IFT Macro | WG 2 – pre-reading

Wednesday 24th May 2023

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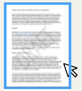
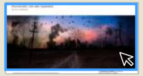
Useful additional pre-reading

(no change from WG1)

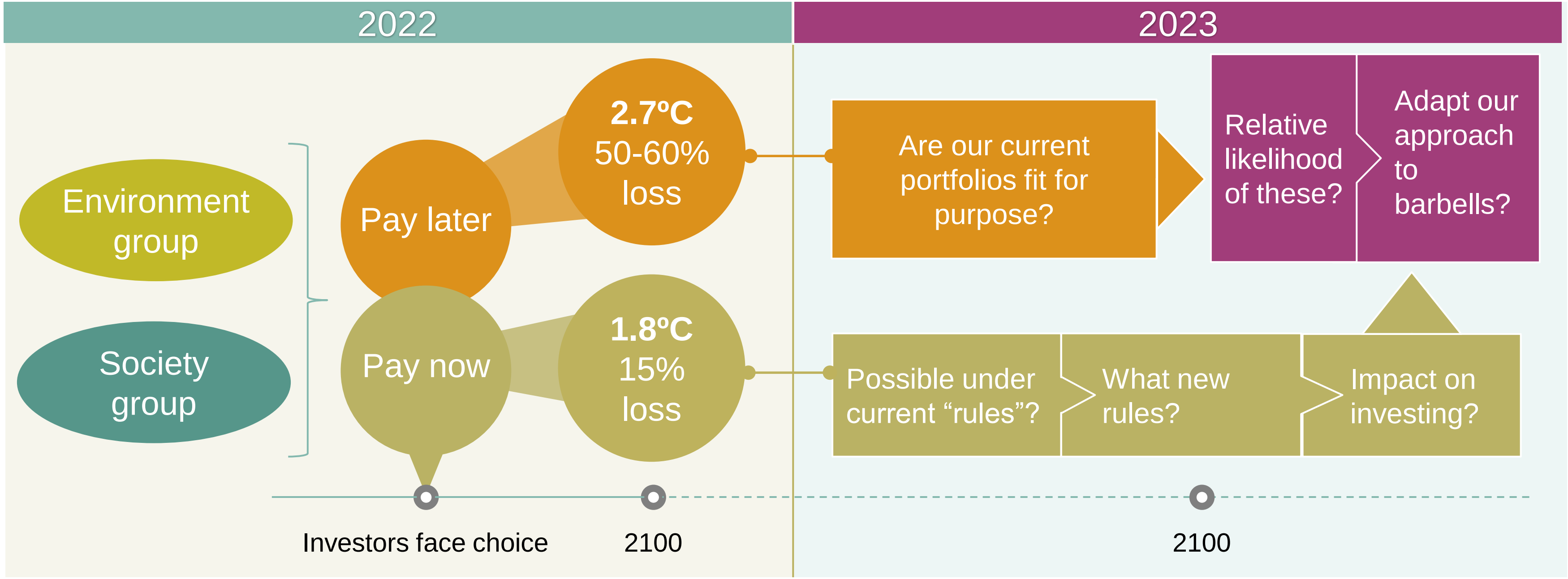
Type	Resource	Details
Research report	Pay now or pay later	Provides evidence and analysis to support the climate beliefs required to drive increased action on climate. To demonstrate to the industry that we must pay now to address climate risks, or we will be required to pay more later.
Investment insight	Phase down or phase-out | is there a difference?	A thought piece considering the winding down of fossil fuels at a high level.
Investment insight	To explore, or not to explore	A thought piece considering whether it is now time to stop exploring for new fossil fuel sources.
Research report	Systemic risk paper	 A draft paper by the Thinking Ahead team on the theory of systemic risk. An application paper for institutional risk management will follow.
Book summary	*Post Growth, Life after Capitalism* by Tim Jackson	 A slide deck summarising the book chapter by chapter.
Articles	Best case scenario 2050 Worst case scenario 2050	Articles based on the book, *The Future We Choose*, by Christiana Figueres and Tom Rivett-Carnac which offers two contrasting visions for how the world might look in thirty years.

Agenda for WG2 | 24 May 2023

East start 15:00 AEST / 06:00 BST
West start 10:00 EDT / 15:00 BST

Time	Agenda Item	Description	
-10	Coffee prequel		
5 minutes	Scene setting (s6-9)	▪ Recap of ask from WG1 ▪ Background and introduction to work done	AC
10 minutes	Summary of qualitative assessment (s10)	▪ Review of the explicit and implicit assumptions within the IEA net zero emissions (NZE) scenario ▪ Executive's conclusion	TH
55 minutes	Discussion on feasibility of NZ target (s11)	▪ How does the working group react to the qualitative assessment? ▪ How much can we rely on models? What level of risk aversion should we apply to model output? ▪ Does this have implications for NZ commitments? How we invest?	All
15 minutes	WG decision re quantitative analysis	▪ Option A | press further into feasibility of IEA NZE; agree or amend project plan (s24-27) ▪ Option B | switch to financial stress test (would be partially qualitative)	All
5 minutes	Next steps	▪ Confirm WG expectations re next phase of research	TH AC
	Close	▪ Thanks for your participation ▪ Next meeting scheduled for 12 July 2023	

Investing for tomorrow – macro view



Time commitment:	5 x 1.5 hours MS Teams calls, plus pre-reading and reviewing
WG call dates:	Mar, May, July, Sep, Nov
Output:	Co-created paper. Possibly, scenarios

Emission pathways analysis

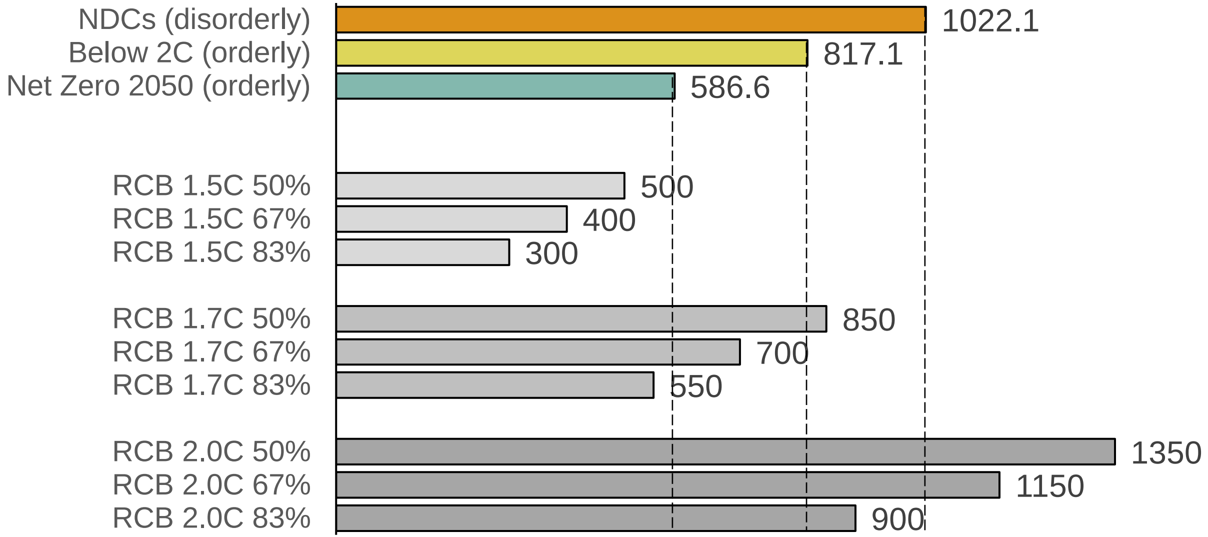
(Global) Carbon budget vs. emissions pathways

The IPCC defines the remaining carbon budget (RCB) as the total net amount of CO_2 emissions that can still occur while limiting global warming to a specified level (eg 1.5C or 2C). Different probabilities of success yield different carbon budgets. Grey bars in the chart below.

We compare the RCBs with the cumulative anthropogenic CO_2 emissions for 3 scenarios projected by NGFS and IEA (coloured bars)

Emissions pathways by scenario (cumulative Gt CO2 from 2020)

Estimated remaining carbon budgets from the beginning of 2020 (GtCO2)



TAI's calculations on NGFS and IPCC data

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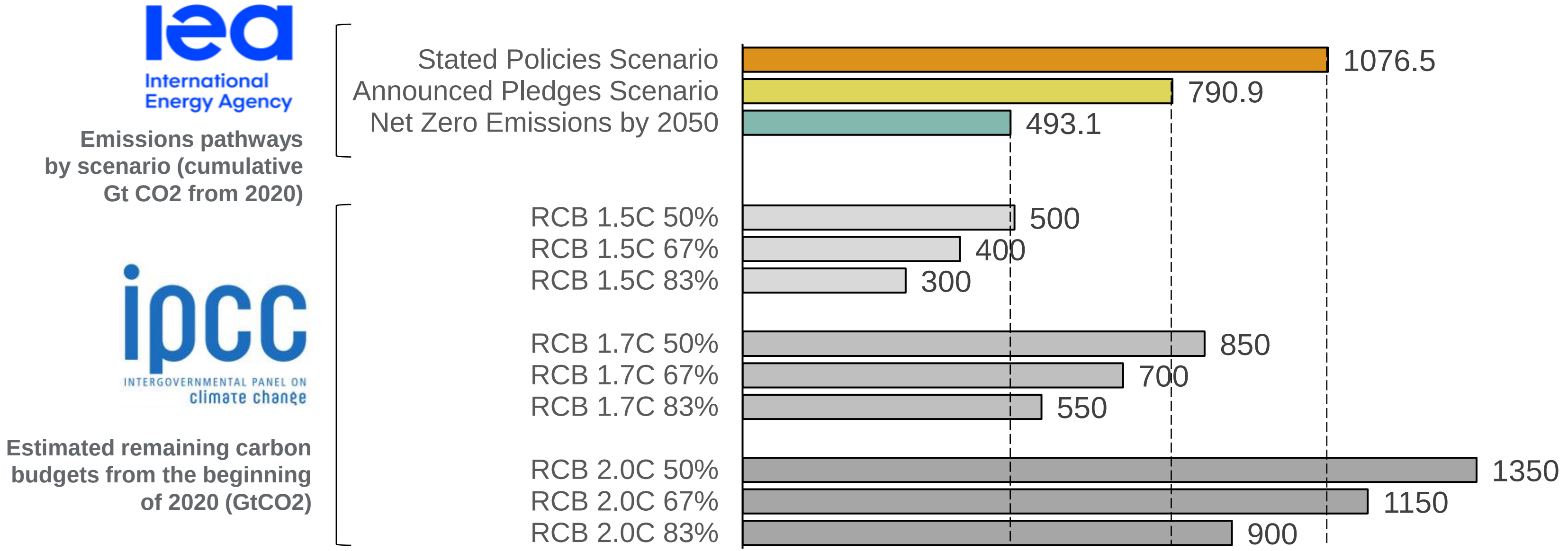

TAI's calculations on NGFS and IPCC data

When does ‘the’ carbon budget run out?

For the 1.5C temperature target, the carbon budget will be depleted much earlier than 2050 for almost all combinations of probability and scenario

		NGFS			IEA		
		NDCs (disorderly)	Below 2C (orderly)	NZ 2050 (orderly)	STEPS	APS	NZ 2050
1.5C	50%	2034	2035	2039	2034	2036	>2050
	67%	2031	2032	2034	2032	2032	2035
	83%	2029	2029	2030	2029	2029	2030
1.7C	50%	2045	>2050	>2050	2045	>2050	>2050
	67%	2040	2044	>2050	2040	2045	>2050
	83%	2036	2037	2043	2036	2038	>2050
2.0C	50%	>2050	>2050	>2050	>2050	>2050	>2050
	67%	>2050	>2050	>2050	>2050	>2050	>2050
	83%	2047	>2050	>2050	2046	>2050	>2050

TAI’s calculations on NGFS and IPCC data

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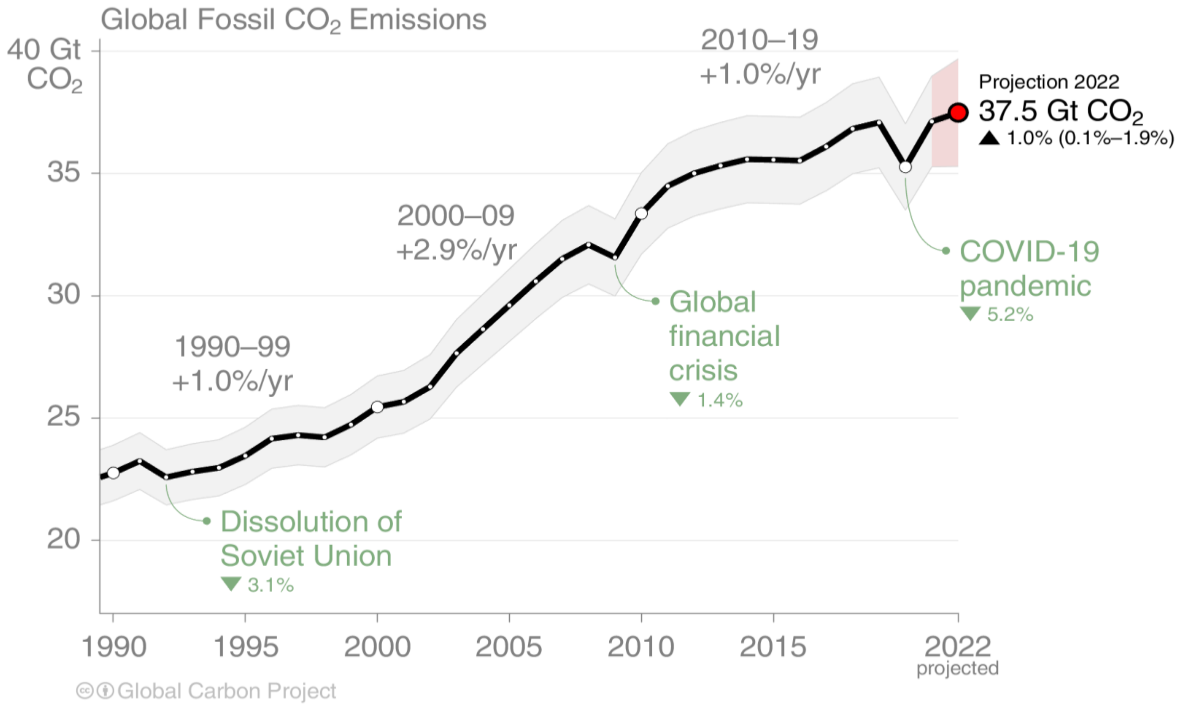
Historic CO2 emissions



CO2 emissions from land-use change in 2022 (projected) 3.9Gt (±2.6Gt)

Total CO2 emissions c 41.5Gt

Source: Global Carbon Project

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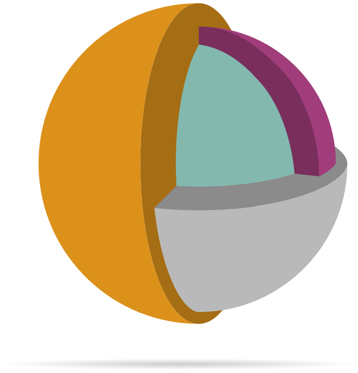
Summary of qualitative assessment of IEA NZE scenario (slides 13-22)

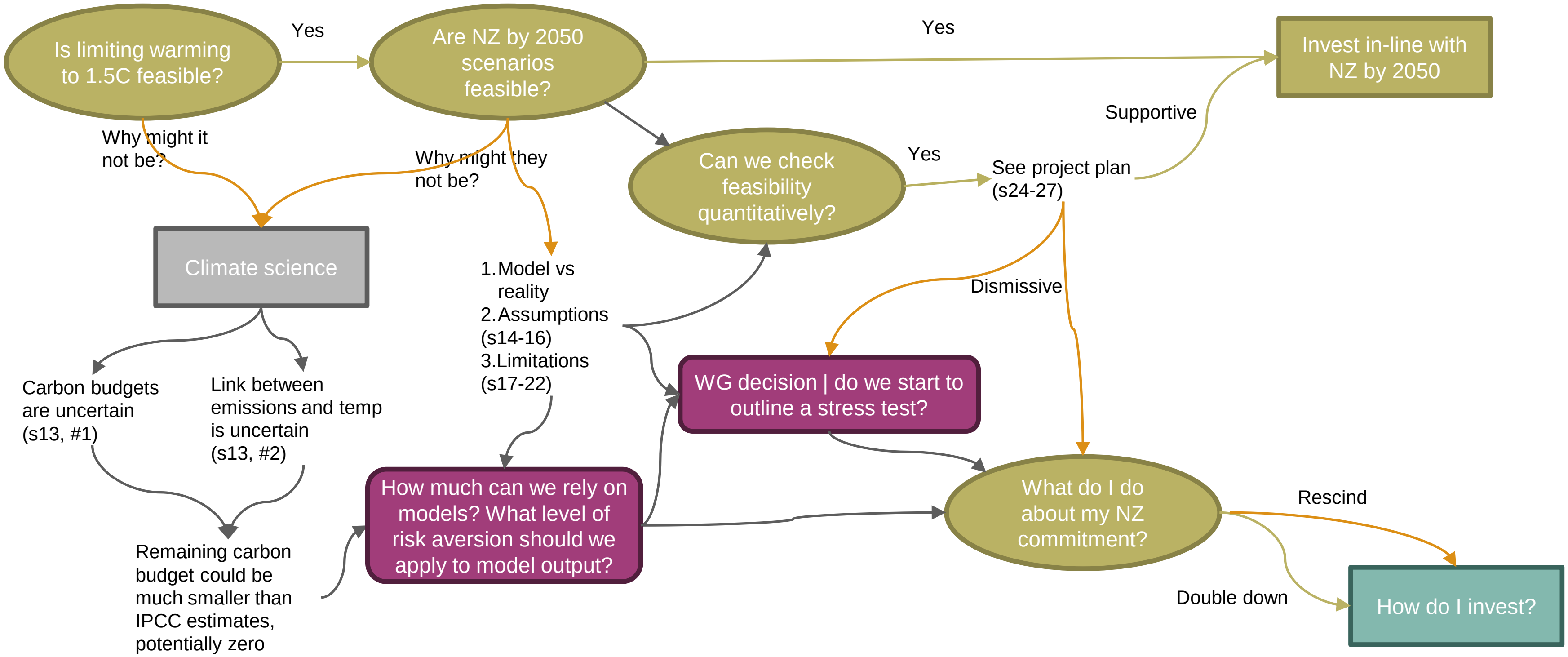


- An arguable carbon budget is fully spent
- Unnatural orderliness
- No risk buffer
- 'Priced to perfection'

- NZE is a partial real-world scenario, not a financial scenario. It is built by the energy industry, for the energy industry. It is NOT a financial stress test

Context	Key item	Implicit assumption/ limitation
Climate science	Carbon budget	▪ Wide error ranges ▪ Based on subjective assumptions ▪ Not acceptable chance of failure (50%)
	GHG concentration and temperature rise	▪ Equilibrium climate sensitivity (ECS) is uncertain ▪ Earth system sensitivity (ESS) is greater, implying >3C warming at current GHG levels
General commentary on NZE scenario		▪ Role of government in scenario differences ▪ Differential pace of NZE by economies ▪ Orderly transition assumptions
Open questions on climate policies and strategies		▪ Fossil fuel prices, carbon price, biofuels, emissions removal
Model assumptions assessment	Basic assumptions (on some modules of the IEA GEC model)	▪ Perfect competition ▪ Perfect information, atomic agents ▪ Price signalling -> rational decision making ▪ Perfect foresight: complete market knowledge
	Variability	▪ Lack of transparency and comparability in model assumptions and outcomes, and difficulties in assessing likelihood and financial risks of scenarios
	Understanding of transition narrative	▪ Assumptions of frictionless transition and absence of feedback mechanisms ▪ No adequate capture of the complexity of the transition to a low-carbon economy ▪ Lack of understanding of the potential severity and timescales of climate-related risks
	Model oversimplifications	▪ Limited capacity to incorporate complexities (non-linearity, tipping points, uncertainty) ▪ Neglected climate events and links between climate, ecosystems and natural resources often excluded ▪ Insufficiently capture acute physical risk shocks ▪ Rational expectation assumptions don't reflect reality
	Information loss along the climate scenario modelling chain	▪ Scenario modelling may result in information loss ▪ Insufficient passthrough of extreme tail risks and variation ▪ IAMs lack sub-sectoral and country-specific breakdowns ▪ Lack of scenario and model granularity

The feasibility of net-zero investing



Scenario assumptions assessment

IEA net zero emissions (NZE) scenario assumptions | explicit and implied

Climate science provides less certainty than implied by climate scenarios

1. There is a carbon budget of 500 GtCO2e available (implying a 50% chance of not exceeding 1.5C). Source IPCC
    - In what other area of risk management is a 50% chance of failure acceptable? Lower chance of failure = lower carbon budget = IEA NZE no longer holds
    - Carbon budgets have wide error ranges (>100%). Uncertainties noted in IPCC SR1.5 are (i) uncertainty in climate response +/-400Gt, (ii) carbon & methane release -100Gt, and (iii) non-CO2 mitigation +/-220 Gt
    - The IPCC carbon budgets depend on their own assumptions [which, arguably, do not hold]: (a) strong action on non-CO2 emissions [methane levels are at an all time high (≈1C of warming)], (b) no big shift in the Atlantic meridional overturning circulation (AMOC) [probably weakening], and that we do not cross any unexpected tipping points [temperature thresholds have been reduced through time, with possibility that we have passed one or two already]
    - From the IPCC AR6 FAQ: “Estimating the size of remaining carbon budgets depends on a set of choices. […] These choices can be informed by science, but ultimately represent subjective choices.” (here)
2. We know the relationship between atmospheric GHG concentration and temperature rise
    - The main assumption here is equilibrium climate sensitivity (ECS), which is how much we expect the planet to warm when we double GHGs. The stable consensus has been 3C for 2x GHGs (we have already doubled GHGs)
    - ECS is uncertain. IPCC AR6 report gave a range of 2.5C – 4C, with an 18% chance of being greater than 4.5C
    - ECS includes some simplifying assumptions. In particular it assumes ice sheets and vegetation are fixed, which they are not. Earth system sensitivity (ESS) models what happens as vegetation, ice sheets and other factors change. It is assumed to be greater than ECS, suggesting that we could exceed 3C of warming at current levels of GHGs (ie net zero tomorrow)
    - It takes time for the Earth to warm, giving a window of opportunity to reduce GHGs to safe levels before this heating occurs

IEA NZE scenario assumptions | explicit and implied (2)

General commentary regarding all IEA scenarios. From here

3. Decisions made by governments are the main differentiating factor between scenarios
    - Insert your own belief re government action here
4. Advanced economies move to achieve net zero emissions at a faster pace and thus earlier than in other IEA scenarios, and earlier than emerging market and developing economies
    - On one level this is uncontroversial (eg China aiming for NZ by 2060, India by 2070). On another it implies that developed countries will agree to decarbonise more quickly than current commitments
5. NZE assumes an orderly transition. This includes ensuring the security of fuel and electricity supplies at all times, minimising stranded assets where possible and aiming to avoid volatility in energy markets
    - See next slide for detailed commentary

IEA NZE scenario assumptions | explicit and **implied** (3)

IEA global energy and climate (GEC) model

6. **Perfect competition**
   - This refers to a standard set of assumptions from economics. Among this set, competitive energy markets are characterized by perfect information and atomic economic agents, which together preclude any of them from exercising market power (see next bullet). These assumptions are described for a sub-model (TIMES), but the effect of various constraints means that equilibrium is not (or is unlikely to be) reached in the main model.
   - While we could criticise each of the standard assumptions, we acknowledge that it is very difficult to build a tractable model without them (the main alternative would be to use agent-based modelling, and embrace different problems). We therefore restrict ourselves to only note that the Russia/Ukraine-induced energy shock demonstrates that these assumptions are unrealistic. In particular, it appears clear that some agents, or groups of agents, do have market power and can move prices. Consequently, real-world experience is unlikely to be as smooth (orderly) as the model suggests.
7. **Perfect foresight**
   - This belongs within the standard set of economic assumptions, but we draw it out here to emphasise that real-world disorder is more likely.
   - The perfect foresight assumption means each agent has complete knowledge of the market's parameters, present and future. In other words, amongst other things, energy capacity can be added or withdrawn with no (costly) mistakes. We suggest mistakes are likely, and that energy supply could oscillate between shortage and glut.

IEA NZE scenario assumptions | explicit and implied (4)

From here

8. International fossil fuel prices (p19)
   - “Bioenergy is an important renewable energy option in all of its forms” [13% of total energy supply 2030 (renewables inc bio 31%); 19% 2050 (70%)] Q: do we agree? Where do we stand on this highly-divided issue?
9. Carbon price (p18)
   - NZE CO_2 price / tonne in 2030 is $140 in advanced economies with NZ pledges (lower in other countries). This would add $62 per barrel of oil (0.4261 tonnes of CO_2 per barrel). How reasonable is this assumption?
10. Biofuels (p19)
    - In the IEA scenarios this is an input – and reflects the price level required to stimulate the required level of supply. In the real world, price and quantity are jointly determined. Quantity can be influenced through high prices (see carbon price below), or other measures such as a ban on new supply (exploration). For illustration, NZE crude oil price/barrel in 2030 is $35.
11. Emissions removal
    - [in 2050 DAC is removing 393Mt pa, a 23% CAAGR for 29 years] Q: can anything grow at 23%pa for 29 years?
    - [over same 2021-2050 period CO_2 emissions fall in industry (10%pa), transport (8.8%pa), buildings (13%pa)]
    - [NZ requires 1.5Gt pa removal by 2050, with vast majority coming from bioenergy] Q: (see above) does bioenergy count as carbon removal? Does bioenergy at this scale compromise agriculture or reforestation?

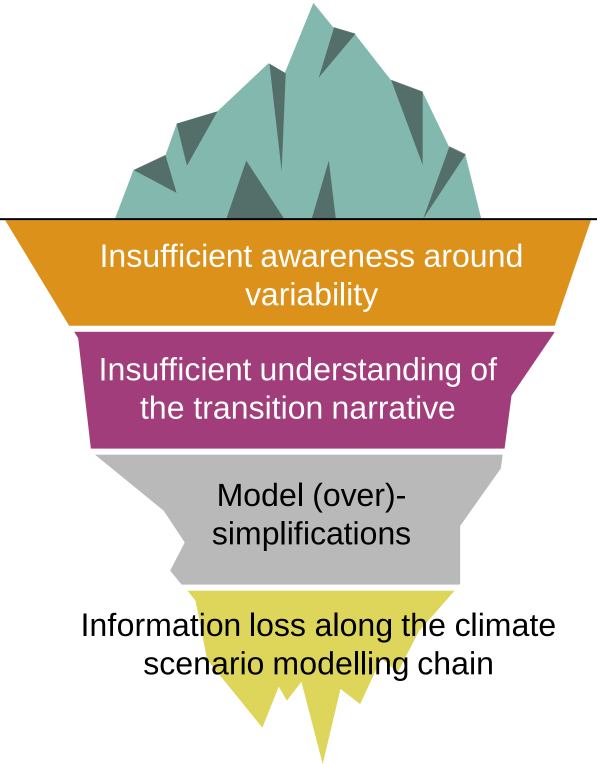
[data from IEA spreadsheet]

Model assumptions assessment from main providers (IEA, NGFS, IPCC)

Source: Toward a framework for assessing and using current climate risk scenarios within financial decisions

Models

(think 'explicit assumptions')



(1)

(2)

(3)

(4)

Limitations

(think 'implicit assumptions')

(1) Variability and (2) Understanding of transition narrative

Source: Toward a framework for assessing and using current climate risk scenarios within financial decisions

1. Insufficient awareness around variability of parameters and/or assumptions

- Lack of transparency of model's key assumptions
- Lack of comparability across scenario providers (eg how the energy system is modelled)
- Significant variability in the financial risk outcomes
- Difficulties in attaching a likelihood, and judging the level of conservativeness of some key assumptions (eg how likely are each of the scenarios against each other; what are the consequences for carbon-intensive energy firms and resulting financial risks from a faster uptake of renewables than anticipated in the IEA scenarios)

2. Insufficient understanding of transition narrative

- Different macroeconomic model types lead to significant differences in the transition narrative
  - Some general equilibrium models impose restrictions on the money supply (Pollitt and Mercure, 2017). This leads to additional public sector spending (eg investment in renewables) crowding out private sector investment. Within these models, the transition to a low-carbon economy is framed as diverting away from a general equilibrium, with the economic system recovering from such a deviation and bouncing back to an equilibrium (Bolton et al., 2020). This shift is associated with high economic cost in the short-medium turn (Mercure et al., 2019)
  - Other model approaches account for crowding in effects, and therefore new spending/investment has wider positive effects. These models frame the transition as having a positive net economic effect (Mercure et al., 2019)

(2) Understanding of transition narrative (cont)

Source: Toward a framework for assessing and using current climate risk scenarios within financial decisions

Assumptions of frictionless transition and absence of feedback mechanisms

Economic and financial frictions

- Most climate scenarios rely on integrated assessment models (IAM) based on optimum policy pathways which represent smooth trends along the time horizon to reduce complexity
- Traditional macroeconomic models (adopted by providers) are not suitable for capturing associated frictions (eg rapid large-scale transformation to a low carbon economy and potential short-term volatility along the transition pathway)
- Models' assumptions do not adequately cover the spectrum of discrete shock events (eg failure of adopted policy pathways)

Energy system frictions

- Models assume a smooth transition to low-carbon technologies without friction (eg lobbying for/against carbon tax may increase as the energy system becomes greener)
- Amplification mechanisms are often ignored (green technology investment reduces cost and increases competition with fossil fuels, driving further green investment)
- Tipping points cause sudden asset stranding without smooth divestment due to rapid system shifts

Labour market frictions

- Limited representation of labour frictions that might create bottlenecks when transitioning to a net-zero energy system

(2) Understanding of transition narrative (cont 2)

Source: Toward a framework for assessing and using current climate risk scenarios within financial decisions

Assumptions of frictionless transition and absence of feedback mechanisms (cont)

Financial market frictions

- Assumptions may lead to misaligned expectations on financial markets
  - Brown and green companies may be valued differently by investors' belief in the green transition. Realignment of stock price?
  - This may trigger rapid system movement, causing sudden stress and slowing investment for transition
  - Current scenarios do not account for such behavioural frictions and feedback mechanisms between the real economy and financial markets

Policy frictions

- Existing scenarios use carbon tax as a policy proxy, but it has limitations, such as insufficient geographical differentiation, distortionary effects of other policies, and failure to represent misalignments between climate commitments of different jurisdictions (Mercure et al, 2019)
- Existing scenarios fail to consider the delay between policy implementation and real-world emission reduction due to assuming an instantaneous market response in models (Asefi-Najafabady et al, 2021)

(3) Model (over)simplifications

Source: Toward a framework for assessing and using current climate risk scenarios within financial decisions

- **Neglected climate events |** several phenomena induced by climate change such as migration, crop yield shocks, and social instabilities in exposed regions, as well as feedback loops are neglected in IAMs and hence cannot be represented in climate pathways for financial exercises (Asefi-Najafabady et al, 2021; Weyant, 2017)
- **Climate links |** the links between climate, ecosystems and natural resources (eg soil, water, forestry) which are known to be important drivers of financial risk (Dasgupta, 2021) are often excluded
- **Non-incorporation of environment risks |** Almeida et al, 2023 highlight existing scenarios used by central banks and FIs currently do not sufficiently incorporate broader environmental risks, such as nature-related risks, in part due to methodological challenges around modelling nature-economy interactions with financial sector dependence
- **Complexity and non-linearity |** more broadly, IAMs remain limited in their capacity to incorporate complexities in relation to non-linearity, tipping points, and uncertainty
- **Rational expectation |** rational expectation assumptions lead to individual components of the system being optimised. However, real behaviour is different, as participants have limited knowledge to make appropriate choices. For instance, reflecting the behaviour of fossil-fuel dependent states in supporting international climate negotiations and carbon tax policies remains irrational, with many geopolitical factors around comparative advantages driving decisions (Mercure et al, 2021)
- **Physical shocks |** current model approaches and scenarios insufficiently capture acute physical risk shocks in models that aim to capture the climate repones to assumed emission pathways (Pitman et al, 2022; Ranger et al, 2021)

(4) Information loss along the climate scenario modelling chain

Source: Toward a framework for assessing and using current climate risk scenarios within financial decisions

Information loss and insufficient passthrough

- Scenario modelling chains include various sub-models that are linked together, subsequently feeding into macroeconomic and lastly financial models
- Simplified transmission channels and interaction effects with varying degrees of granularity may result in significant information loss and an increase in the uncertainty along the modelling chain
- Especially, the insufficient passthrough of extreme tail risks, cross-sectional and geographical variation ultimately results in a loss of information that would be needed by the financial sector

Loss of information and relevant risk variation

- Most IAMs and macroeconomic models do not feature a firm-level, sub-sectoral and country-specific breakdown of climate-adjusted economic pathways. Therefore IAMs may produce sub-sectoral impacts from regional climate policies, which are then translated into financial pathways using a macro-model that lacks the sophistication to reflect sub-sectoral dynamics (eg NGFS's *NiGEM*)
- The resulting impact and risk distribution will therefore miss relevant variation. When such impacts serve as inputs into financial models to uncover risk at the counterparty level (eg to assess the transition impact on FIs balance sheet) this will not be directly possible without additional downscaling or expansion of the initial scenario pathways

Scenario and model granularity

Models lack sufficient granularity needed by the financial sector and too much room is left for scenario expansion to adequately capture the full spectrum of the risk range

Project plan

Project plan

Potential questions we might answer

Questions	
Considering the existing scenarios, particularly those designed to achieve net zero or limit global warming to 1.5C by 2050…	
Just transition	▪ Are DMs and EMs required to decarbonise at different rates, in particular are EMs permitted to decarbonise at a slower rate than DMs recognising ability to do so and responsibility for historical emissions? ▪ Are EMs permitted to converge to DM standards of living as measured by, for example, GDP/capita, energy usage/capita
Technological feasibility	▪ Is the projected scale-up of CCS + broader emissions removal feasible? ▪ Is the projected level of energy efficiency improvement achievable? ▪ Is the projected increase in renewable energy capacity achievable? ▪ Is the projected increase in EV volume, solar PV panels etc… feasible? Does Earth possess enough rare minerals to see this become a reality?
Social feasibility	▪ Is it possible to achieve the necessary crop yield improvements to support the projected population? ▪ Can growth rates (based on historical trends) for DMs be sustained and if not what "haircut" to these growth rates is required? ▪ What is the projected decrease (if any) in aviation travel and car ownership per person to achieve projected emissions reductions? Is this feasible?

Timeline: to present next WG 3, 12th July

Diagnostics

We will run these diagnostics on the parameters/data for each scenario to answer the questions

Diagnostics	
Just transition	▪ Global and regional emissions vs allocated carbon budgets ▪ EM energy usage/capita ▪ EM food consumption/capita
Technological feasibility	▪ Required scale up in CCS capacity ▪ Rate of electrification vs historical trend ▪ Rate of renewables growth vs historical trend ▪ Renewable capacity vs renewable demand ▪ Change in required use of key industrial outputs ▪ Required supply of critical metals
Social feasibility	▪ DM energy usage/capita ▪ DM food consumption/capita ▪ Cars/capita ▪ Aviation travel/capita

Scenarios and regions

We will examine a number of scenarios and analyse data from a number of regions

Scenarios

1. IEA: NZ2050
2. NGFS: Net Zero 2050, Below 2C, Delayed transition (as the disorderly scenario)
3. IPR: RPS (1.5C) and FPS (~1.8C)

Regions

- US + Europe
- China + India
- Global
- Probably also want EM/global south aggregate

Parameters/data

We will collect the following data to answer the forementioned questions

Data	
Macro	▪ GHG and CO_2 emissions ▪ Population ▪ GDP ▪ Energy consumption ▪ Personal consumption
Policy/regulatory	▪ Carbon price (I think Carbon budget we take as a given from IPCC) ▪ Energy price – overall, FF, renewable ▪ FF consumption – proxy for regulation to phase down/out ▪ Land protection and restoration – perhaps also something about amount of land used for sequestration/amount of CO_2 sequestered?
Technology	▪ Renewable capacity – solar, wind, other; total and additions ▪ Share of renewables in electricity ▪ Electricity as % of energy consumption – perhaps focus on key sectors (chemicals, steel, cement, etc…); probably need info on the overall final energy mix ▪ CCS + broader emissions removal – need to think about whether this is by capacity or amount actually stored ▪ EV volume
Behavioural/society	▪ Food production/consumption ▪ Industrial production/consumption – chemicals, steel, cement ▪ Energy investment ▪ Vehicle fleet total size ▪ Aviation travel (person kms)?

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Appendix

Resources on climate equity/just transition

- Existing climate mitigation scenarios perpetuate colonial inequalities (link)
- Climate Equity Reference Calculator (here)
- EM vs. DM | Kaya projections

Implicit assumptions | Zero-Emission Commitment (ZEC) and feedback

An integrated approach to quantifying uncertainties in the remaining carbon budget

ZEC gives the temperature increase or decrease 50 years after reaching net-zero emissions. It shows any lagged temperature response

The IPCC Special Report on Global Warming of 1.5 °C (SR1.5) is a prominent recent assessment of the Remaining Carbon Budget (RCB). SR1.5 used a new approach of a segmented framework that allows for calculating the RCB directly from an estimate of Transient Climate Response to Cumulative CO2 Emissions (TCRE). Carbon budgets are subject to uncertainty in the TCRE, as well as to non-CO2 climate influences.

$$TCRE = \frac{\Delta T_{anth}}{E} \times (1 - f_{nc})$$

$$TCB = E \times \left(\frac{\Delta T_{lim} - \Delta T_{ZEC}}{\Delta T_{anth}}\right) \times \left(\frac{1 - f^*_{nc}}{1 - f_{nc}}\right)$$

$$RCB = E \times \left(\left(\frac{\Delta T_{lim} - \Delta T_{ZEC}}{\Delta T_{anth}}\right)\left(\frac{1 - f^*_{nc}}{1 - f_{nc}}\right) - 1\right)$$

- **E** = Cumulative historical CO2 emissions
- $\boldsymbol{\Delta T_{anth}}$ = Current anthropogenic contribution to observed warming
- $\mathbf{f_{nc}}$ = Current non-CO2 fraction of total anthropogenic forcing
- $\mathbf{f^*_{nc}}$ = eferfer
- $\boldsymbol{\Delta T_{lim}}$ = Global mean warming target (human-induced warming, free from influences of forced or unforced natural climate variability)
- $\boldsymbol{\Delta T_{ZEC}}$ = Zero-Emission Commitment (temperature increase or decrease 50 years after zero emissions…)

- $\boldsymbol{(\Delta T_{lim} - \Delta T_{ZEC}) / \Delta T_{anth}}$= Available future warming between present-day and the temperature target
- $\mathbf{1 - f^*_{nc} / 1 - f_{nc}}$= the time-evolving non-CO2 contribution to temperature change, as represented by the ratio of future to present-day forcing fractions

Included in the RCB is the uncertainty in $\boldsymbol{\Delta T_{ZEC}}$ which was only recently quantified and thus **not included** as a quantified uncertainty in the SR1.5 (or any other) carbon budget analysis. On near-term decadal time scales relevant to achieving the 1.5 °C or 2.0 °C target, this $\boldsymbol{\Delta T_{ZEC}}$ term also accounts for the additional changes in global mean temperature due to **feedbacks**, such as permafrost carbon release that are not captured by the TCRE but may contribute to warming on longer time scales.

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