declines significantly from 2030, but the use of oil as a feedstock for chemicals continues

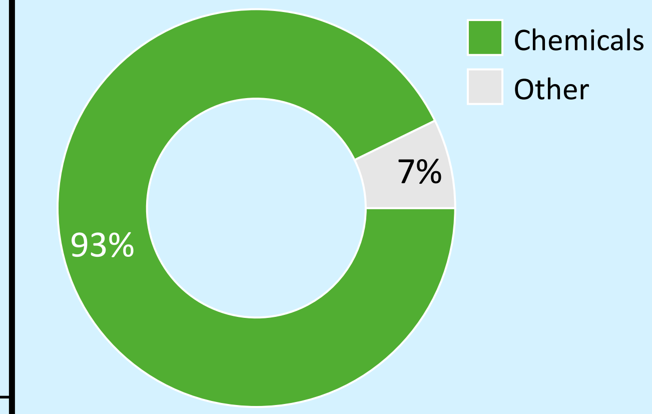
Non-energy use accounts for 10% of demand in 2020 but almost 30% in 2050

Global oil demand, million barrels per day



- The rise of EVs reduces oil demand for transport by over 70% from 2020 – 2050. By 2050, oil is still used for aviation and shipping
- However, because industrial decarbonization is slow, oil remains the main feedstock used for chemicals

Non-energy oil demand, 2050
million barrels per day



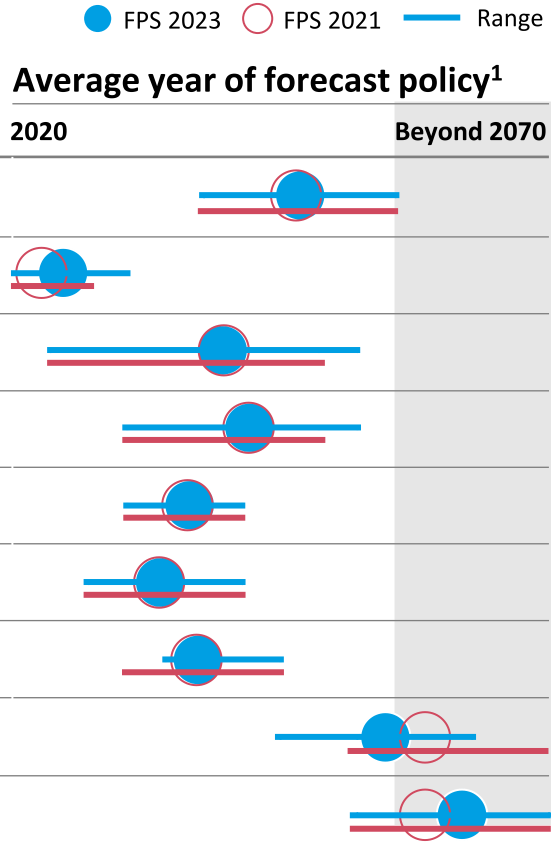
1. Oil used as a fuel to heat industrial processes: "energy use". Excludes "non-energy" use of oil as a feedstock

INEVITABLE POLICY RESPONSE

Energy system policies have remained similar to those in FPS 2021 – none have changed more than 5 years

Industry and new coal are the policy areas with the largest changes compared to FPS 2021

Policy Area	Policy Lever	Key Policy Changes relative to FPS 2021
CO_2 emissions	Net Zero CO_2	India decelerated to a net zero target of 2065[3]
Power	New coal	China continues to build new coal until 2030
	All coal	EU ends coal generation slightly sooner
	Clean power	UK and Indonesia accelerated relative to FPS 2021, South-East Asia and South Africa decelerated
Buildings	Heating	Central & South America and South Africa decelerated to 2045 and 2050 respectively
Transport	LDVs	Gulf States accelerated ICE phase out for both LDV and HDV, while Russia, Eurasia and Indonesia all decelerated. UK HDV target has been decelerated to be in line with other AEs and Brazil also decelerated
	HDVs	
Industry	Fuel	The decarbonisation of industry fuel emissions has been brought forward relative to process emissions, but industry remains the latest sector for forecast policies to decarbonize
	Process	



1. Average year policy of forecast to be achieved, weighted by current sectoral emissions for each modelled region
2. Including direct air carbon capture and storage (DACCS) negative emissions
3. Only USA, India and Australia net zero announcements were forecast in FPS 2021

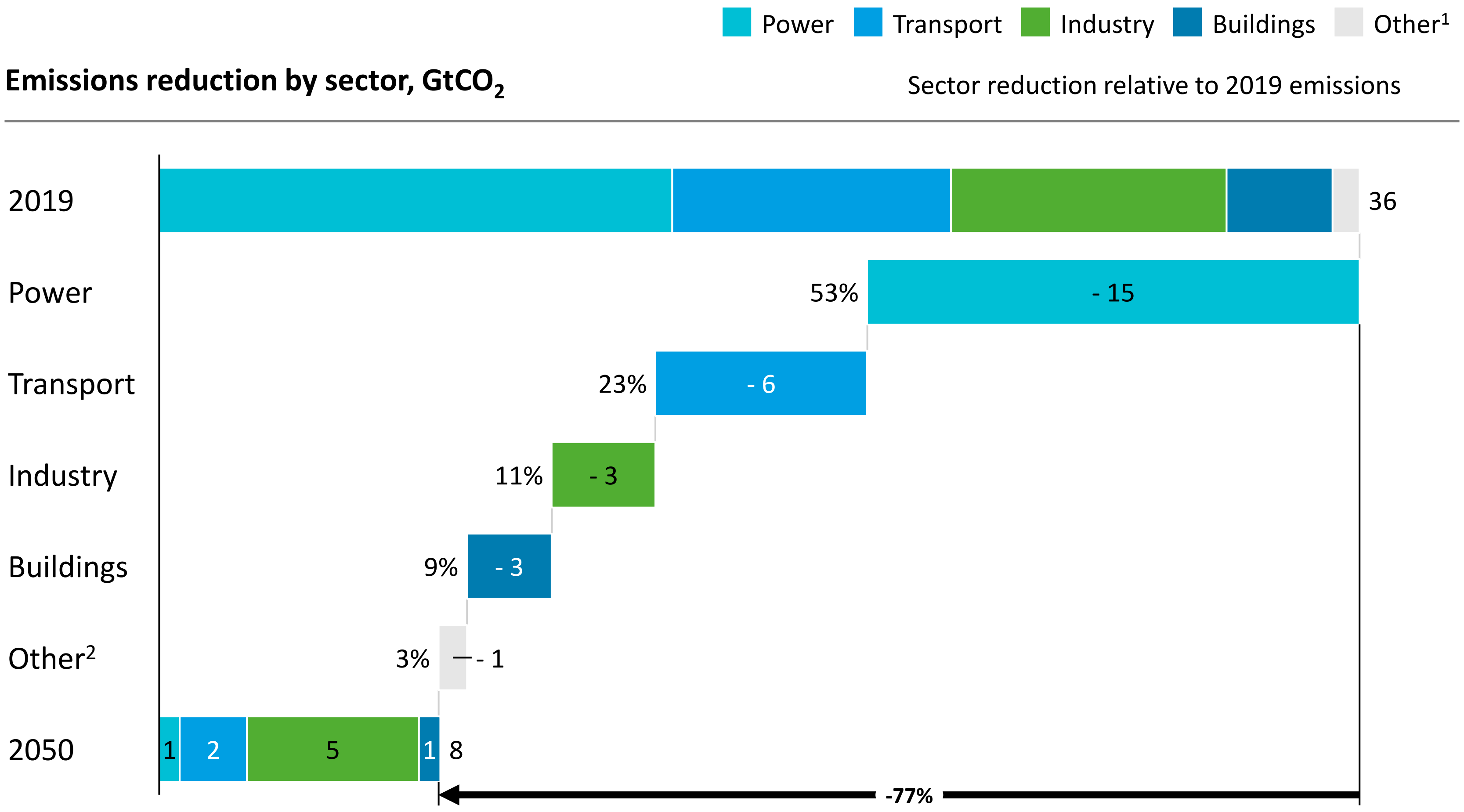
Note: See appendix for further detail on policy forecasts by modelled region

INEVITABLE POLICY RESPONSE

75% (21$GtCO_2$) of emission reductions to 2050 come from power and transport, while industry is latest to decarbonize

Power and transport are the first sectors to decarbonize in FPS 2023

Emissions reduction by sector, $GtCO_2$



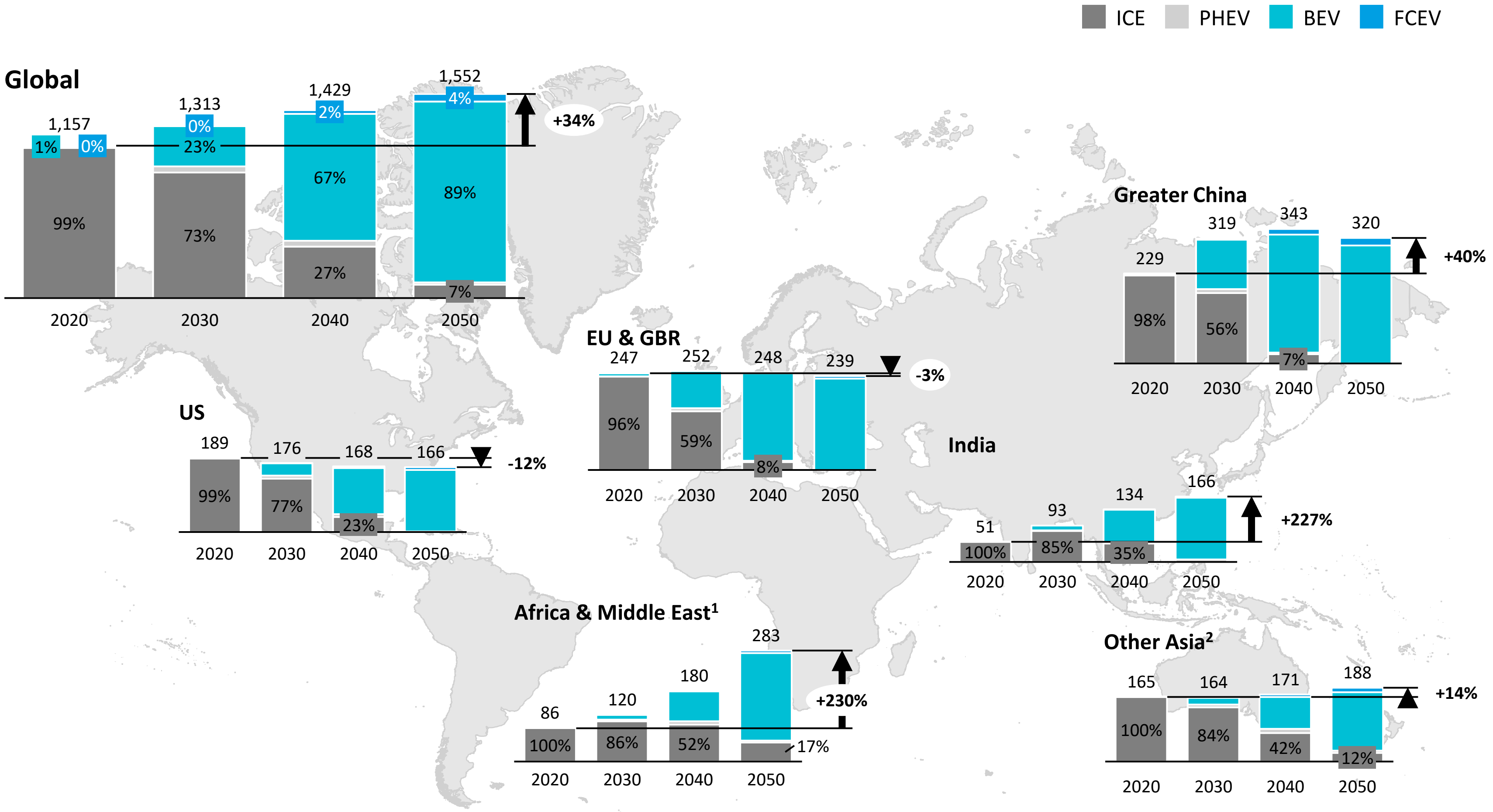
- The decarbonisation of power enables other sectors to then abate emissions through higher electrification
- The transport sectors also decarbonises quickly and significantly with AEs already reducing emissions today
- Harder-to-abate emissions in industry and buildings are tackled through a mix of policy support, emerging technologies, and improved efficiencies

1. Includes removals from DACCS

INEVITABLE POLICY RESPONSE

In the FPS, zero-emission vehicles (ZEVs) reach over 90% of the car fleet by 2050

Passenger car fleet, millions



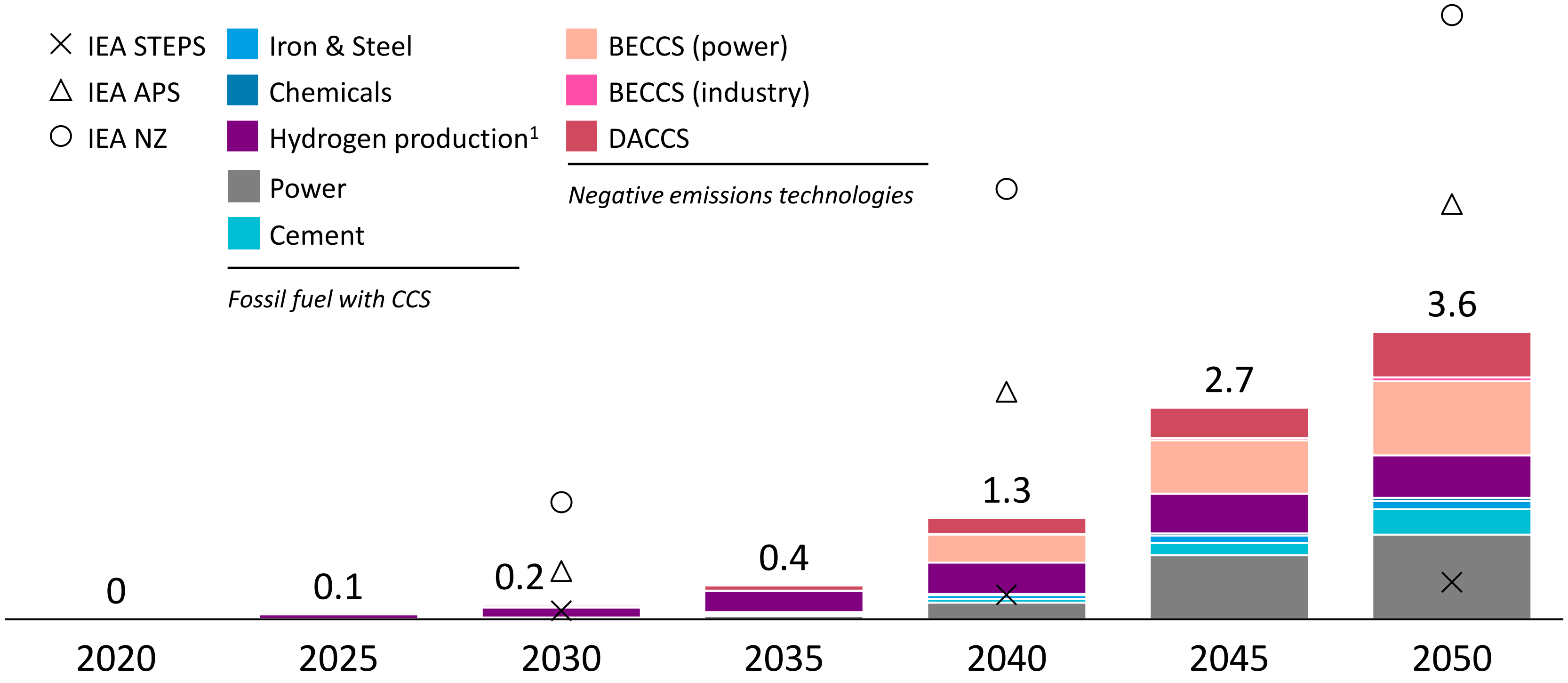
1. SSA, SAF, MENA
2. AUS, JPN, KOR, IDN, SEAO, SA, EURA

- **Car numbers in Africa and India more than triple** to 2050, while absolute numbers fall in the US and Europe
- China and Europe are almost fully decarbonised by 2040, after which the **majority of remaining ICE vehicles are in EMDEs**
- Pure **battery electric vehicles are the dominant technology,** however plug-in hybrid vehicles initially and later hydrogen fuel cell vehicles gain a small share in market segments with large travel distances

INEVITABLE POLICY RESPONSE

Over 3 $GtCO_2$ are captured by 2050 in FPS 2023, a third of which is from negative emissions technologies

Carbon dioxide captured by CCS removed by BECCS and DACCS, $GtCO_2$



1. Not including that used in ammonia and methanol production

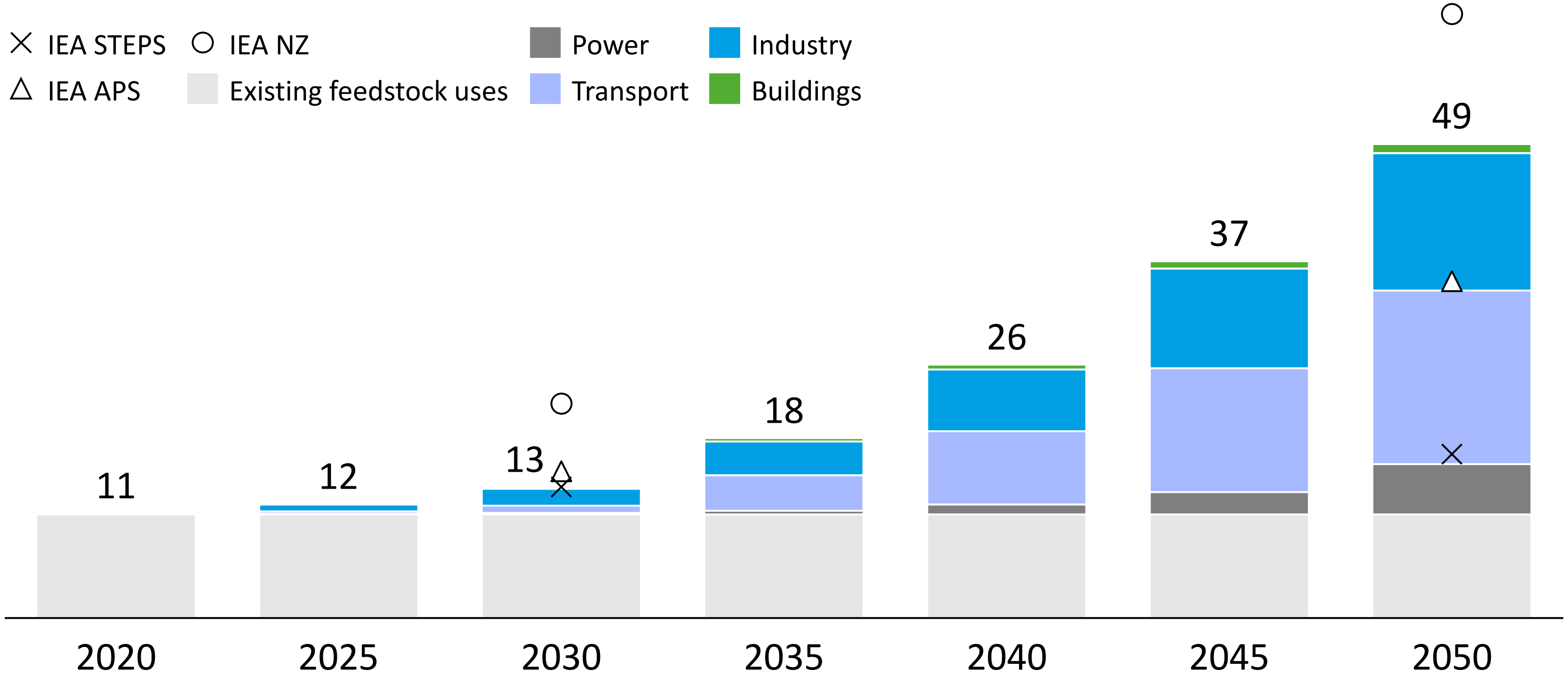
Source: IEA WEO (2022)

- Carbon capture and storage (CCS) and removals in the FPS is comparable to the IEA APS, where policy requires hard-to-abate sectors to reduce their emissions
- In FPS, a larger uptake of Direct Air Carbon Capture & Storage (DACCS) happens in the 2040s when stakeholders act to accelerate towards net negative emissions, even while industrial sources are slower to decarbonize

INEVITABLE POLICY RESPONSE

Clean hydrogen demand comes from synfuels for aviation and shipping, steel production and flexible power generation

Hydrogen demand by sector, EJ



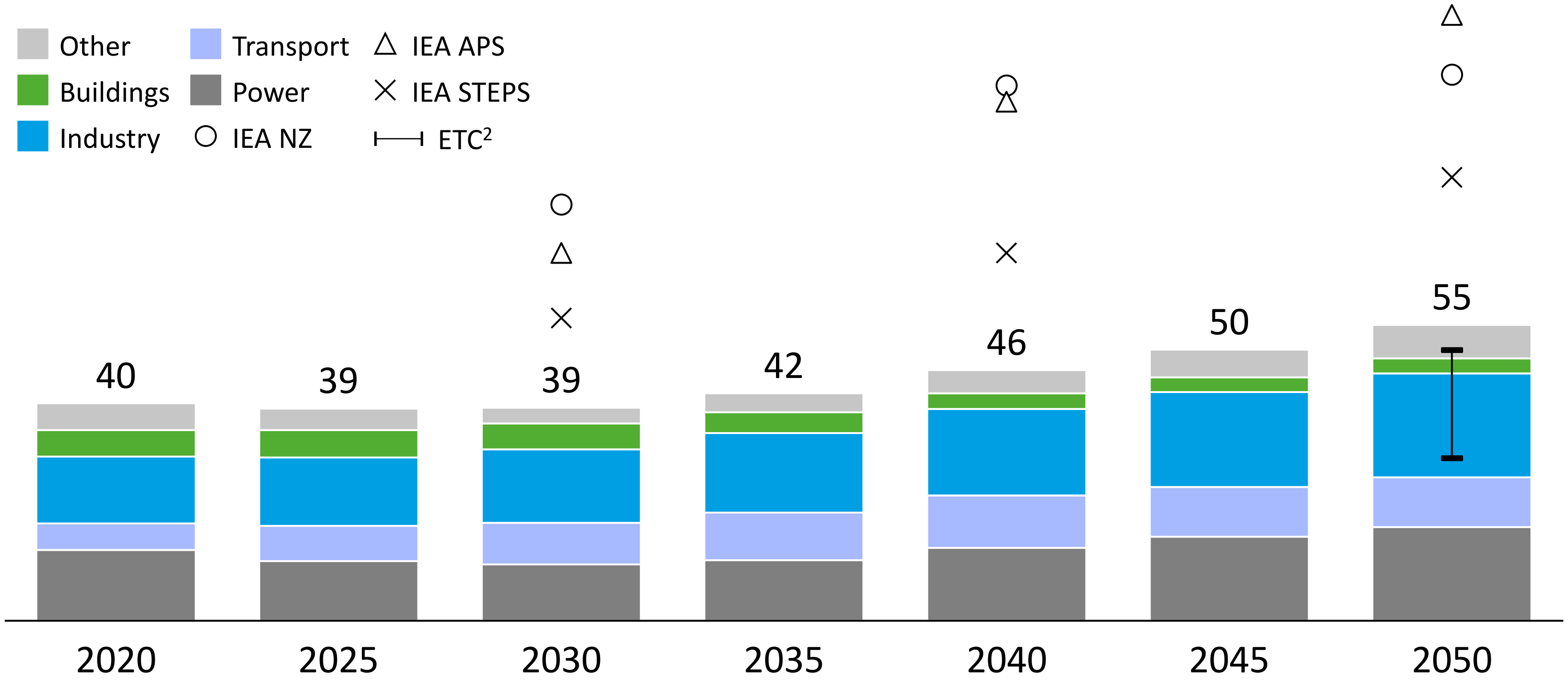
Source: IEA WEO (2022)

- Before the 2030s the FPS sees limited growth in H_2 demand, mainly in the 'traditional' chemicals sector
- More meaningful growth occurs when new industrial uses, and particularly synthetic non-road transport fuels begin to scale
- Compared to IEA scenarios, FPS sees more synfuels (as an alternative to more biofuels), and a marginally greater role in the power mix

INEVITABLE POLICY RESPONSE

Biofuels in aviation and biomass power transitioning to BECCS moderately increase bioenergy use from 2020 to 2050

Modern[1] primary bioenergy demand by sector, EJ



1. Traditional biomass used in cooking and heating is not included, and assumed to phase out by 2030 in line with SDG
2. An estimate of the global supply of sustainable biomass that could be available to the energy system. This range reflects a 'prudent' estimate, achievable without major changes to land use, technology or behaviour. ETC's 'maximum potential' case, with extremely ambitious systems change leads to a supply of c.100EJ – just enough to satisfy IEA NZ demand

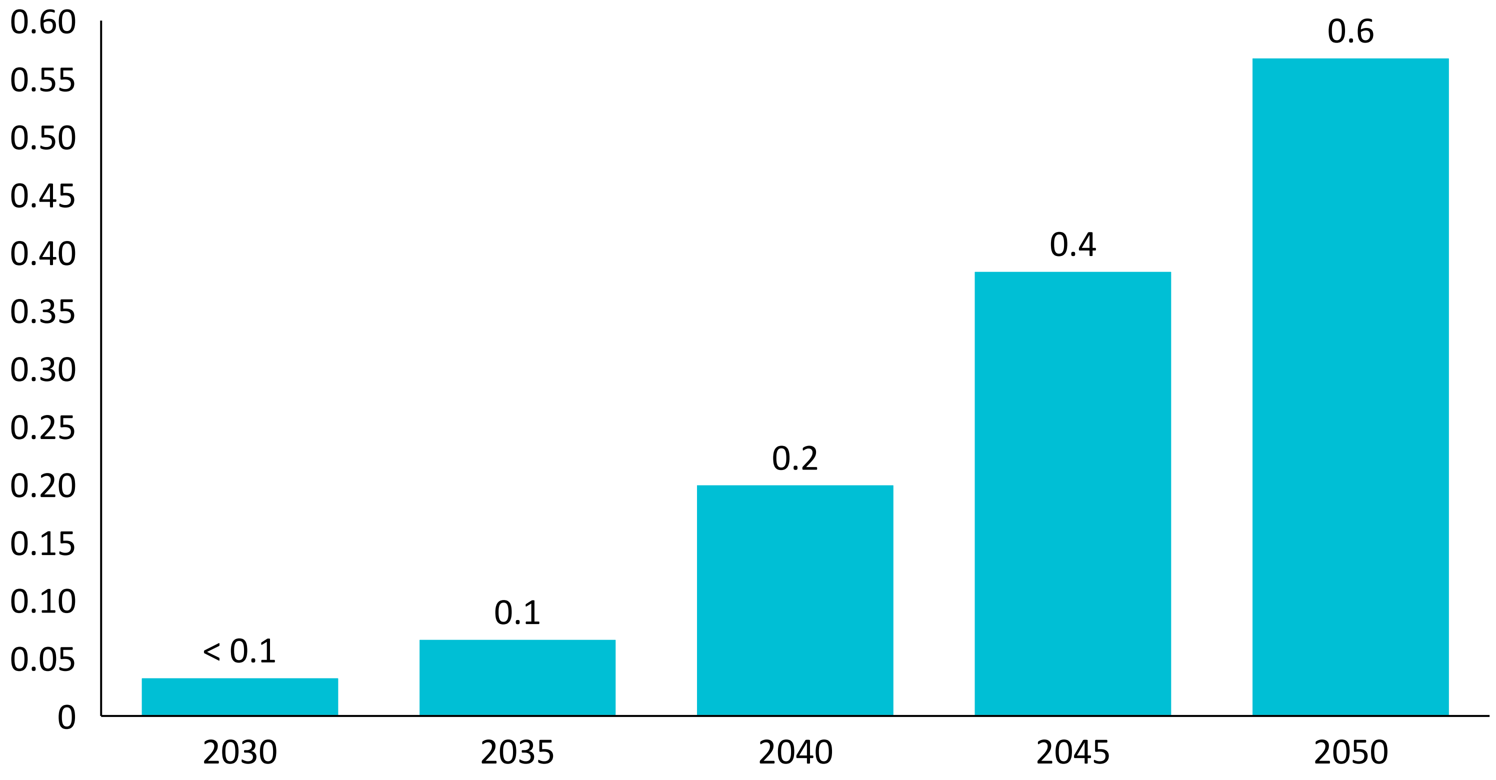
Source: IEA WEO (2022); Energy Transition Commission (2021), Bioresources within a Net-Zero Emissions Economy

- Energy system scenarios like the IEA's are often predicated on ambitious availability of sustainable biomass
- The FPS limits long-term demand primarily to use cases with few green alternatives, given the competition for land and biomass across both land & energy systems
- More details on the role of bioenergy are available in the bioenergy report

INEVITABLE POLICY RESPONSE

FPS 2023 includes 0.6Gt of DACCS by 2050, predicated on a significant cost reduction as removals ramps up

Global DACCS carbon removals, 2030-2050, $GtCO_2$/year



1. Value for energy demand per tCO2 captured taken at the lower bound of values reported by the National Academy for Sciences

Source: IEA, National Academy for Sciences, McKinsey Voluntary Carbon Markets modelling

- **FPS 2023 sees DACCS reach 0.6 $GtCO_2$/year by 2050**, predicated on near-term demonstration DACCS sites, which move the technology along the learning curve in the 2030s and **reduce costs to as low as $150/$tCO_2$**
- By the 2040s, **growing demand for removals and lower costs drives rapid uptake**
- Removing 0.6 $GtCO_2$ in 2050 would require 2 - 5 EJ of power, or an **additional 1-2% of FPS 2023 global power demand**[2]
- At the lower end of the cost range, DACCS removals would **cost around $100 billion annually by 2050**
- **DACCS wins over BECCS in the long run once land costs are taken into consideration**

INEVITABLE POLICY RESPONSE

There are range of other highly uncertain but disruptive trends which are not explicitly modelled

Transformative technologies and behaviour present uncertainty in future demand and supply within the global energy system. Four trends with high disruption potential are:

IILLUSTRATIVE, NOT EXHAUSTIVE

Generative AI & Automation

Rethinking work

- Artificial intelligence has the potential to reshape how work is done, with significant implications on society and energy systems
- For example, **AI-powered grids** could optimize power grids and boost renewable penetration, while **automation** could lead to increased leisure time, with impacts on energy consumption

A changing social order

Rethinking social structures

- The increasing importance of critical minerals to the energy transition is leading to **shifting global supply chains**, with potential geopolitical implications
- A potential realignment towards **multipolar blocs** could change demand and trade patterns, as well as impact the ability of global and local institutions to enact a just transition

Behavioral shifts

Rethinking mobility & consumption

- **Mobility-as-a-service** and **connected autonomous vehicles** could transform road transport and upend ownership models
- Consumer-led demand changes could drive shifting energy consumption – for example the rise of **remote working** and the resurgence of ‘**flight shaming**’ following a period of post-COVID ‘revenge travel’

Enhanced geothermal

Rethinking clean power

- **Enhanced geothermal power could provide clean baseload power** to complement intermittent renewables. According to the National Renewable Energy Laboratory, it could generate ~ 10% of US electricity by 2050[1]
- However, to become a viable solution, it still needs further technology innovation, and market and policy support

1. National Renewable Energy Laboratory, 2023, Enhanced Geothermal Shot Analysis for the Geothermal Technologies Office

Source: McKinsey Global Institute (2022) ‘On the cusp of a new world order?’

INEVITABLE POLICY RESPONSE

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INEVITABLE POLICY RESPONSE

(2/3) IPR 2023 Top FPS Model Results – Land Use and Nature

Demand for land	**1. Population and income growth drive demand for food, energy and materials, increasing demand for productive uses of land** • Global food demand increases by 21%, as income and population growth increase food demand in EMDEs. Increasing demand for housing could drive demand for timber in construction, driving the expansion of commercial forest plantations
Land conservation and restoration	**2. Climate and nature action drive demand for land conservation and restoration, restricting the potential for agricultural land and plantation expansion onto natural land** • Increasing nature action leads to the protection of an additional 980 Mha of natural vegetation, stabilizing biodiversity intactness to 2020 levels by 2050 • By 2050, action to halt deforestation reduces emissions by ~1.8 $GtCO_2$ /yr., while other policy and market incentives helps capture an additional ~3.8 $GtCO_2$ /yr
Emissions from land sector	**3. Increasing GHG costs in the agricultural sector, coupled with behavioural shifts and technological innovation stabilize emissions from methane and nitrous oxide emissions from agricultural production** • Behavioral shifts and innovation drives consumers away from emission-intensive proteins, leading to a peak in ruminant meat production by 2035, towards alternative proteins and poultry meat • Innovative agricultural practices and inputs increases nitrogen fertilizer uptake efficiency, reducing nitrous oxide emissions from fertilizer use • Technical mitigation of on-farm emissions from agriculture (e.g., through feed additives) become key to reducing methane emissions from livestock production, particularly emissions from enteric fermentation
Land use products	**4. The transition impacts key land use products:** - **Food:** Real food prices continue to decline relative to 2020, as diet shifts and food waste reductions decrease pressure on agricultural production. Diet shifts reduces demand for livestock products and feed crops, while food waste reductions makes the overall agricultural system more efficient and stabilizes total caloric demand to 2020 levels - **Materials:** Timber production grows by 22%, to respond to an increasing demand for sustainable construction materials. The growth affects all regions, particularly current market leaders such as Europe and the US

INEVITABLE POLICY RESPONSE

Four key macro trends shape the land sector over the next 30 years, under the FPS 2023

Growing populations and incomes

- **Population and income growth drive food demand, particularly in emerging economies**
- Over the next 30 years, population grows by 1.3x[1]
- GDP is expected to grow 2x as fast[2] in non-OECD economies, particularly in Tropical Africa

Climate and biodiversity policies

- **Climate and nature policy increases transition risks for "unsustainable" players in the agriculture and land use sector**
- Climate action incentivizes net-zero deforestation. Nature-based solutions (NBS) can help achieve climate goals by halting deforestation and pushing afforestation
- Biodiversity ambition increases restoration and conservation of natural ecosystems. Biodiversity credits could incentivize the uptake of biodiverse NBS, achieving both climate and biodiversity outcomes

Evolving consumer preferences

- **Diets shift, driven by environmental and health concerns, and increasing innovation in alternative proteins**
- A shift to alternative proteins increases demand for plant-based products but reduces feed production
- Diet shifts away from animal proteins reduces pressure on the land use system

Technology investment and uptake

- **GHG pricing, demand shocks and land scarcity drive increased investment in technological innovation in**:
  - Productivity-enhancing agricultural technologies, including both traditional methods (e.g. improved irrigation) and emerging methods (e.g. vertical farming)
  - Technologies that mitigate on-farm emissions, such as precision agriculture and improved livestock feed
- Increases in bioenergy demand in turn increase the demand for second generation bioenergy crops

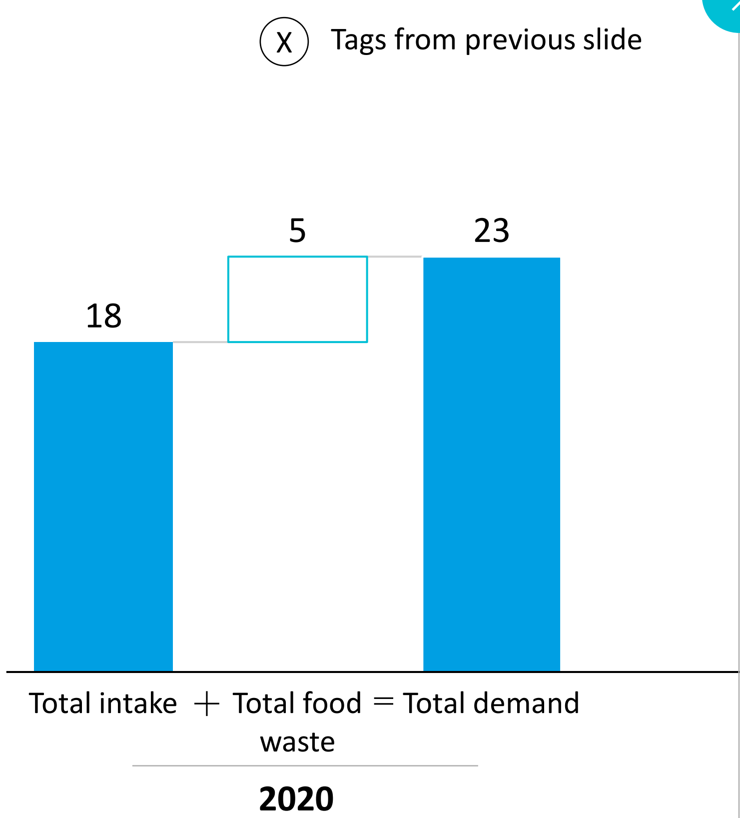
1. United Nations
2. The World in 2050 Report

INEVITABLE POLICY RESPONSE

Global food demand increases by 21%, as income and population growth increase food demand in EMDEs

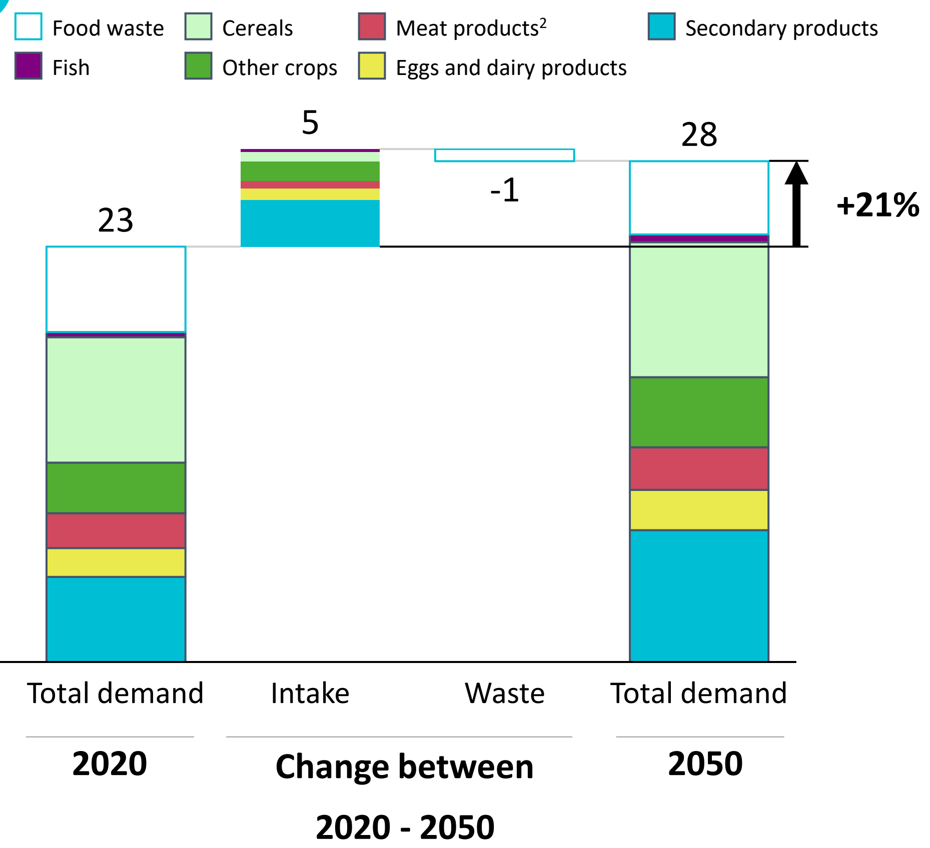
Composition of global caloric demand in 2020

Tn Kcal/day



Change in global caloric demand (2020 – 2050)

Tn Kcal/day



1. Even so, the US still remains above the global average per capita caloric demand
2. Conventional proteins

Regional differences

Per capita food demand declines in AEs, as slow GDP growth is offset by food waste reductions.

Between 2020 and 2050, caloric intake in the **US** remains stable, but **food waste declines by 18%** reducing average per capita food demand by over 600 calories.[1]

By 2050, EMDEs account for 86% of total caloric demand.

Tropical African countries witness the fastest growth in demand, as **their share of global food demand increases from 11% to 20%.**

INEVITABLE POLICY RESPONSE

The Policy Forecast remains largely consistent with 2021, though it shows some deceleration in ambition in the agricultural sector and includes three new forecast areas

Nature Action | Climate Action

Acceleration | Deceleration | No change

Policy Area	Policy Type	Policy Lever		Change in Forecast Relative to FPS 2021
Agriculture	Climate Action	**Emissions from agricultural production**	Policies that encourage farmers to significantly reduce emissions from agricultural production	
Land Use	Climate Action	**Afforestation and Reforestation**	Policies which encourage farmers to carry out significant afforestation and reforestation	
		Deforestation- free supply chains	Implementation of policies that require agricultural commodity inputs to be deforestation-free	New Forecast Area
Nature	Nature Action	**Land protection**	Achievement of Dec 2022 COP15 Biodiversity target of protecting 30% of land and marine area	New Forecast Area
		Nature incentives	Implementation of policies to deliver market incentives to improve biodiversity	New Forecast Area

Policy Implications

1. Deceleration in some countries is often due to a delay in announcement of the policy expected in FPS 2021. However, these are mostly technical and have a small impact on overall land use projections
2. In the case that a country's policy ambition decelerates, this occurs before 2030, resulting in a low impact on the sustainable transition of agriculture in the short term
3. Area protection policies limits agricultural land expansion which interact with other agriculture policies as land competition increases

INEVITABLE POLICY RESPONSE

FPS 2023 land use modeling reflects the latest research and modeling improvements since the release of FPS 2021

Lever	Update	Change between FPS 2021 and FPS 2023
Diet shifts	More detailed picture of the alternative protein market; assessment revised down to reflect latest developments in dietary shifts	Revised production and cost data by protein type and production method Ruminant meat production falls less between 2020 and 2050, with a revision from peaking in 2030 to peaking in 2035
Timber demand	Assessment revised down to reflect latest developments in low-carbon construction (10% of all new builds use wood as a construction material)	Assessment updated based on latest estimates of timber demand from low-carbon buildings[1] Increase in industrial roundwood production from 2020 to 2050 revised down from 83% to 22%[2]
Nature-based solutions	Sequestration estimates revised down to account for marketability of NBS types. Avoided emissions estimates for NBS carbon credits revised down to account for a more realistic baseline, limitations in the demonstration of additionality, and challenges in demonstrating carbon sequestration for some types of interventions	FPS 2023 shows lower avoidance emissions relative to FPS 2021 but maintains sequestration values for removals values. Land-based emission avoidance drops to ~1.8 $GtCO_2$/yr by 2050, but removals sequester ~3.8 $GtCO_2$/yr
Food waste	New assessment to account for policy ambition to reduce food waste	Additional food demand can be met by smaller production increases Food waste[3] now assessed to fall globally from 26% of food being wasted in 2020 to 20% in 2050

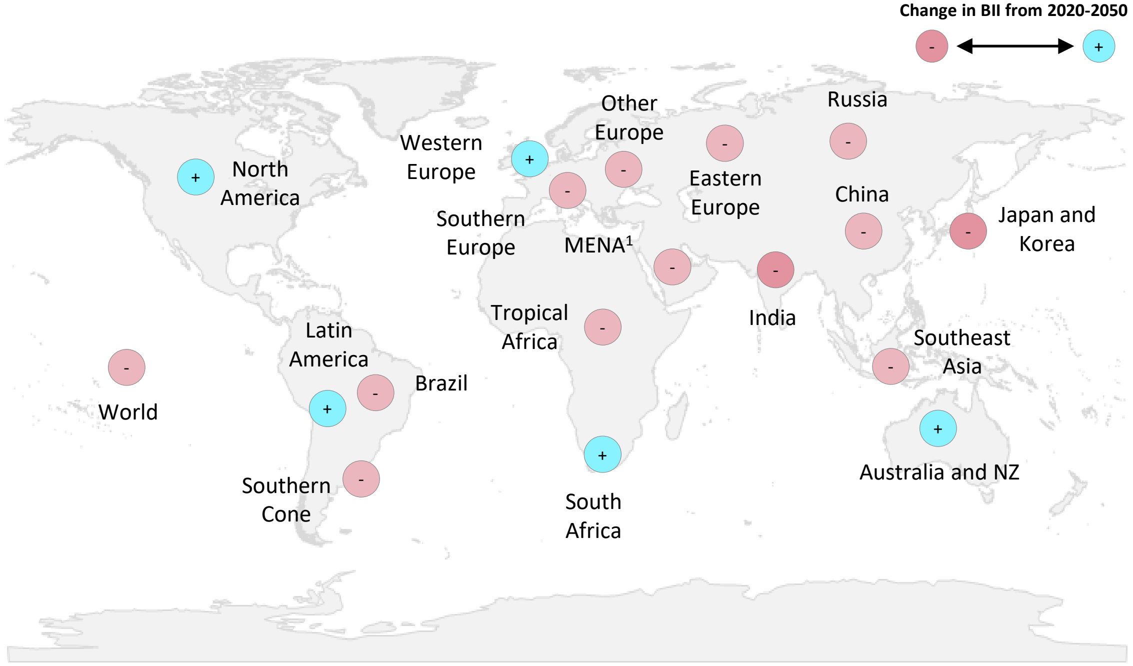
1. Estimates based on Churkina et al. (2022) https://www.mdpi.com/2071-1050/14/7/4271
2. Industrial roundwood outlook aligned with FAOSAT IRW outlook (+25% by 2050) https://www.fao.org/documents/card/en/c/cc2265en
3. Food waste is calculated as a share of total food consumption and refers to all food wasted post-farm gate. In FPS 2023, the share of food wasted declines relative to 2020, while in FPS 2021 food waste as a share of food consumption remained constant

INEVITABLE POLICY RESPONSE

Conservation and restoration policies reverse biodiversity loss to 2020 levels by 2050

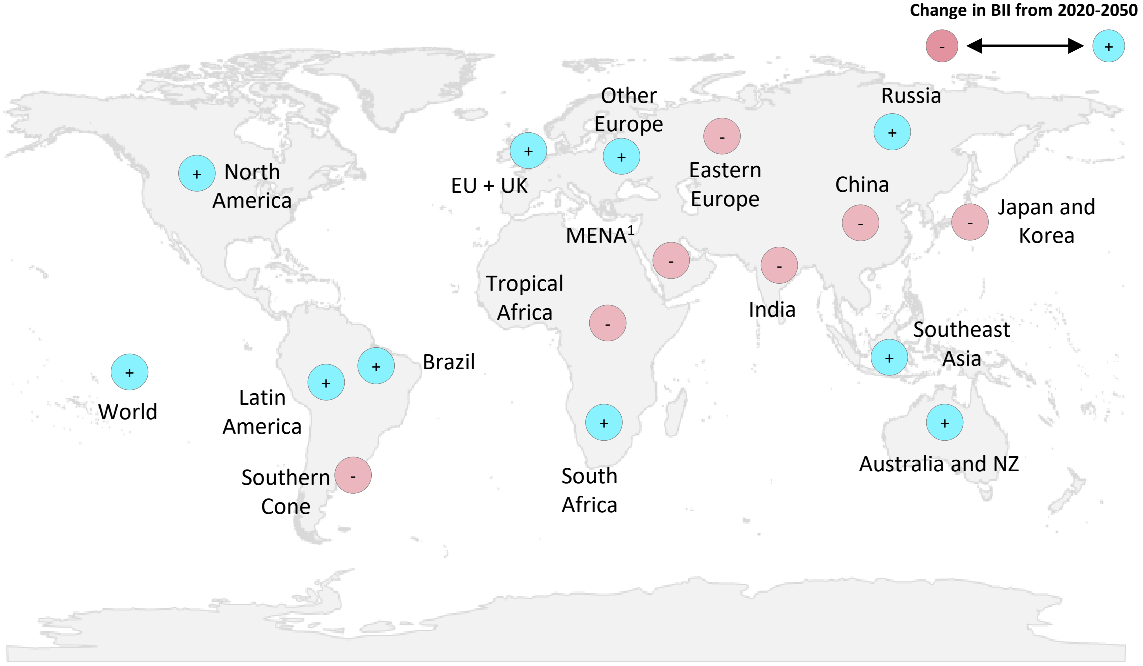
FPS 2021: Change in biodiversity 2020-2050, BII

Pursuit of climate-only policies results in continued biodiversity decline globally and in critical regions such as Tropical Africa, Southeast Asia and Brazil



FPS 2023: Change in biodiversity 2020-2050, BII

Nature policies related to protected areas, restoration and biodiversity valuation drives biodiversity recovery globally and in critical biodiversity-rich regions



1. Middle East and Northern Africa

INEVITABLE POLICY RESPONSE

Macro trends involve significant shifts for each of the major land use products - food, materials, energy, nature and urban space

Land system

Several products compete for land, including food, materials, energy and natural capital

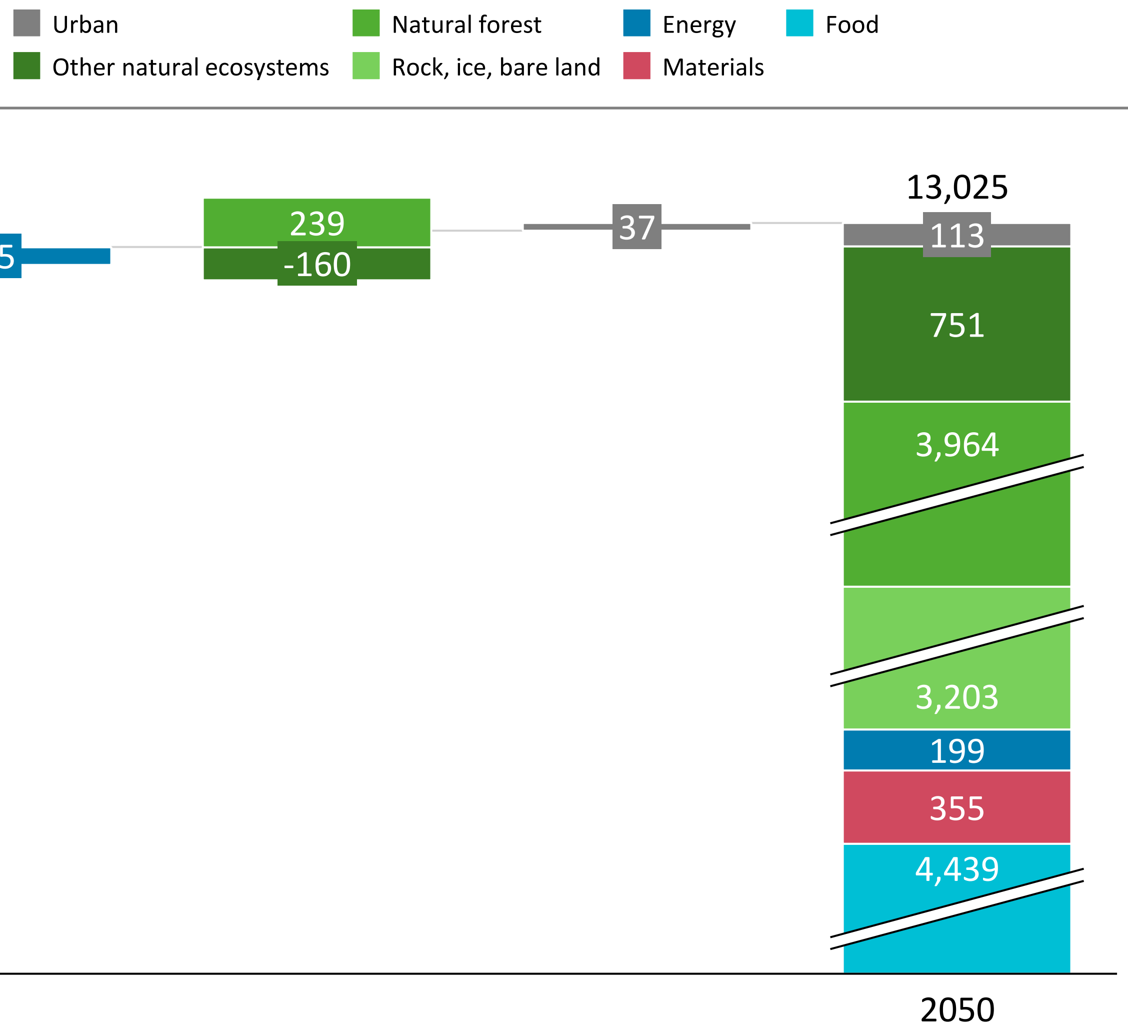
Climate and nature targets and affordability outcomes represent constraints on the products we consume from the land system

Improving yields, changing consumption habits, and reducing waste can all ease competition and improve tradeoffs

Land system	Context
Food	Per capita food demand grows by 26% globally as countries become wealthier and increase their consumption. Waste reductions and a shift in per-capita consumption away from animal products eases land use competition and reshapes the food mix by increasing the reliance on alternative proteins.
Materials	Demand for sustainable alternatives to emissions-intensive materials like steel, cement and synthetic fibres increases. Increased demand for wood in construction leads to a +22% growth in timber production by 2050. Land availability and biomass supply are limited and become increasingly scarce as demands on land and sustainable materials grows.
Energy	Though use of traditional biomass has slowly declined, it has more than been offset by accelerating increases in consumption of modern biomass. Our in-depth analysis explores bioenergy's demands on land and their implications for land competition.
Nature	Nature is at the heart of the transition and regulators are increasingly aware of the need to protect it. A combination of nature and climate policies (e.g., area protection and carbon and biodiversity pricing) increase the value of natural capital. Conservation policies protect an additional 980Mha of natural land by 2050. As natural land is preserved and restored, land availability for productive uses is further constrained, increasing land use competition.
Urban	Urbanization has been a key driver of land use change, but it is concentrated around major cities. Its effect on global land competition is limited compared to the other categories of land use.

Under FPS 2023, shifts in policy, consumer preferences and technology combine with increasing demands on the land system to shift land use away from agricultural land toward nature and bio-based energy and materials

FPS 2023 land use change 2020 to 2050, Mha land



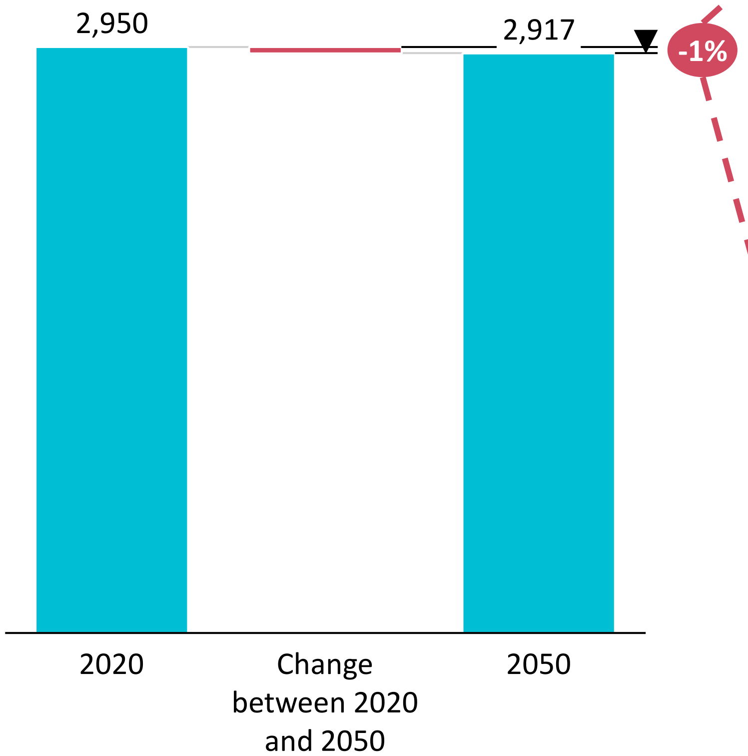
Source: FAO Forestry, FAO Land Use, FAO Land Cover, IPR team analysis

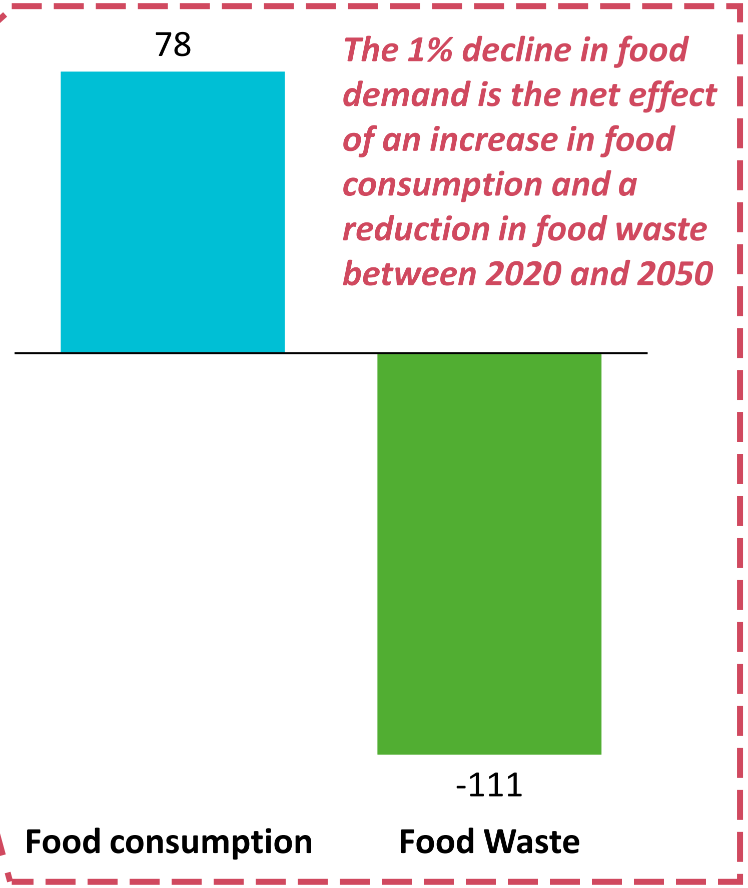
INEVITABLE POLICY RESPONSE

Overall, the food waste reductions offset the increase in consumption, leading to a 1% decline in global per capita food demand by 2050

Global per capita food demand

Kcal/capita/day





Innovation[1] and increased[2] consumption of "surplus food" reduce global food waste globally

For example, labelling campaigns have been effective in the UK, where improved labelling reduced food waste by 14% between 2007-2012. Examples of future innovation include AI-based sales, harvest and food waste forecasting; new storage and preservation technologies

The decline in food waste is primarily driven in Advanced Economies.

Though declining globally, per capita food waste increases in EMDEs as income growth pushes up waste, outweighing the impact of measures pushing down waste. In Tropical Africa, for instance, the share of food waste increases from 18% to 22% of demand

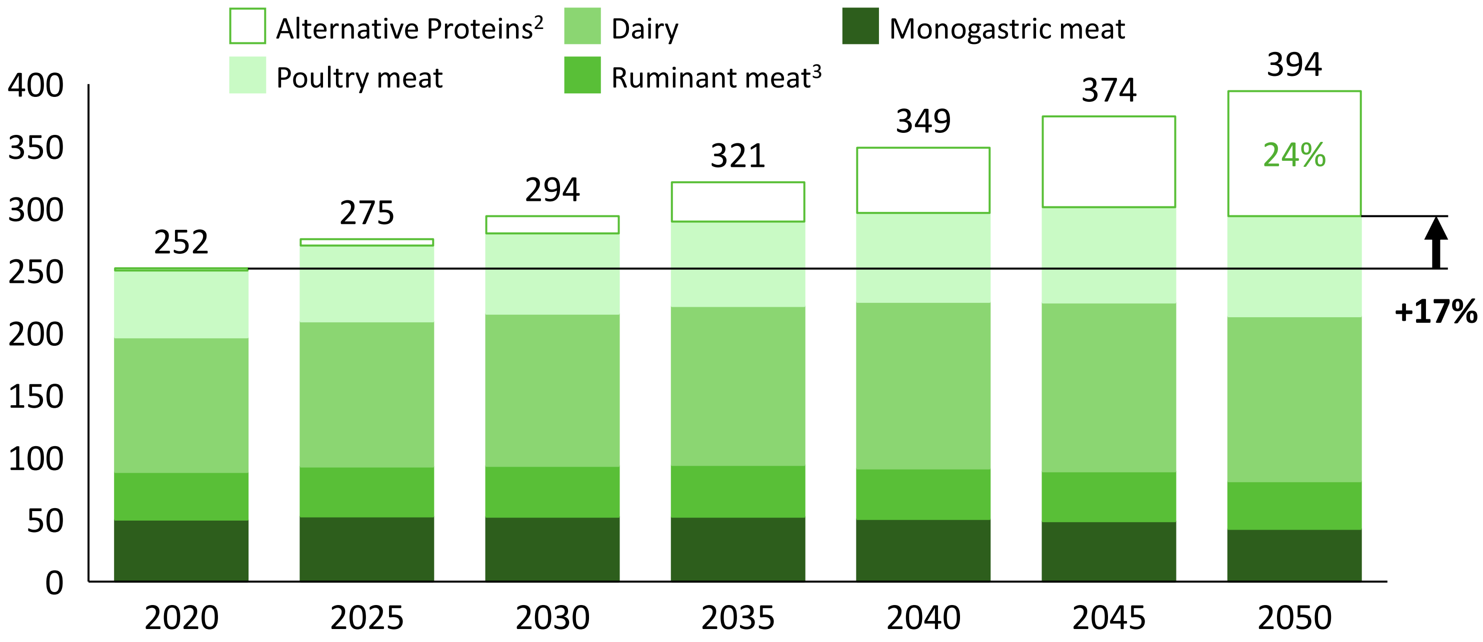
1. AI-based sales, harvest and food waste forecasting; new storage and preservation technologies
2. Education and labelling programs aimed at reducing food waste at the consumption stage; policy incentives for food donation such as tax exemptions; development of secondary markets to sell food surplus and non-standard food products

INEVITABLE POLICY RESPONSE

Diet shifts transform the food mix, increasing use of alternative proteins

Global Protein Production, Mt DM[1] per year

Though global livestock production increases **by ~17%** by 2050, a diet shift to alternative proteins reduces overall reliance on animal products. In 2050, alternative proteins represent close to a quarter of global proteins production.



Note: 2020 baseline per capita food demand is calculated by Bodirsky et al (n.d.), using dietary data such as incomes, age distributions and BMI, calibrated against historical food demand data from FAO

1. Mega Tonnes of Dry Matter
2. There is a minor difference between the published ppt and the value drivers as the former accounts for all alternative proteins (including eggs and fish), while the latter only includes meats and dairy alternatives
3. Ruminants are herbivores with three- or four-chambered stomachs, such as cattle and sheep

Defining Alternative Proteins

Plant-based Alternative Proteins

Incorporates plant-based protein sources such as soy, pea, wheat etc.

Fermented Alternative Proteins

Proteins manufactured through microorganism breaking down organic matter to produce proteins (e.g., tempeh)

Cell-based Alternative Proteins

Proteins produced by growing animal cells in a laboratory setting without the need to raise or slaughter animals

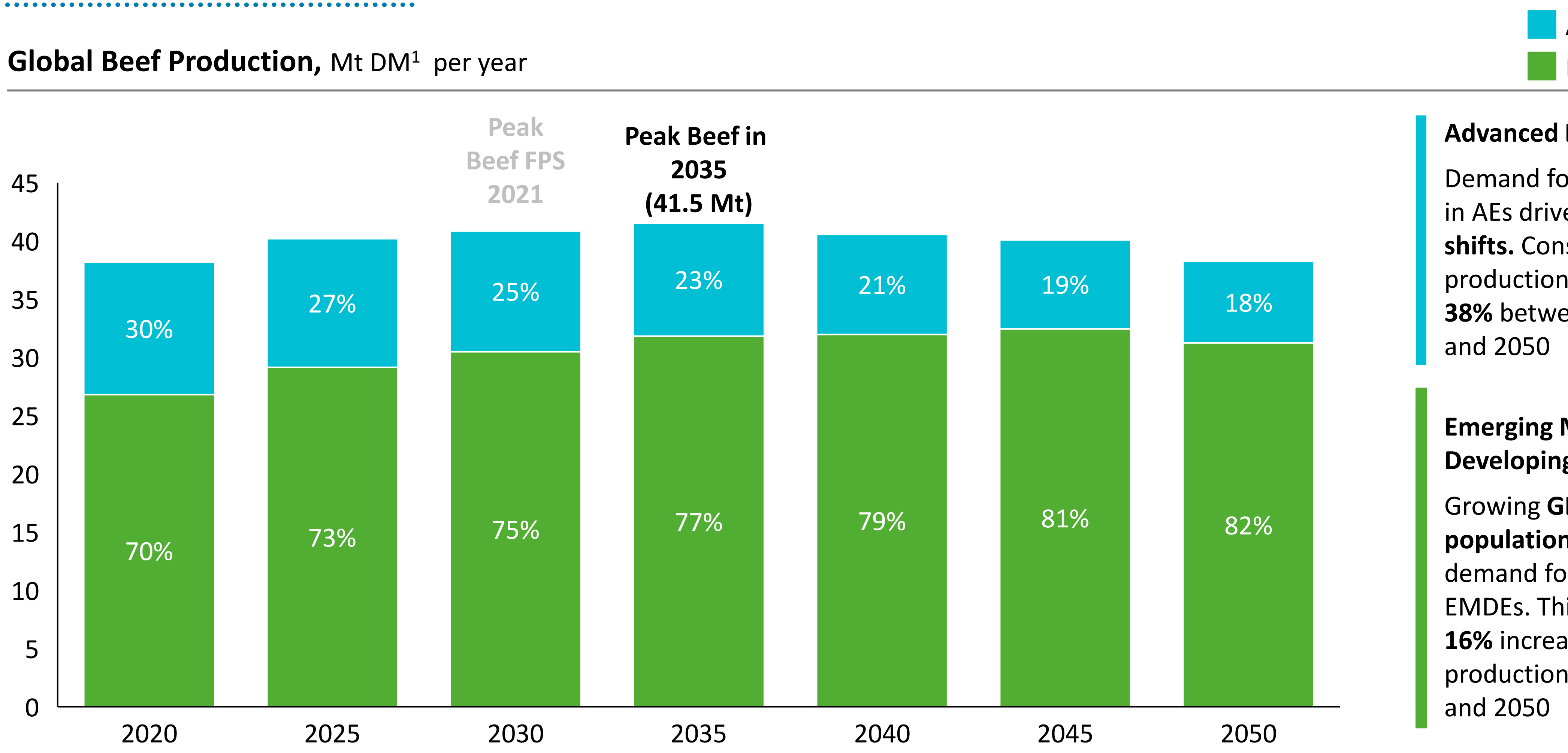
Insects/New Animal Sources

Proteins from alternative animal sources that are often cheaper and less CO_2 intensive than conventional production

INEVITABLE POLICY RESPONSE

Global beef production peaks in 2035 and begins to decline slowly, driven by declining demand from OECD countries

Global Beef Production, Mt DM[1] per year



Advanced Economies

Demand for beef reduces in AEs driven by **diet shifts.** Consequently, beef production reduces by **38%** between 2020 and 2050

Emerging Markets and Developing Economies

Growing **GDP** and **population** drives the demand for beef in EMDEs. This results in a **16%** increase in beef production between 2020 and 2050

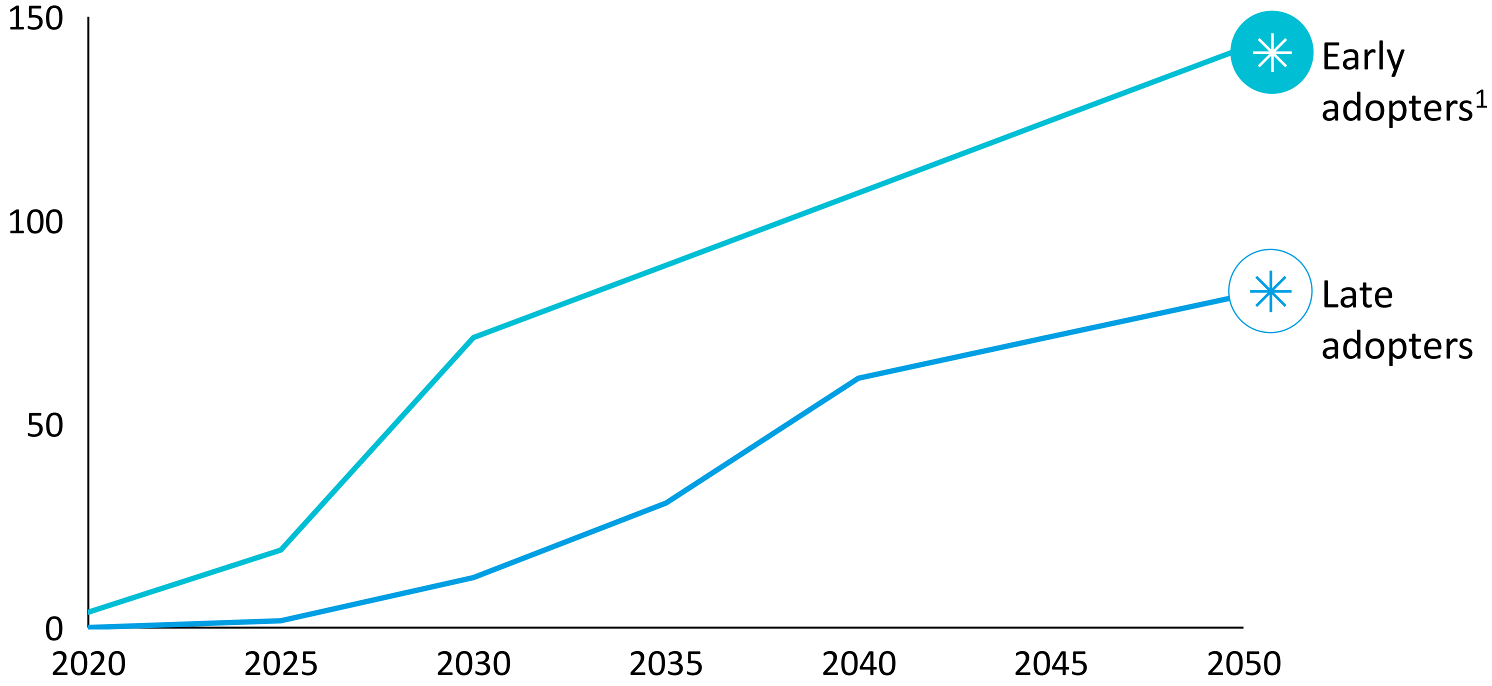
1. Mega tonnes of Dry Matter

INEVITABLE POLICY RESPONSE

Carbon prices grow substantially, increasing market-based incentives for Nature-Based Solutions

FPS 2023 Carbon Prices (2020 US$/$tCO_2eq$)

Carbon prices representing the gradual incorporation of carbon incentives in land use practices, which varies depending on regional ambition.

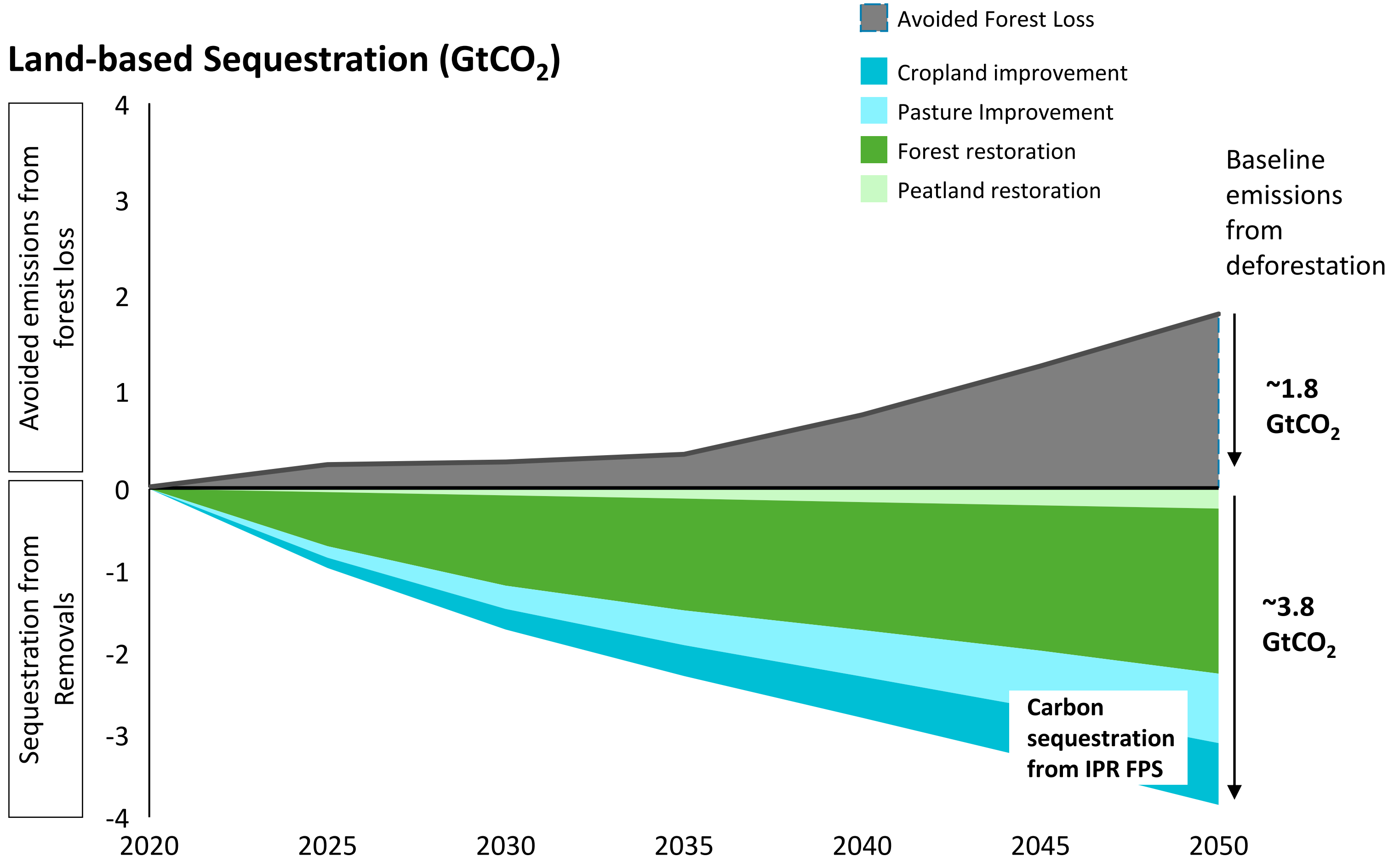


1. Early adopters include Australia and New Zealand, most of EU + UK, Canada, China, Scandinavian countries, South Africa, Japan.

- There is a price differential between energy and land use until compliance markets start covering land use. Under the FPS 2023, land use is increasingly covered by compliance markets after 2025 for early adopters
- Land use carbon prices gradually rise, moving closer to carbon prices in energy and industry. Changes in carbon prices affect NBS uptake: demand is highest if NBS prices are lower than other offset projects, supply only increases if carbon revenues are high enough to outcompete potential agricultural profits
- Other non-CO_2 GHGs are priced differently. N_2O and CH_4 emissions from agriculture are often harder to abate, and policymakers are expected to protect these emissions somewhat to avoid impacts on food prices

INEVITABLE POLICY RESPONSE

By 2050, action to halt deforestation reduces emissions by 1.8 $GtCO_2$/yr, while other policy and market incentives helps capture an additional ~3.8 $GtCO_2$/yr



1. The reference scenario projects the land use change we would expect to see without NBS policies that conserve forest land, improve practices to optimize sequestration, and create new ecosystems. These values represent the difference in removals and reduction between the FPS 2023 scenario and this reference scenario, as a baseline.
2. Ecosystems described here refer to major land-based and carbon-rich ecosystems (e.g. forests, peatland, mangroves, pastureland)

Under FPS, forest-based removals are key for the climate transition as they're responsible for two thirds of the total shift in land-based emissions against a reference scenario[1].

Land-based emissions avoidance and removals **can be broken into three categories:**

Avoided Forest Loss

- Practices that prevent the loss of existing ecosystems (e.g. avoided deforestation)
- NDCs to protect land for biodiversity contribute to the avoidance of ~111 Mha of forest loss
- Reduces emissions by **1.8 $GtCO_2$** relative to a reference scenario[1] by 2050

Agricultural Improvement

- Practices that improve carbon retention in agricultural lands (e.g. soil or production improvements)
- Removes **1.6 $GtCO_2$** a year by 2050, equivalent to ~938 Mha

Ecosystem Restoration

- Practices that creates new ecosystems[2] (e.g. restoration of natural forests and other ecosystems)
- Removes **2.2 $GtCO_2$** a year by 2050, equivalent to ~302 Mha

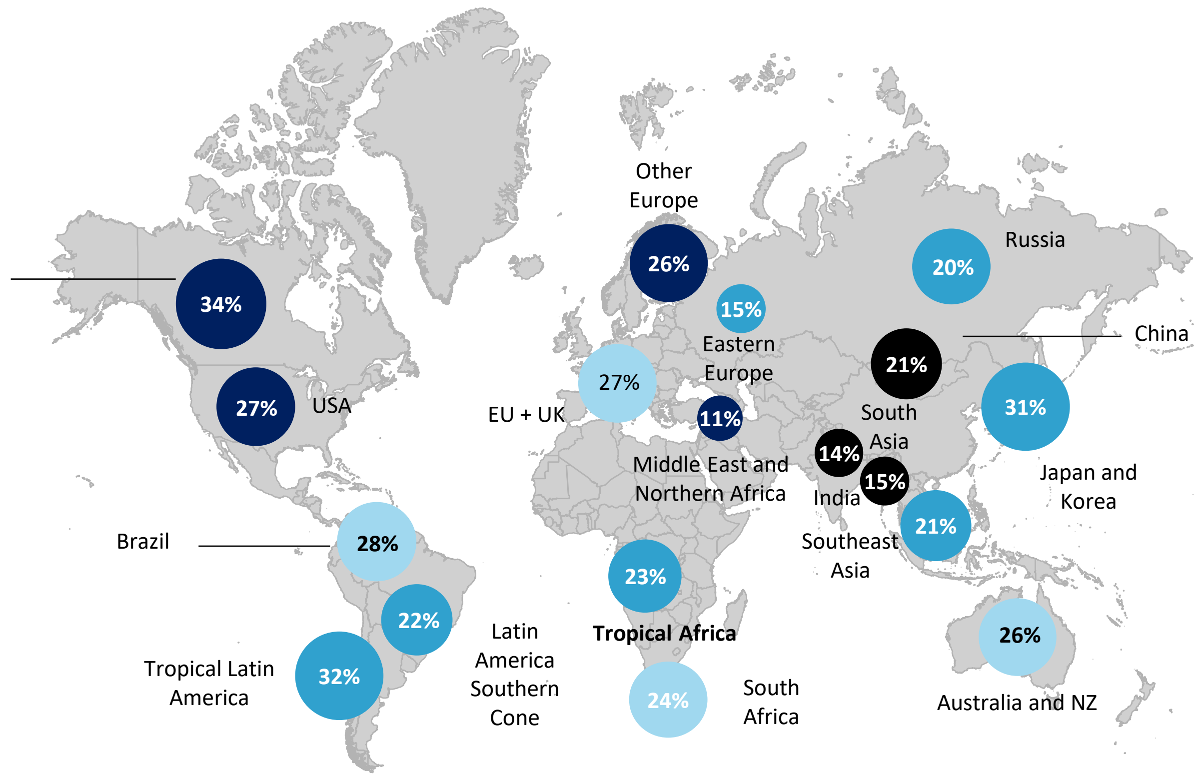
INEVITABLE POLICY RESPONSE

Under FPS 2023 biodiversity and nature policies protect an additional 980 million hectares of natural vegetation[1] from 2020-2050….

Additional land protected[2],
(FPS 2023 compared to Current Protection[3])

Low[2] — High[2]

% **Natural vegetation under conservation in 2050 as % total land**



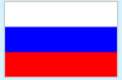
1. Natural vegetation includes primary and secondary forestland
2. Low ~ 50%; High ~1100%
3. 'Current Protection' refers to a counterfactual scenario where protected areas are kept at current levels
4. End of deforestation is defined as a reduction in average annual deforestation by more than 95% versus the 1990-2020 level alongside net increase in forest cover.

…shifting production away from biodiversity hotspots

Regional Implications

Land protection is already ambitious in Brazil, so the increase in conservation of natural vegetation between 2020-2050 is low. Coupled with ambitious policies and market incentives to end deforestation[4], strict area protection helps restore natural vegetation and increase forest area.

China faces a substantial increase in protection of natural vegetation, though the share of natural vegetation protected remains below that of European, African and American regions.



Russia already protects a large share of its natural vegetation as low population density and high amounts of unproductive land create less barriers to protecting land from agricultural production.

India protects ~13% of natural vegetation by 2050. Although this a relatively low share, it represents a significant increase from 2020-2050, driven by a push in policies which protect natural land.

INEVITABLE POLICY RESPONSE

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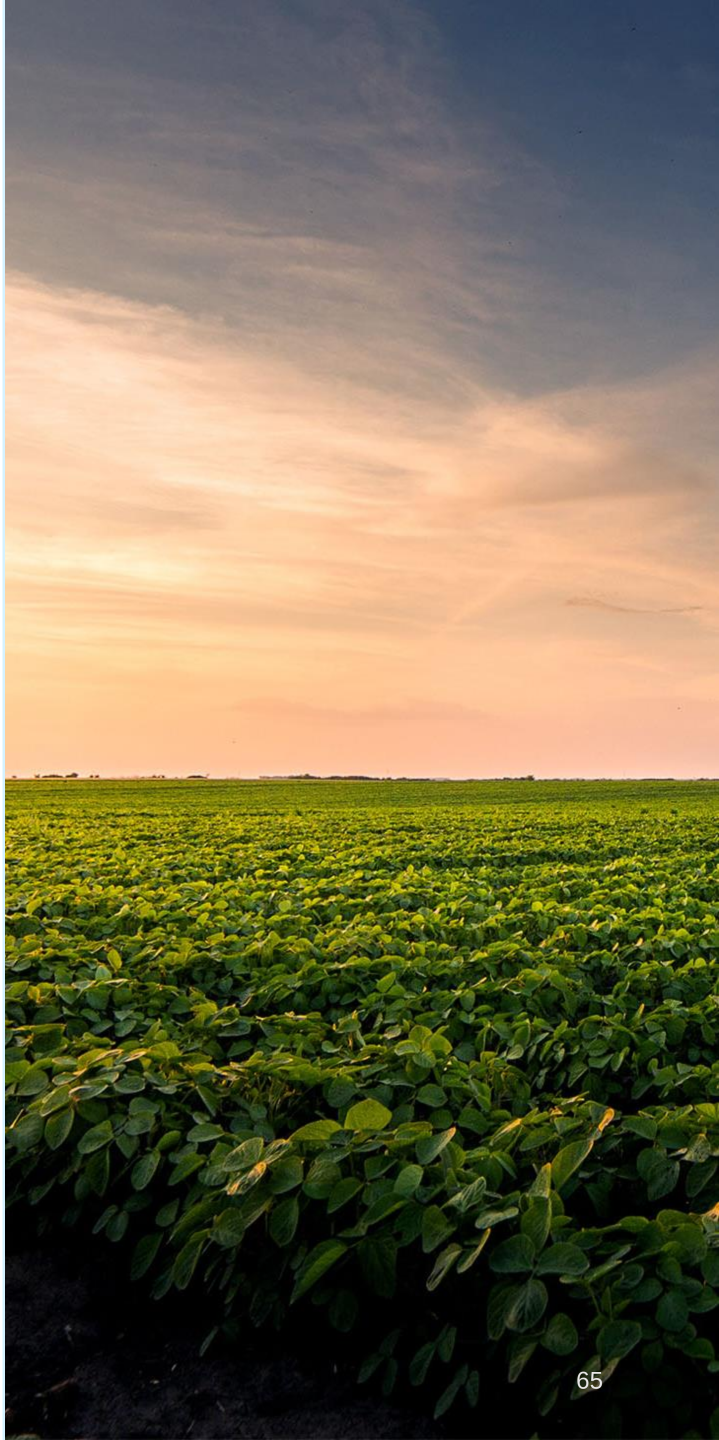
BIOENERGY: IMPLICATIONS FOR INVESTORS

Takeaways from IPR FPS 2023

1. Land scarcity implies sustainable sourcing policy is expected to constrain bioenergy
2. Unabated biomass plays a long-term role in the aviation, shipping and pulp & paper sectors, but is otherwise outcompeted by cleaner, cheaper alternatives
3. Waste and residues are expected to make up a growing share of feedstock as a more sustainable alternative to the 1G crops currently common. Some 2G dedicated biomass crops will likely be required to meet demand, but is limited to ~91Mha
4. BECCS scales up significantly to ~1GT of removals in power and cement industries, but further growth is constrained by high land opportunity costs combined with increased competition from DACCS
5. There is a mismatch between current bioenergy infrastructure and what is needed in the long term. Location and feedstock mismatches create both investment opportunities and stranding risks.



INEVITABLE POLICY RESPONSE

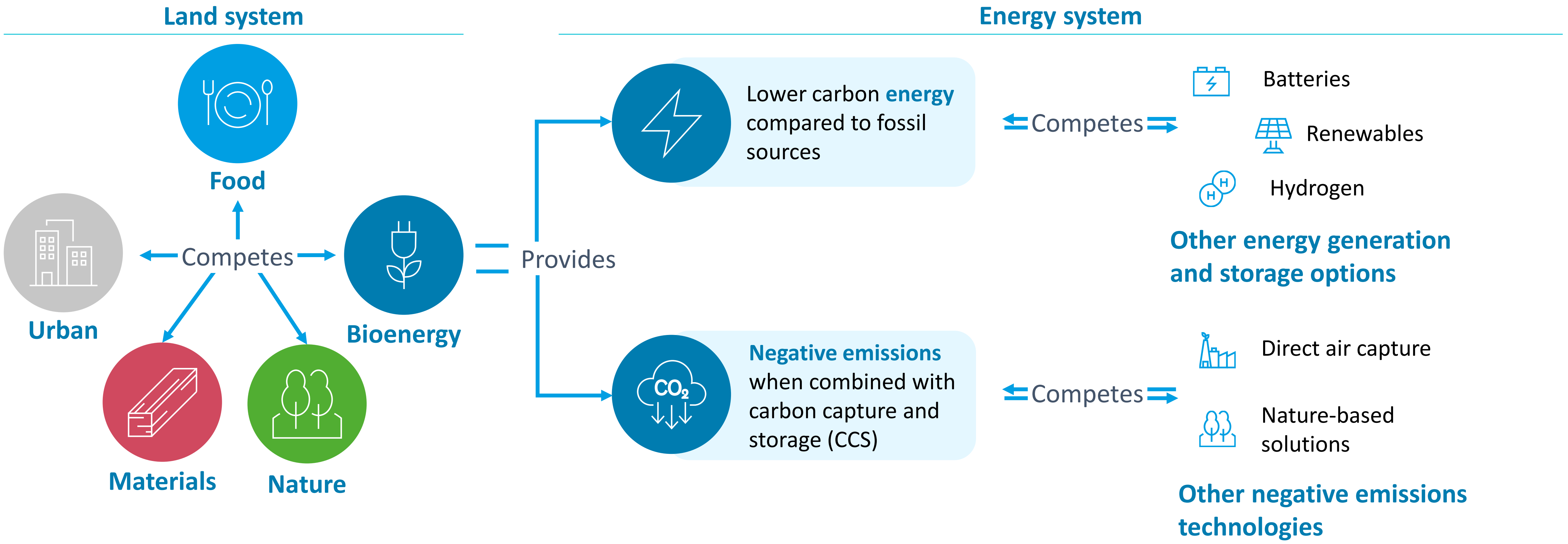
KEY FINDINGS

1. Bioenergy competes for scarce land in a system increasingly asked to provide more food, materials, urban space, and natural ecosystems
   - Bioenergy is costly for the land system to produce, but can facilitate decarbonization by delivering both low carbon energy and negative emissions when used with carbon capture and storage (CCS)
   - There are many competing demands for a fixed amount of land, and bioenergy might displace other uses that currently store carbon. This opportunity cost can be represented as the time required for bioenergy to capture and store the carbon it displaces (the "carbon payback period")
   - To be useful in the energy system, biomass must be either lower cost or more sustainable than other decarbonization technologies
2. Sustainable sourcing policy makes feedstock a critical determinant of bioenergy's competitiveness
3. Policymakers are expected to increasingly introduce sustainability guardrails for sourcing biomass, including avoiding nature displacement, deforestation, food competition, and irrigation
   - There are ~30 EJ of potential supply of waste and residue feedstocks that minimally compete for land and are currently underutilized. Bioenergy demand beyond that must be met with land dedicated to growing biomass
   - By 2050, IPR FPS uses 91Mha of land with a low carbon payback period, most of which is in arid or cold biomes, and none is in tropical biomes where re/afforestation could be a more efficient store of carbon
   - Current bioenergy capital stock does not match locations of sustainable dedicated supply, implying the industry needs to transition away from 1G crops toward waste and residues and build out new infrastructure
4. Bioenergy without CCS is likely to be outcompeted by lower carbon alternatives in most energy system applications
   - Aviation, shipping and the pulp & paper industry are exceptions - a lack of cleaner alternatives and very inexpensive self-supply of waste and residues make unabated bioenergy cost competitive through 2050
5. Bioenergy with carbon capture and storage (BECCS) in industry and power is costly but offers negative emissions. Significant scale up is possible to ~1 $GtCO_2e$ of BECCS removals, but will then be outcompeted by DACCS
   - Power and cement applications together represent ~13 EJ of BECCs by 2050. This contrasts with other prominent transition outlooks, many of which expect a larger role for bioenergy
   - As with bioenergy in transport, BECCs applications are also expected to transition away from the unsustainable 1G crops currently used, toward agricultural residues and some dedicated 2G lignocellulosic biomass

INEVITABLE POLICY RESPONSE

Bioenergy bridges land and energy: Competition forces difficult trade offs between competing uses

Climate, **nature**, and **affordability** outcomes represent **constraints on the outputs** we consume from the land system. Maintaining and restoring forested area, for example, is necessary for emissions and biodiversity targets to be realized

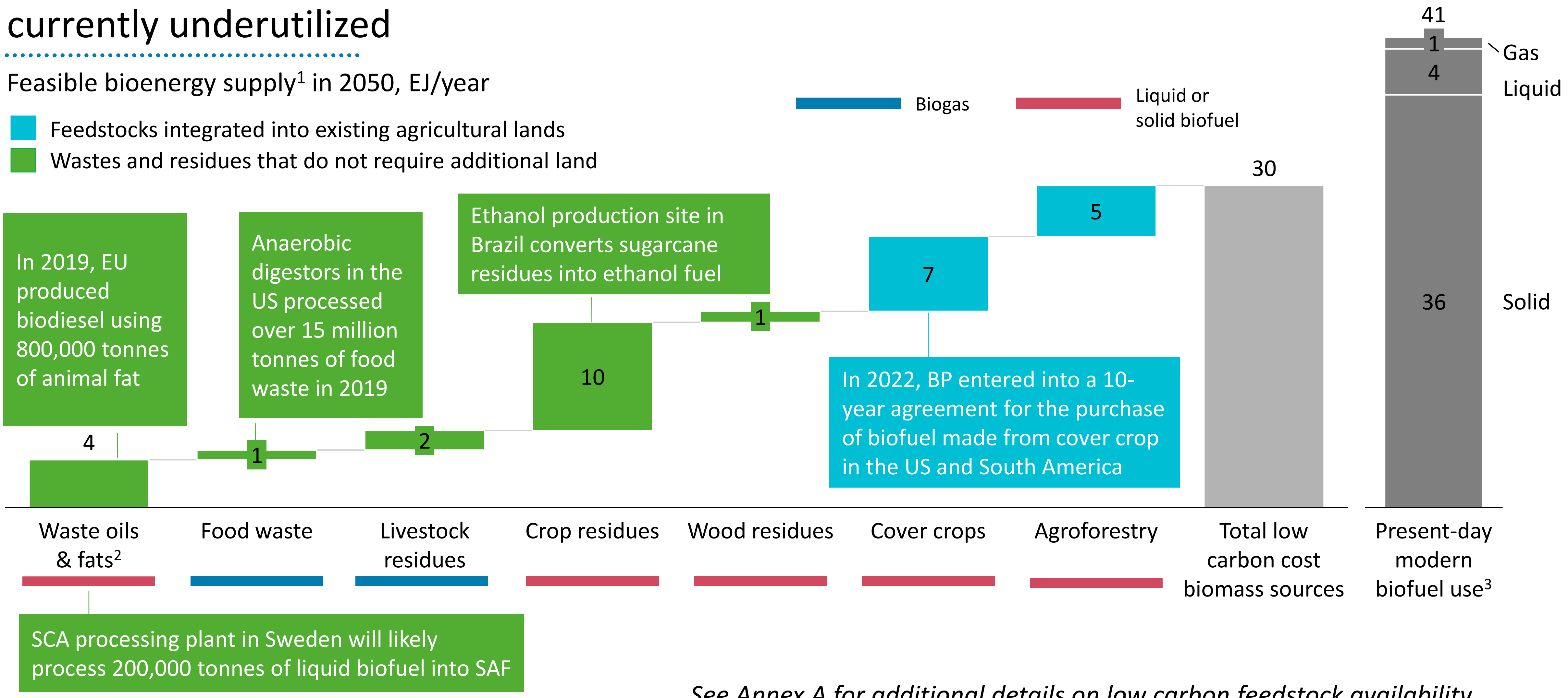


Improving yields, changing consumption habits, and **reducing waste** can all **ease competition** and improve tradeoffs

INEVITABLE POLICY RESPONSE

Low carbon cost biomass sources become limited in availability, but are currently underutilized

Feasible bioenergy supply[1] in 2050, EJ/year



See Annex A for additional details on low carbon feedstock availability

1. Estimates represent final energy consumption, following conversion losses.
2. Includes tall oil, palm oil mill effluent (POME), used cooking oil (UCO), and animal fats/tallow.
3. Around 16 EJ of solid biomass is estimated to be sourced from tree plantations & short-rotation crops, which require dedicated land. The liquid biofuels category likewise includes a large fraction sourced from 1G crops for transport fuels (ethanol & biodiesel).

Source: US EPA, SCA, Toldrá-Reig et al. (2020), ICCT, Upstream, Raizen

INEVITABLE POLICY RESPONSE

Applying four guardrails can limit the high environmental costs of dedicated biomass

Policymakers are expected to increasingly move toward sustainable biomass sourcing requirements

Policy driver	Description	Example policy
No nature displacement	Recent drive for **land sparing to protect high biodiversity areas, restricting alternative uses for the land**. We exclude land area that is included in the World Database on Protected Areas (WDPA) and that has a score above 400 on the IUCN species richness index.	In summer 2022, over **100 countries (including EU) committed to 30x30 protection**: to protect at least 30% of land and oceans by 2030.[1]
No deforestation	Policies implemented to **restrict dedicated bioenergy crop** production in areas of high carbon stock value. Cutting mature carbon stock further increases the **opportunity costs of planting bioenergy** crops vs. alternative options such as planting forest. We exclude land with an above-ground vegetation carbon stock higher than 30 tC/ha, soil carbon higher than 100 tC/ha, and peatland, which has extremely high carbon density.	EU's Renewable Energy Directive **limits fuel produced on previously high carbon land** such as forests, wetlands and peatlands.[2]
No food competition	**First generation bioenergy crops directly compete with food production** and are therefore subject to government restrictions especially in the context of current geopolitical conflict. We exclude all areas that are in the top 30% of yields for maize, rice, wheat, and soybean.	Germany moved to **ban food crops in biofuel production** in response to high food prices after the invasion of Ukraine.[3] **UK bioenergy support schemes** limit food crops for bioenergy, due to **food security and indirect land-use change emissions**[5].
No irrigation	Recent literature finds that the use of **irrigated biomass would double the global area and population under water stress** thereby exceeding the effects of climate change itself.[4] We exclude all areas that need to be irrigated in order to grow bioenergy crops.	UK biomass policy statement defines the effect of biomass production on water as a key concern.[5]

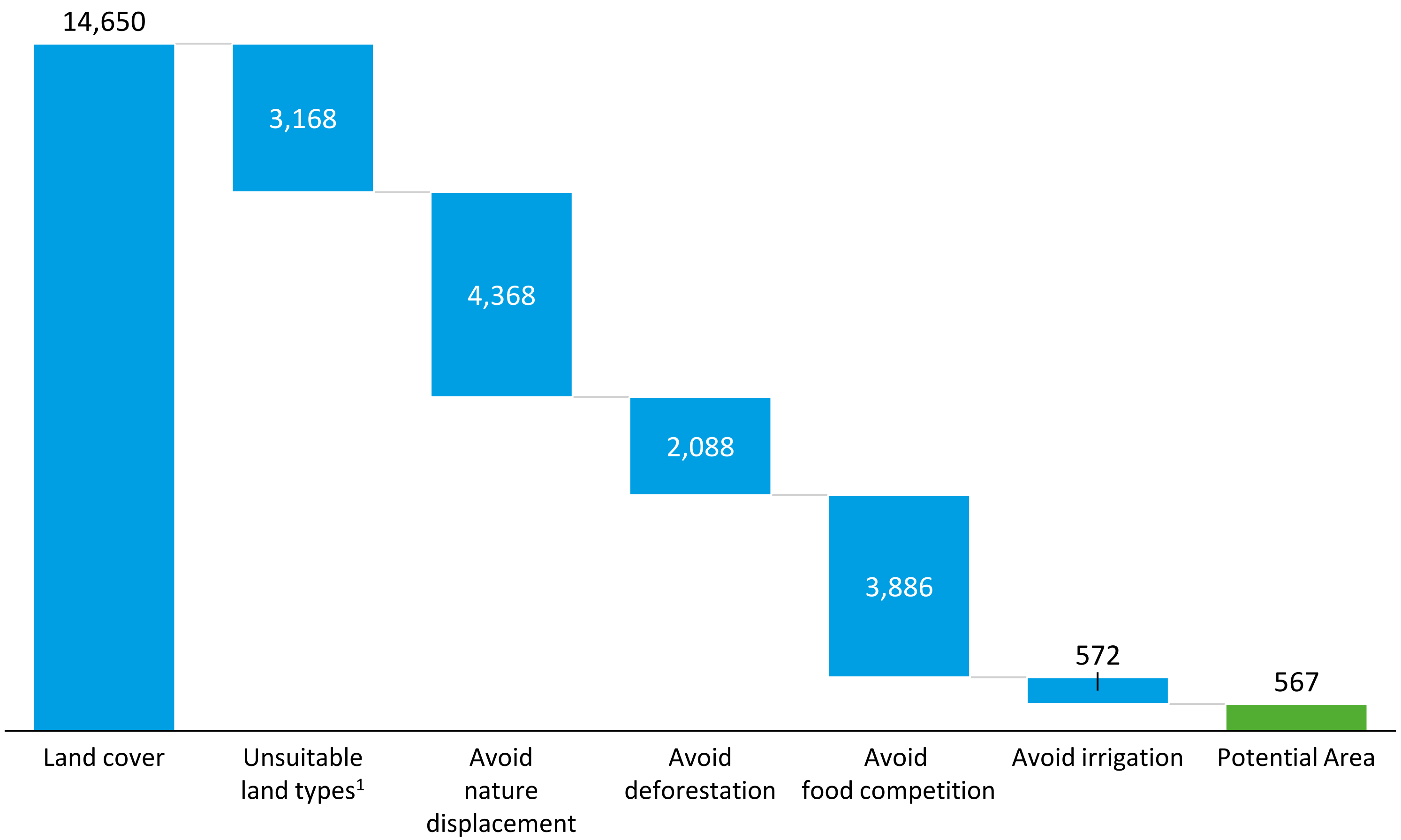
Note: After applying the sustainability guardrails, a carbon payback period is calculated for the remaining available land to determine the most effective method of storing carbon assuming that land is optimizing for carbon storage. Note also that these guardrails focus on environmental impact, but policymakers may also introduce social guardrails, such as avoiding the displacement of native populations

1. World Ocean Day, 2. European Commission, 3. Clean Energy Wire, 4. Stenzel et al. (2021), 5. UK Department for Business, Energy and Industrial Strategy

INEVITABLE POLICY RESPONSE

567 Mha in five different biomes satisfy basic sustainability criteria

Potential area for dedicated biomass crops after applying sustainability guardrails, Mha



After applying the sustainability guardrails, a carbon payback period is calculated for the remaining available land to determine the most effective method of storing carbon

1. Exclusion of bare lands (e.g., deserts), urban areas, inland water bodies (lakes and rivers), and areas of permanent snow and ice.

Source: ESA CCI medium-resolution land cover; UNEP/IUCN (WDPA); IUCN; Spawn et al. Sci Data 2020; Xu et al. 2017 PEATMAP; Heiderer & Kochy 2012; Monfreda et al. GBC 2008; Biradar et al. 2009

INEVITABLE POLICY RESPONSE

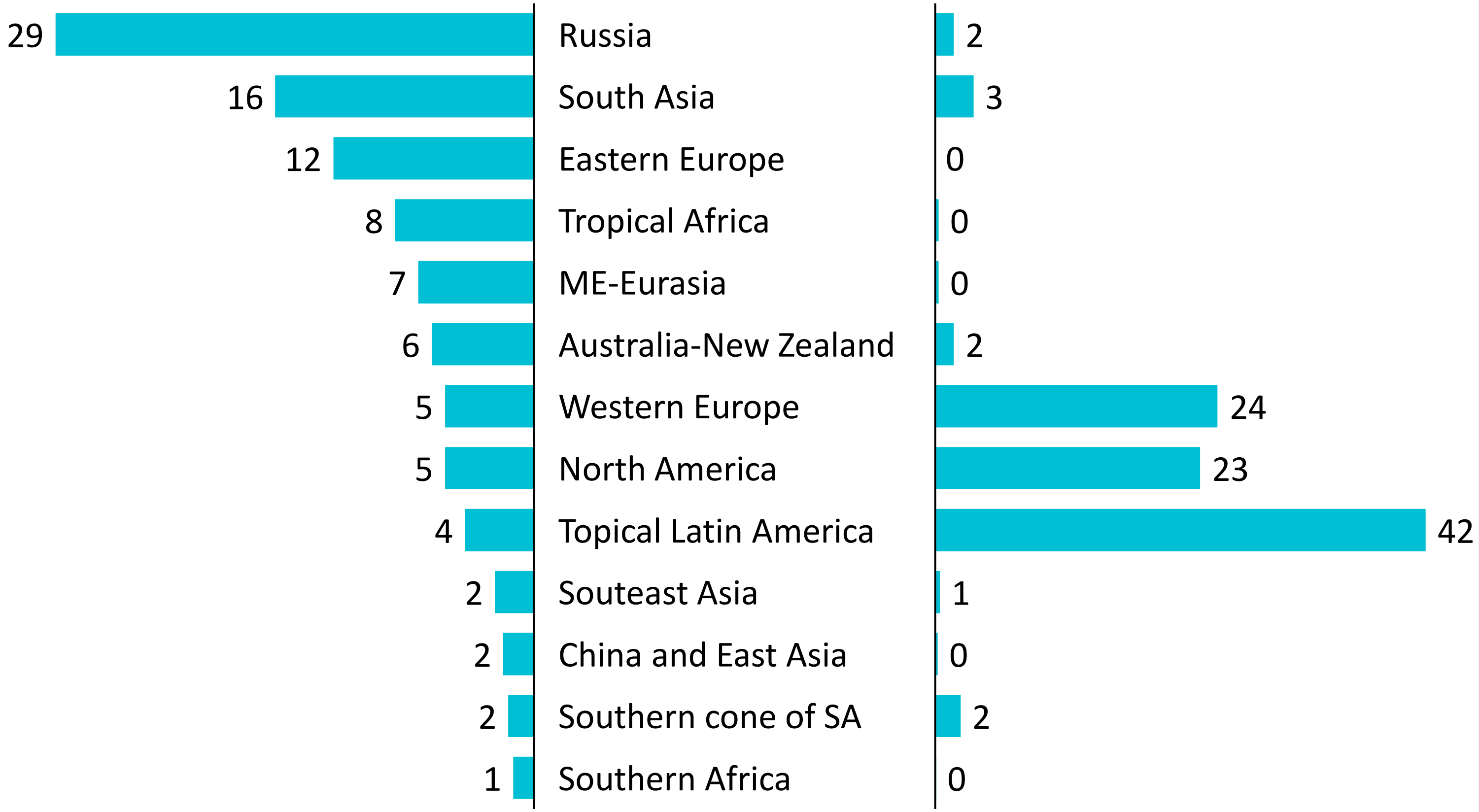
Land suited to bioenergy is typically far from current demand

Potential dedicated crop area[1]

% of global area after four guardrails (100%=567 Mha)

Biomass power plants[2]

% of global capacity



Land for dedicated bioenergy is available, though not where there is existing demand

For example, the largest biomass power plant capacity of 12,800 MW is in Brazil, where there is very little potential for energy production from sustainable dedicated bioenergy crops (< 0.1 EJ). However, there is around 3 EJ available from waste streams in Brazil.

That implies that relatively little of the bioenergy capital stock currently deployed is well positioned for sustainable long-term supply. Feedstock sourcing is an important challenge for these plants if they are to continue operating long term.

1. Area that has met the sustainability guardrails to avoid nature displacement, deforestation, food competition, and irrigation.
2. Source: Global Power Plant Database . Dataset for 2021 includes power plants that use biomass feedstocks and is non-exhaustive for infrastructure associated with the bioenergy industry (e.g., biofuel refineries).

INEVITABLE POLICY RESPONSE

Most end uses of biomass simply provide energy, but adding CCS can also provide negative emissions in power and industry

Energy provision

Bioenergy has a similar chemical composition to fossil fuels so releases a similar amount of energy. However, the carbon sequestered by growing biomass means the **lifecycle emissions are lower than fossil fuels**. Because they are similar, bioenergy can often be used with **existing fossil infrastructure.**

End-uses for which biomass can only provide energy include:

- Road transport
- Shipping
- Aviation
- Buildings

These end-uses cannot be used for negative emissions because sources are not sufficiently concentrated for CCS

Carbon removals (Negative emissions)

For end-uses with concentrated sources of CO_2 emissions, **CCS can be added to provide net-negative emissions**. This is bioenergy with carbon capture and storage: BECCS. Because CCS captures most "tail-pipe" emissions, the amount of carbon sequestered by growing biomass is greater than the amount emitted during combustion.

End-uses for which biomass can provide negative emissions in addition to energy include:

- Power
- Industry

These negative emissions applications compete against alternatives such as Direct Air Carbon Capture and Storage (DACCS)

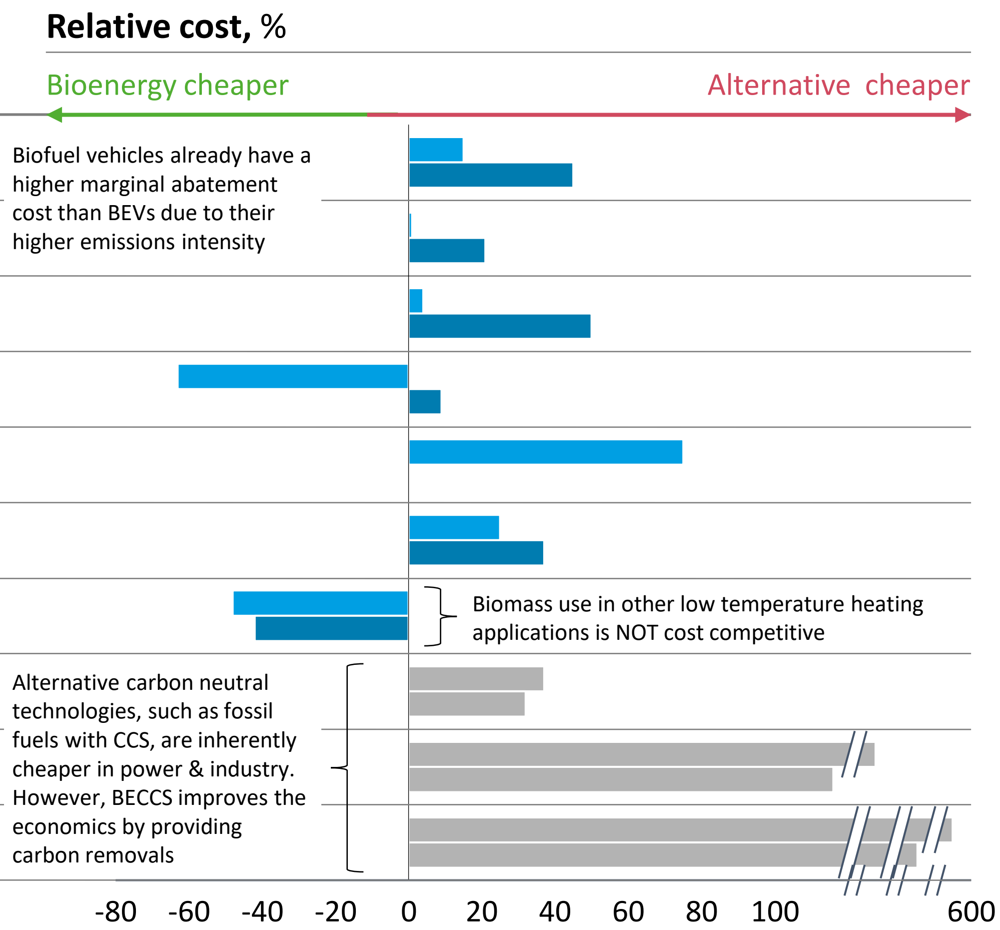
INEVITABLE POLICY RESPONSE

Bioenergy is a long-term decarbonization option in aviation and some niche uses, but is not cost competitive otherwise

⊗ Unlikely (other than for niche or transition uses) ✓ Likely

SELECTED END USES, NOT EXHAUSTIVE

Sector	End use	Feedstock: Current	Feedstock: Future	Alternative	Long-term option
Transport	Light-duty vehicles[1]	1G crops	N/A	BEV	⊗
	Heavy-duty vehicles[1,2]	1G oil crops	Residues	BEV	⊗
	Shipping[1]	1G oil crops	N/A	Ammonia	⊗
	Aviation	1G oil crops	Residues	Synfuels	✓
Buildings	Space heating[3]	Wood residue	N/A	Electrification	⊗
Industry	Iron & steel (no CCS)	Wood pellets	N/A	H2DRI EAF	⊗
	Pulp and Paper process heating[4]	Wood residue	Wood residue	Electrification	✓
	BECCS for cement	Wood pellets	2G crops	Gas CCS	✓ (grey)
	BECCS for other high T industry	Wood pellets	2G crops	Gas CCS	✓ (grey)
Power	BECCS for power	Wood pellets	2G crops	CCGT CCS	✓ (grey)

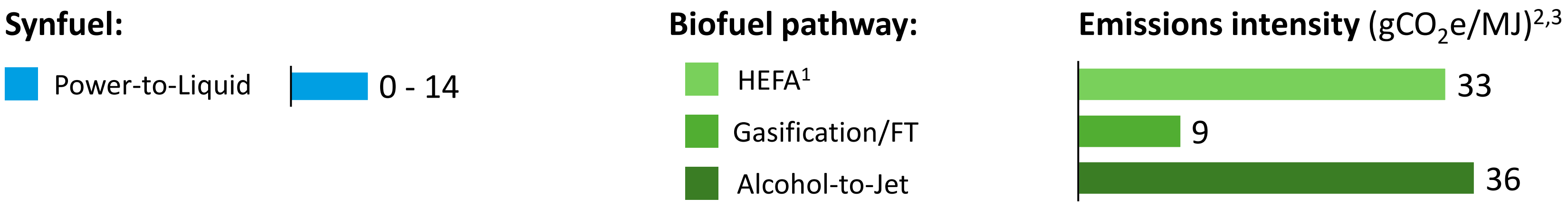


Note: BECCS technologies are compared here against alternative focused only on end use, and as such relative costs do not incorporate any possible payment for removals. See next sub-section for further comparison against alternative emissions removals options

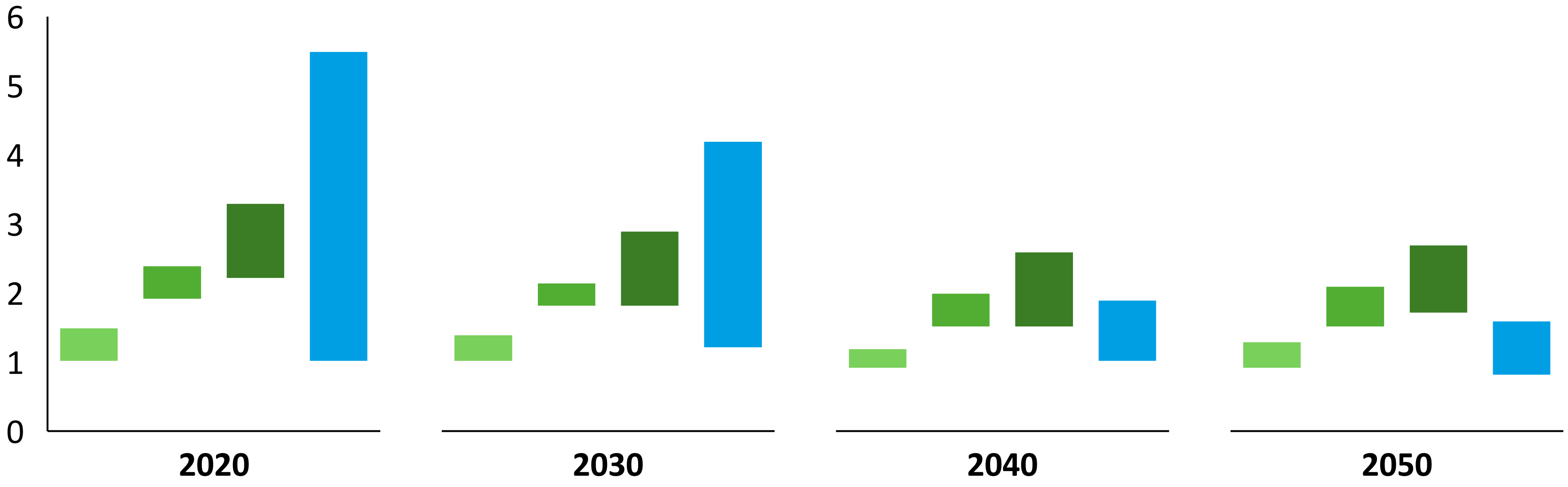
Source: 1. ETC, 2021, Bioresources within a Net-Zero Emissions Economy; 2. Transport and Environment, 2020, How to decarbonise the UKs freight sector by 2050; 3. Khan et al, 2023, Life cycle cost analysis (LCCA) of Stirling-cycle-based heat pumps vs. conventional boilers (assuming biogas boiler); 4. Pulp and paper is one application of low temperature process heating, and is the only industrial application in which biomass is lower cost than other low carbon alternatives because it can self-supply the wood residues

INEVITABLE POLICY RESPONSE

AVIATION – Biofuels are likely to be cheaper than synfuels for the next ~20 years



Sustainable aviation fuel production cost
Thousand USD/t of kerosene



1. Hydroprocessed Esters and Fatty Acids. Advanced biofuel produced from oily feedstocks
2. EASA, 2023, Fit for 55 and ReFuelEU Aviation; Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ensuring a level playing field for sustainable air transport
3. ICAO, 2022, Life Cycle Emissions of CORSIA eligible fuels

Aviation biofuels are currently the only decarbonization option and will likely be competitive until at least 2040. RefuelEU targets > 50% of biofuels in the sustainable fuel mix out to 2050[2]. Feedstocks for these fuels are currently mostly 1G oil crops, but increasingly move toward utilizing waste oils.

Synfuels potentially have advantages in terms of resource use (e.g., water, land), but their emissions intensity depends on the source of CO_2.

Synfuel costs depend on the cost of green power and the source of CO_2 capture: DACCS based fuels currently ~ 5x more expensive than fuels with CO_2 from local CCS.

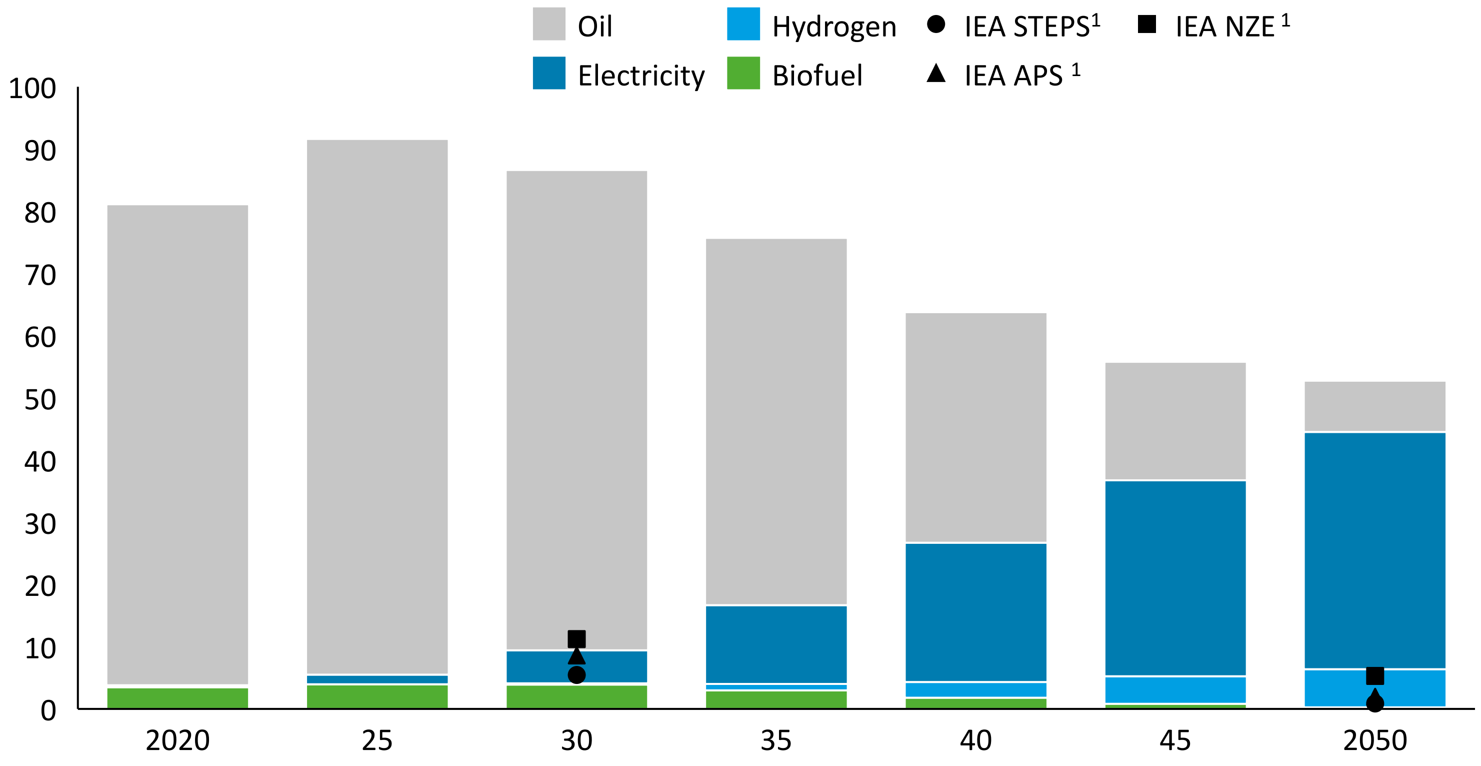
While synfuels could potentially be cost competitive by 2040 or 2050, there remains a great deal of uncertainty relative to biofuels.

INEVITABLE POLICY RESPONSE

Road – biofuels are used for the next 20 years but are eventually phased out

Demand peaks in the 2020s and drops to almost 0 by 2050

FPS 2023 energy demand, EJ



1. Applies bioenergy shares from IEA World Energy Outlook, 2022 to FPS23 demand

Electrification (and eventually fuel cells in some applications) is the **greenest and cheapest decarbonization** option in road transport. 1G biofuels will likely continue to be used in the current fleet.

Ethanol, produced from sugar crops, is **already being phased out** in most countries so FPS23 demand peaks in 2025 for light duty vehicles.

However, FPS23 biodiesel demand from 1G oil crops **peaks in 2030** for heavy duty vehicles where alternatives are less mature.

INEVITABLE POLICY RESPONSE

Carbon payback periods measure the carbon opportunity cost of land dedicated to bioenergy crops

Carbon payback period (CPP) is the **amount of time** that a **bioenergy crop** needs to be grown before it absorbs more **carbon than if that area was re/afforested instead**

$$CPP_i = (ACSi + ACPi)/((1 - c) * yi * CS)$$

y = yield of biomass crop in area i

CS = carbon content per ton of biomass crop

CPP = carbon payback period of area i

ACS = current above ground carbon stock associated with area i

ACP = above ground carbon potential associated with a mature forest in area i

c = carbon losses resulting from conversion to energy and subsequent capture and storage

The carbon payback period varies due to differences in **yield** and the **carbon potential** achievable in each locality

Long carbon payback periods imply that biomass crops must be used with CCS for many years before they store enough carbon to be a better option than letting the land naturally regenerate

CPP is a measure of opportunity cost:

- CPP is zero for biomass that does not compete for land such as residue and waste sources
- Biomass that displaces existing carbon stock has a higher CPP
- CPP can be high even for degraded land that does not currently have a high carbon stock if a forest could go there instead
- Note that CPP does not measure impact on biodiversity, water, and food security, so is not the only measure of sustainability
- Policymakers are likely to be **skeptical of subsidizing biomass grown in areas with long carbon payback periods**

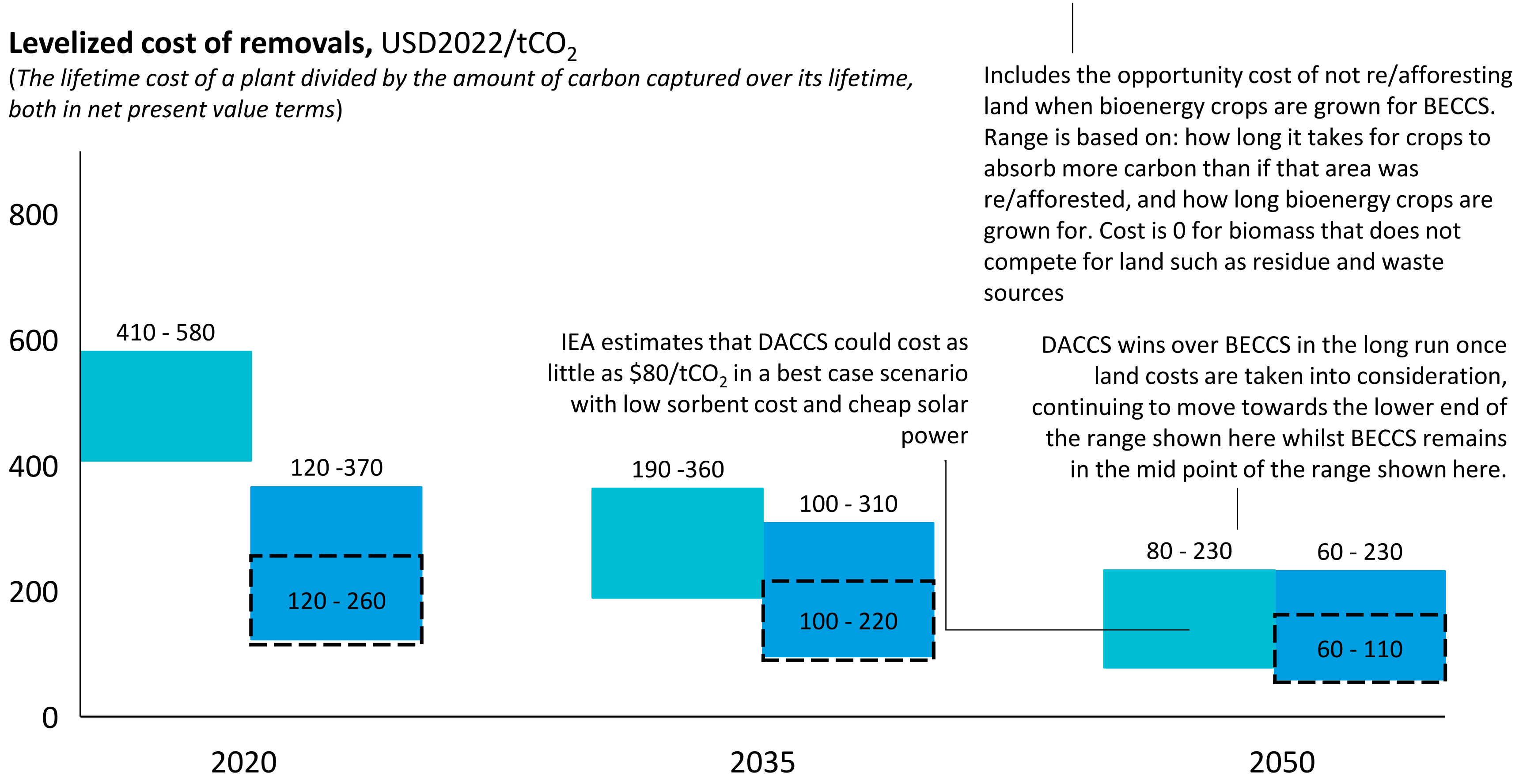
Source: Energy Transitions Commission, analysis based on MAgPIE land system model

INEVITABLE POLICY RESPONSE

Once land-based costs are considered, DACCS is expected to be more attractive than BECCS by 2050

DACCS (IEA, 2021[1]) BECCS – without land costs (IPR analysis[2]) BECCS – with land costs (IPR analysis[2])

Levelized cost of removals, USD2022/tCO_2
(*The lifetime cost of a plant divided by the amount of carbon captured over its lifetime, both in net present value terms*)



1. Primarily based on IEAGHG Technical Report, 2021, Global Assessment of Direct Air Capture Costs. Assumes FOAK is 2020 and NOAK is 2050. Range is from base case (lower) to very ambitious (upper)
2. No land cost estimates in line with Fuss et al, 2018, Negative emissions—Part 2: Costs, potentials and side effects. Land costs calculated based on how long it takes for crops to absorb more carbon than if that area was re/afforested: the carbon payback period (CPP), and how long bioenergy crops are grown for: the removal period . Lower bound = 75-year removal period with 5-year CPP, upper bound = 50-year removal period with 15-year CPP
3. BECCS and DACCS represent two of the most often discussed technology-based removals, however other approaches such as biochar or enhanced weathering also offer potential for removals.

There are multiple considerations in estimating the true levelized cost of removals for BECCS. In particular, land costs are considered explicitly in the modeling for FPS 2023 (see footnote 2), whilst others' estimates typically may not

BECCS applies a relatively mature technology and so is unlikely to experience significant cost reductions. BECCS costs increase if the land impact of growing biomass is considered

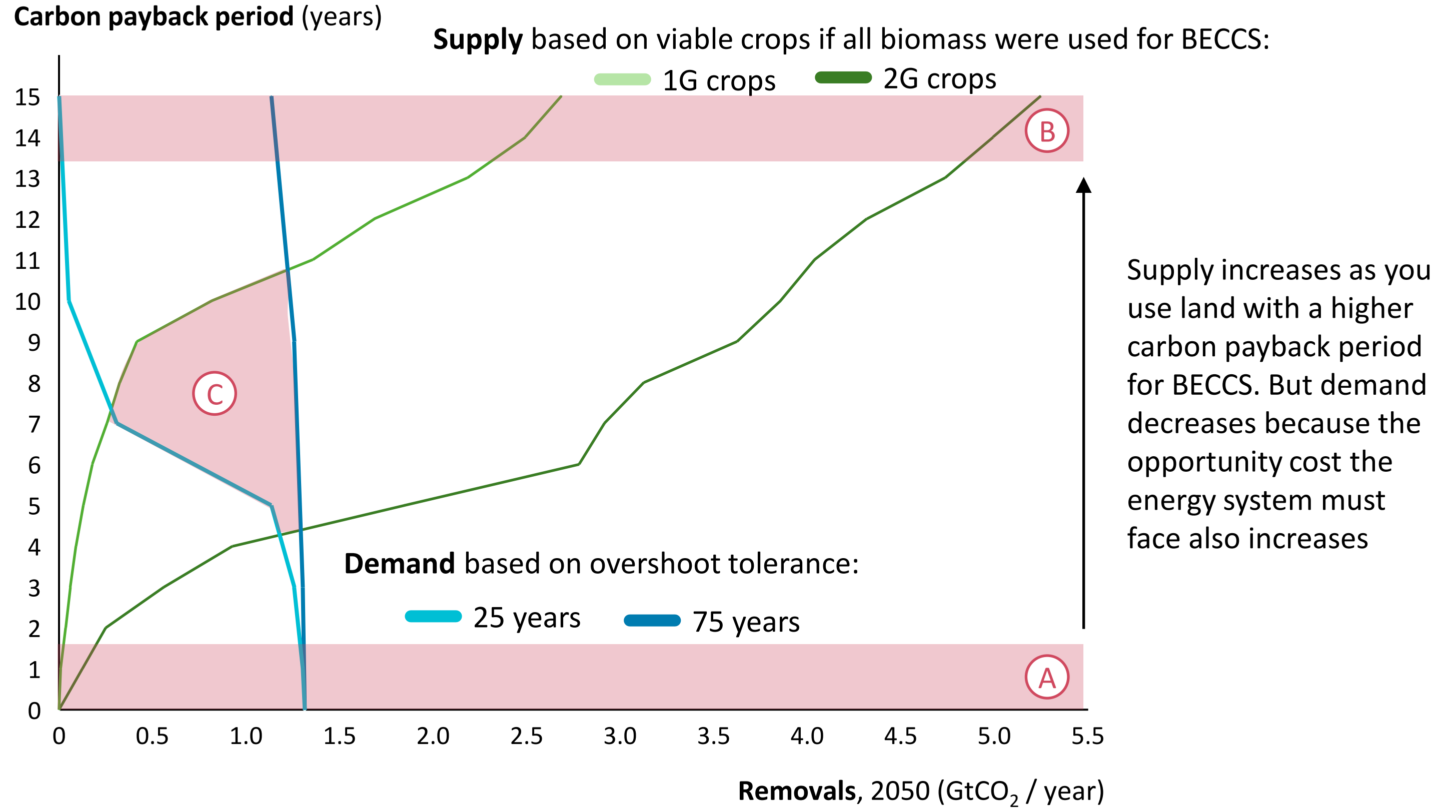
Direct Air Carbon Capture and Storage (DACCS) removes carbon from ambient air and has the benefit of limited land constraints[3]. While it starts from a high baseline, it could see rapid cost reductions as today's demonstrator plants scale, and with access to low-cost renewable energy

INEVITABLE POLICY RESPONSE

BECCS is likely limited to using only biomass from land with lower payback periods

There is ~ 1 $GtCO_2$ of BECCS by 2050 in FPS 2023 based on feasible supply and demand

(A) (B) (C) Denote different possible "states of the world" which vary by carbon payback period



1. The amount of CO_2 removal per unit of energy production in the modeling varies by process and feedstock, but a rough approximation is 1 $GtCO_2$ per 10 EJ. For comparison, BECCS removals in 2050 in the IEA NZE scenario are 1.3 $GtCO_2$ per year.

(A) **Maximum demand but minimum supply**

- All biomass used for BECCS comes from land with low payback periods so there is almost no opportunity cost for BECCS: it is relatively cheap so there is a lot of it
- However, there is little land with low payback periods so biomass supply cannot meet demand

(B) **Maximum supply but minimum demand**

- There is a lot of land available with high payback periods
- However, because the payback period are high, using biomass from that land adds a large opportunity cost to BECCS: it is relatively expensive so there is little of it demanded

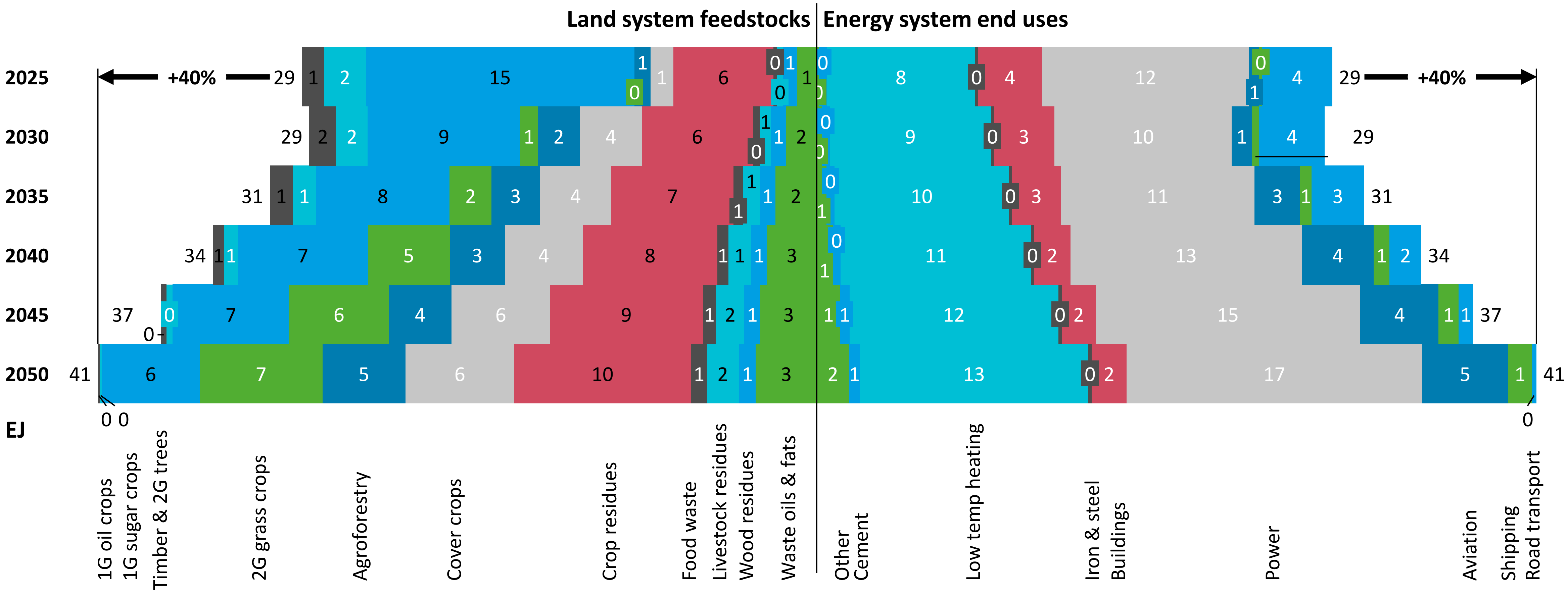
(C) **Feasible range of BECCS removals where demand matches supply: ~ 1$GtCO_2$ by 2050.**[1] The actual amount of BECCS will likely depend on:

- The viability of high-yield 2G crops which provide more supply than 1G crops
- How much biomass is used for other end uses
- The tolerance for overshoot which determines the additional cost of BECCS
- The relative cost of alternative removal technologies such as DACCS

INEVITABLE POLICY RESPONSE

Demand for modern biomass increases only modestly through 2050

Power, aviation, and low temperature heating require additional biomass by 2050



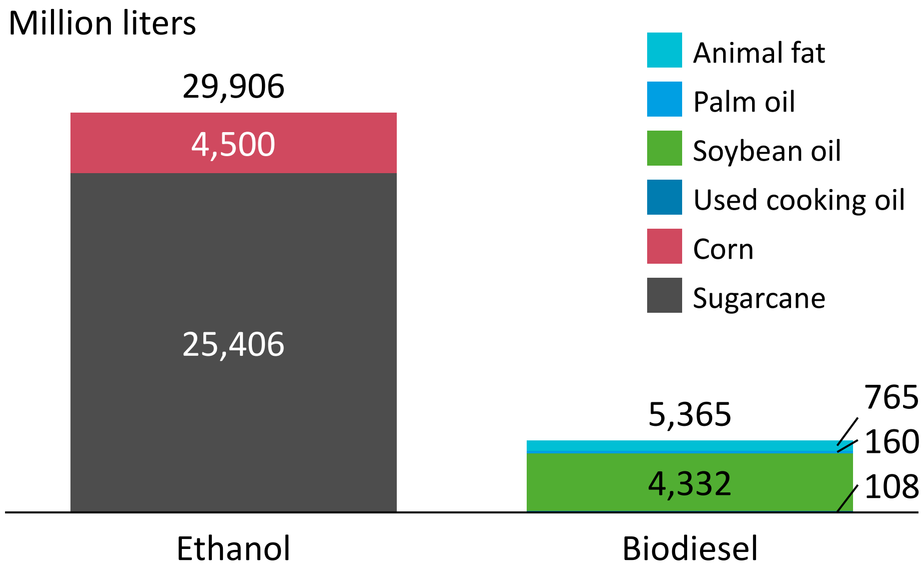
Note: To develop this trajectory, regional supply of feedstocks was matched with regional demand; most regions can use regionally produced low carbon cost feedstocks to meet regional demand for bioenergy; a few notable exceptions include Brazil importing from other Central & South American countries and the EU importing from Eastern Europe & non-EU European countries. On this chart, the power sector demand includes demand from energy transformation that does not use CCS (~4.3 EJ in 2050). This trajectory is integrated into both the energy and land systems modeling. The demand for dedicated land for bioenergy crops is applied as a constraint in the land system modeling.

INEVITABLE POLICY RESPONSE

Case study - Brazil: the transition away from 1g crops to low carbon cost feedstocks requires trade and infrastructure upgrades

- Today, Brazil's liquid biofuel sector is dominated by 1G crops (sugarcane, corn, soy, and palm), requiring around 30 Mha of land. Additional land is required to produce solid biofuels for power
- However, much of this land used today does not satisfy potential future criteria for sustainable production

Current liquid biofuel production



- By 2050, Brazil satisfies its 4 EJ of annual bioenergy demand using low carbon cost feedstocks produced.
- This transition requires investments to modify existing plants to process 2G feedstocks to avoid stranding assets
- It also requires a shift in the location of feedstocks toward more sustainable land (e.g. with lower carbon payback period
- This means a shift from dedicated crops to those connected to agroforestry, cover crops and agricultural waste

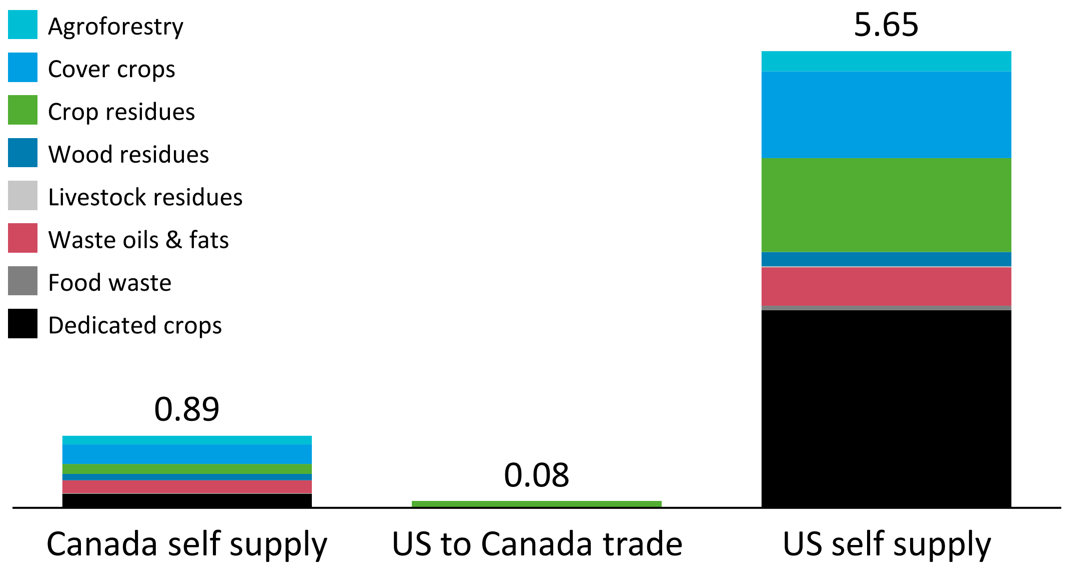
Brazil sustainable feedstock mix in 2050

1. Area that meets the sustainability guardrails for no nature displacement, no deforestation, no food competition, and no irrigation.
2. Source: Global Power Plant Database. Map indicates locations of power plants that use biomass feedstocks and is non-exhaustive for infrastructure associated with the bioenergy industry (e.g., biofuel refineries).

INEVITABLE POLICY RESPONSE

Case study – Canada & Northern US:
Jobs and export opportunities

Low carbon cost feedstock use in 2050, EJ



Bioenergy crops suitable for this region[3]:

- Camelina – Oil crop used for biodiesel and SAF
- Switchgrass – Grassy crop used for power or cellulosic ethanol
- Willow – Fast-growing tree used for power or cellulosic ethanol

- Canada and the US, respectively, account for 2.3% (0.97 EJ) and 13.9% (5.65 EJ) of global bioenergy demand in 2050
- In Canada, dedicated area that meets the sustainability guardrails is relatively small (c.3.5 Mha)
- Imports from the US can be limited to < 10% of the Canadian bioenergy basket if the entire 0.2 EJ available from dedicated crops can be used to meet domestic bioenergy demand
- Saskatchewan and neighboring Alberta together account for 9% of North American onshore CCS capacity, and limited transport would be needed between fields & biomass plants
- Mining & petroleum account for 26% of GDP in Saskatchewan; growth in bioenergy provides an opportunity for employment transition within the energy sector
- In the US, only 35% of the available bioenergy supply from dedicated cropland is required to meet domestic bioenergy demand, and excess supply suggests export opportunities for the US

1. Area that meets the sustainability guardrails for no nature displacement, no deforestation, no food competition, and no irrigation.
2. Source: Global Power Plant Database. Map indicates locations of power plants that use biomass feedstocks and is non-exhaustive for infrastructure associated with the bioenergy industry (e.g., biofuel refineries).
3. Not exhaustive.

Disclaimer

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