

Adjusting 1.5 degree C climate change mitigation pathways in light of adverse new information: Supplementary Information

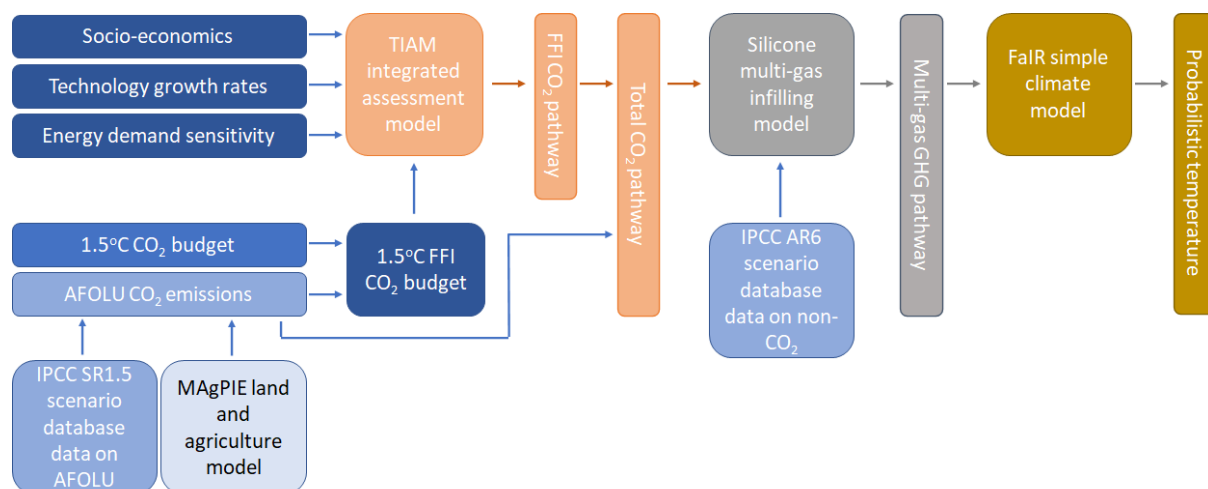
Ajay Gambhir, Shivika Mittal, Robin Lamboll, Dan Bernie, Laila Gohar, Adam Hawkes, Alexandre Köberle, Joeri Rogelj, Jason Lowe

S1 Modelling framework

We use an integrated assessment model (TIAM-Grantham¹) which in this guise represents energy and industrial process emissions with a high degree of technological detail across all energy system sectors.

We constrain the scenarios with a CO₂ budget (for fossil fuel and industrial emissions, as well as land use emissions) of 500 GtCO₂ from 1st January 2020, following IPCC AR6 WGI². We then combine the resulting CO₂ emissions pathway derived from TIAM-Grantham with the CO₂ pathway for land use emissions (specifically, as derived from the median AFOLU pathway in the IPCC SR1.5 database³ for all 1.5°C scenarios) with a non-CO₂ emissions pathway derived from the Silicone⁴ in-filling model. The resulting pathways for all greenhouse gas emissions are then fed into the FaIR⁵ simple climate model, to derive probabilistic temperature pathways.

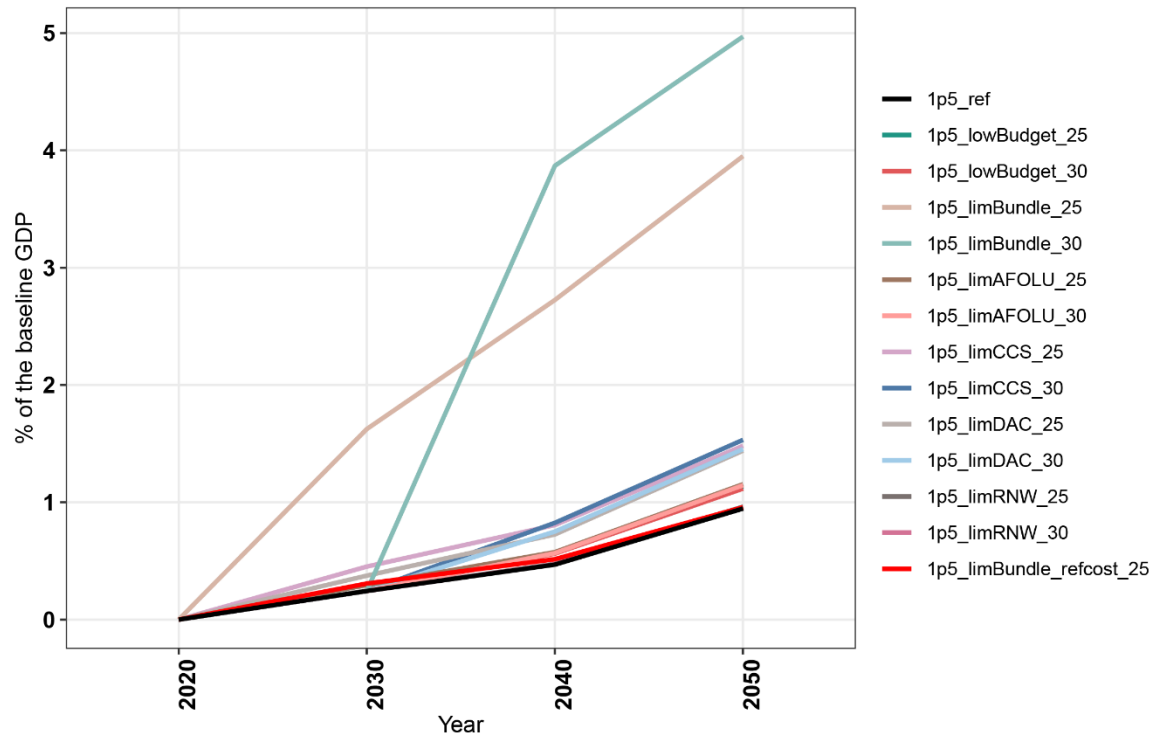
This modelling set up allows us to vary technology deployment rate assumptions, carbon budget levels, and underlying assumptions on energy demand, as required in our study design (Supplementary Figure 1). We use updated SSP2 assumptions as our underlying socio-economic driver, as described in Sognnaes et al. (2021)¹.



Supplementary Figure 1: Model and assumptions framework. Blue boxes designate input assumptions. TIAM model is used to derive fossil fuel and industrial (FFI) CO₂ pathways consistent with the specified carbon budget. AFOLU emissions are derived from either the IPCC scenario database or the MAgPIE model, depending on the specific scenario. IPCC scenario database also used to perform multi-gas infilling, using the Silicone model.

S2 Mitigation costs

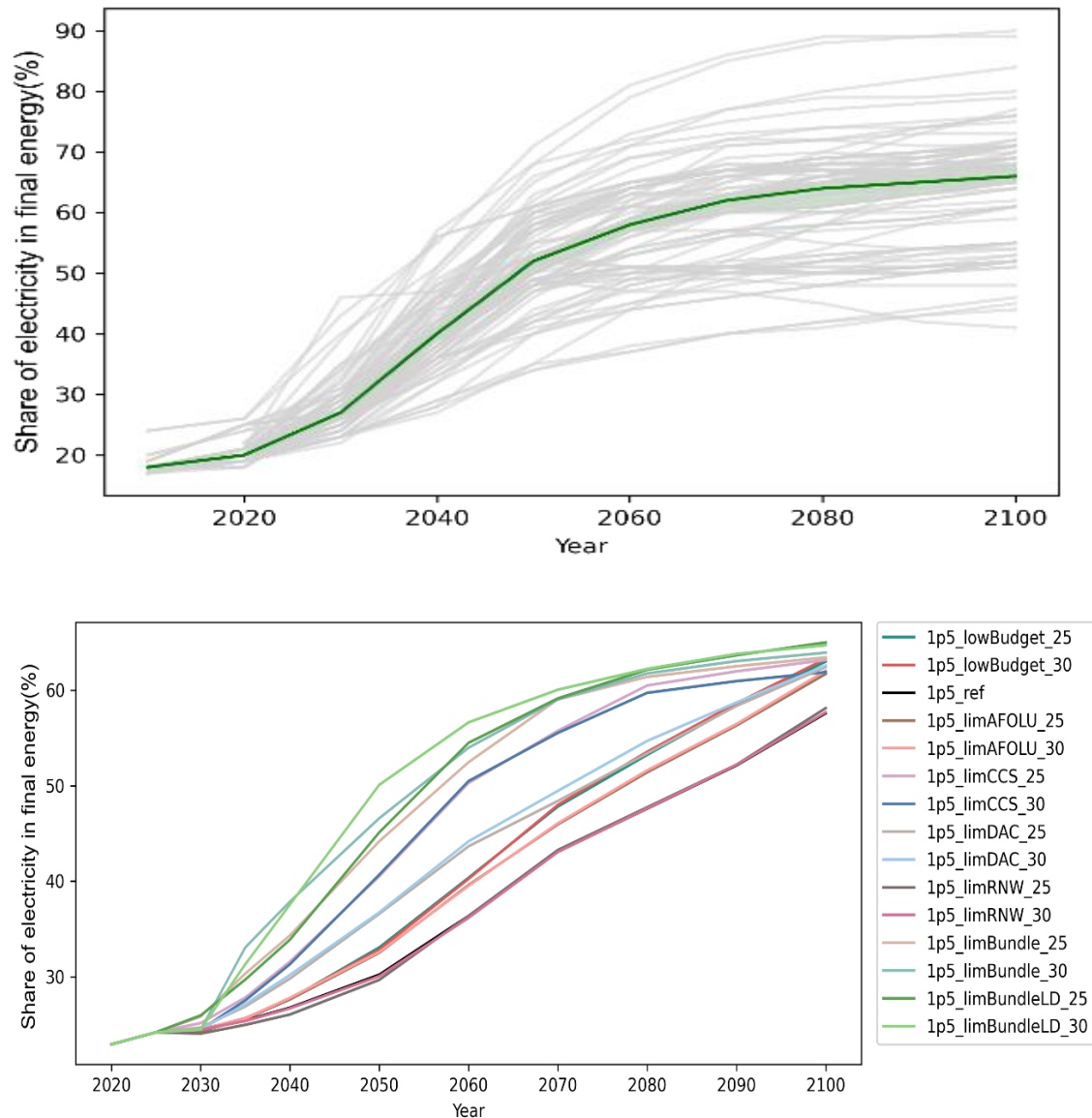
The carbon price implications of the different scenarios are discussed in the main manuscript (and shown in Figure 8 in the main manuscript). In addition, we present in Supplementary Figure 2 the mitigation costs of each scenario. These are expressed as the change in welfare (producer plus consumer welfare) related to the energy system, when comparing each scenario with a “current policies” scenario, as developed and described in Sognnaes et al. (2021) ¹.



Supplementary Figure 2: Annual mitigation cost as share of baseline GDP. Scenarios as shown in the main manuscript, with one additional scenario, labelled “1p5_limBundle_refcost_25”, simulated to provide a similar mitigation cost to the “1p5_ref” scenario, but with all adverse information (except for the carbon budget) arriving in 2023, leading to a course correction in 2025. This allows a minimum carbon budget of 1,100 GtCO₂ whilst achieving the same mitigation cost pathway as the “1p5_ref scenario”.

S3 Electricity as a share of final energy

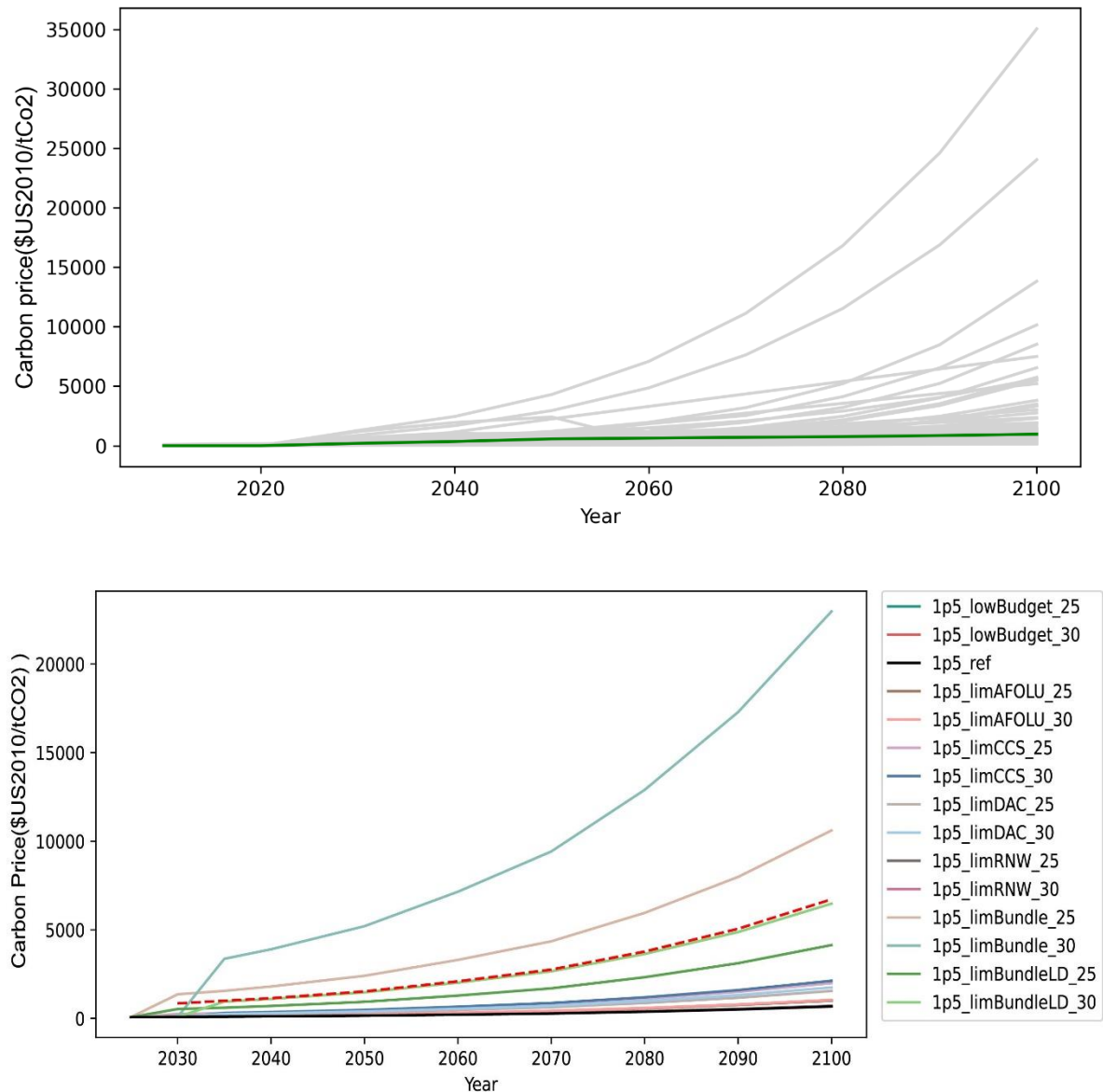
Our scenarios have relatively low levels of electricity as a share of final energy, compared to the median across the IPCC AR6 database⁶ of 1.5°C scenarios with no or low overshoot (i.e. the “C1” category). By 2050, our most electrified scenario (1p5_limBundleLD_30) has an electrification of ~50%, around the median of the IPCC AR6 database⁶. This could suggest that further electrification is possible as a course correction strategy.



Supplementary Figure 3: Electricity as a share of final energy in 1.5°C scenarios. Top panel shows share of electricity in final energy in IPCC AR6 database of “C1” category (i.e. 1.5°C with no or low overshoot) scenarios, including median (green line), whilst bottom panel shows share of electricity in final energy from scenarios in this study.

S4 Carbon prices

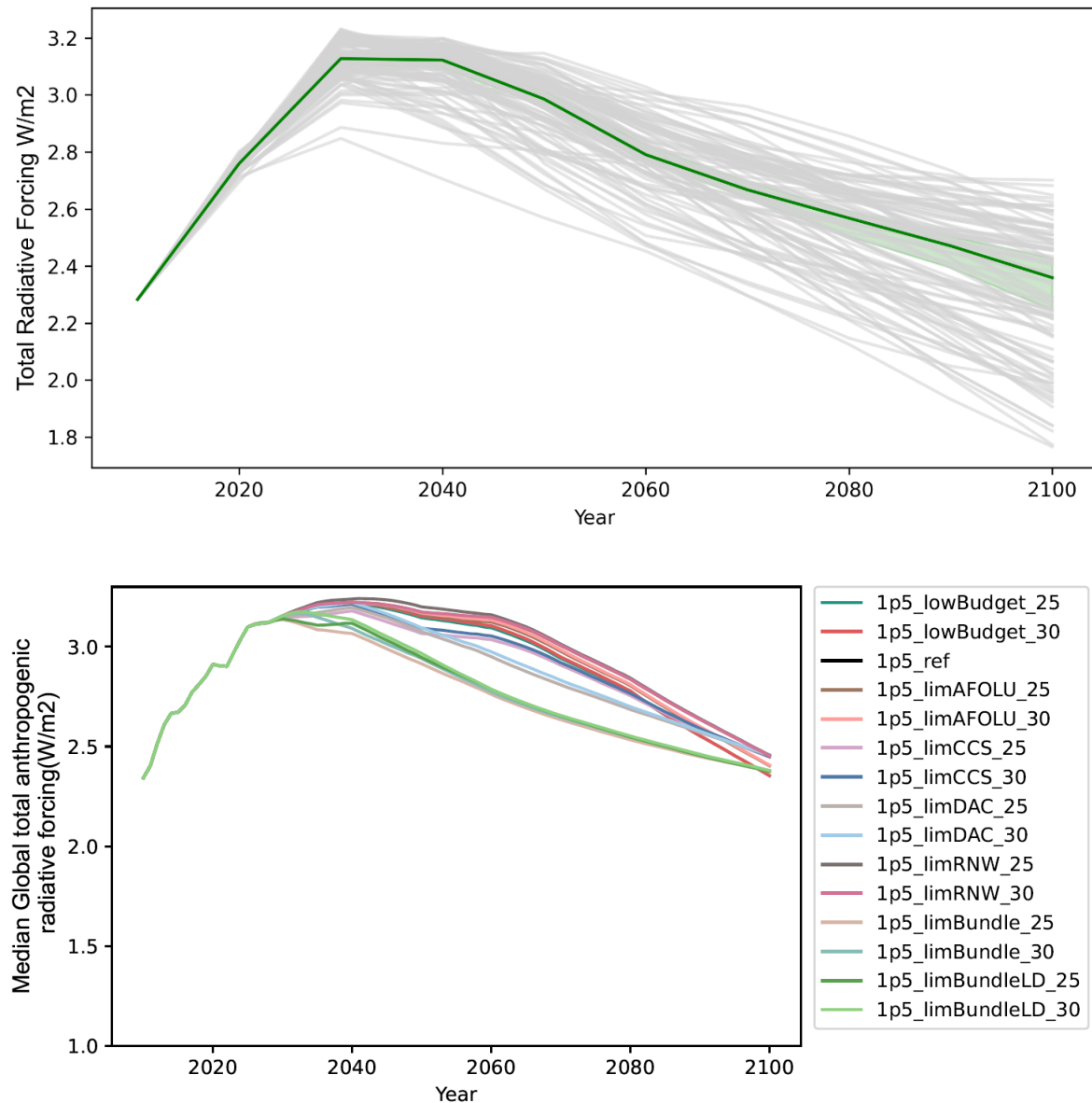
The highest carbon price scenario, 1p5_limBundle_30, rises to ~\$5,000/tCO₂ by 2050 and to over \$20,000/tCO₂ by 2100, indicating severe economic feasibility concerns. This scenario is still, however, just within the range of no or low overshoot (“C1” category) scenarios in the IPCC AR6 scenarios database⁶, as shown in Supplementary Figure 4.



Supplementary Figure 4: Carbon prices in 1.5°C scenarios. Top panel shows carbon price in IPCC AR6 database of “C1” category (i.e. 1.5°C with no or low overshoot) scenarios, including median (green line), whilst bottom panel shows carbon prices from scenarios in this study. Bottom panel red dotted line is for a scenario in which all adverse information is assumed from the start of global mitigation action in 2023 (which means there is no mitigation pathway adjustment in this scenario).

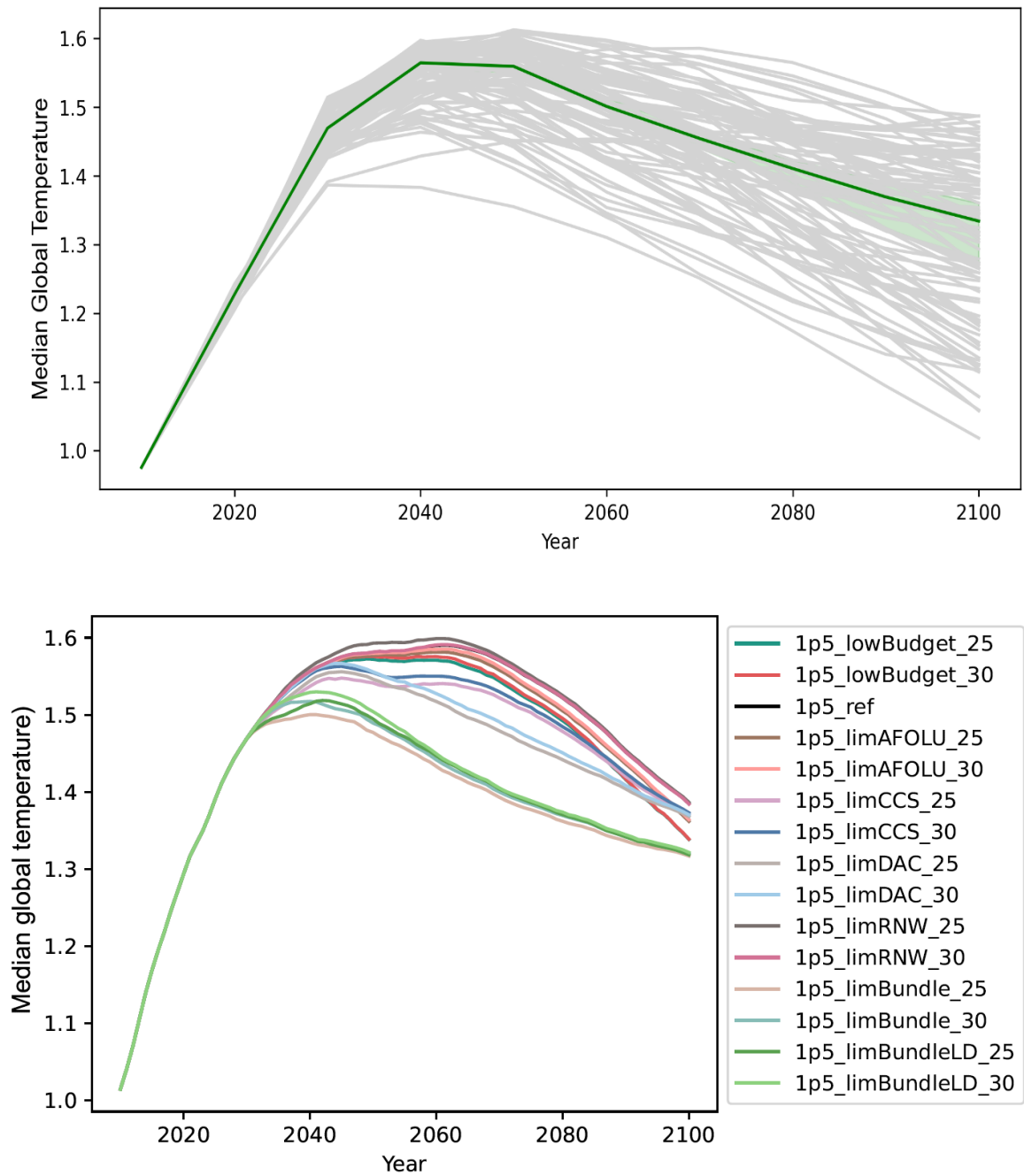
S5 Temperature and climate implications of pathways

Our study's radiative forcing pathways, once non-CO₂ gases have been combined with the CO₂ emissions from the TIAM model (and where appropriate the MAgPIE model or the exogenous CO₂ assumptions from the IPCC SR1.5 database) follow a broadly similar pattern to the median pathway in the IPCC AR6 database⁶ for no and low overshoot (i.e. category "C1") scenarios, as shown in Supplementary Figure 5.



Supplementary Figure 5: Radiative forcing implications. Top panel shows forcing in IPCC AR6 database of "C1" category (i.e. 1.5°C with no or low overshoot) scenarios, including median as red line, whilst bottom panel shows forcing from scenarios in this study.

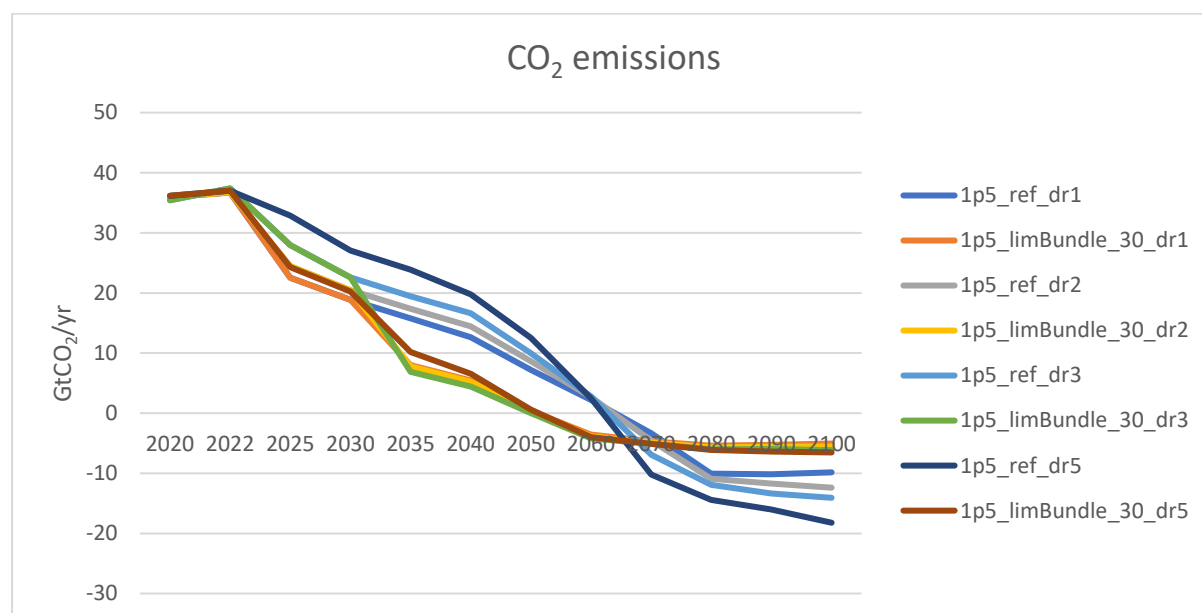
This results in similar temperature pathways, in most cases peaking below 1.6°C and falling back below 1.5°C by end of century (Supplementary Figure 6).



Supplementary Figure 6: Temperature implications. Top panel shows forcing in IPCC AR6 database of "C1" category (i.e. 1.5°C with no or low overshoot) scenarios, including median as green line, whilst bottom panel shows forcing from scenarios in this study.

S6 Emissions pathways with different system discount rates

We show the mitigation pathways for discount rates ranging from 1-5% per year (Supplementary Figure 7). As demonstrated in other literature⁷, lower discount rates see more drastic near-term emissions reductions and less overall net negative emissions in the latter half of the 21st century. This is demonstrated by their smaller 2020-2050 cumulative carbon emissions. All scenarios in which DAC and CCS growth rates become limited tend to have similar pathways, given the lack of availability of net negative emissions in the latter half of the 21st century. As such, the differences in cumulative CO₂ emissions in the period 2020-2050 for discount rate variants of these scenarios are far less marked than in the 1p5_ref scenarios.

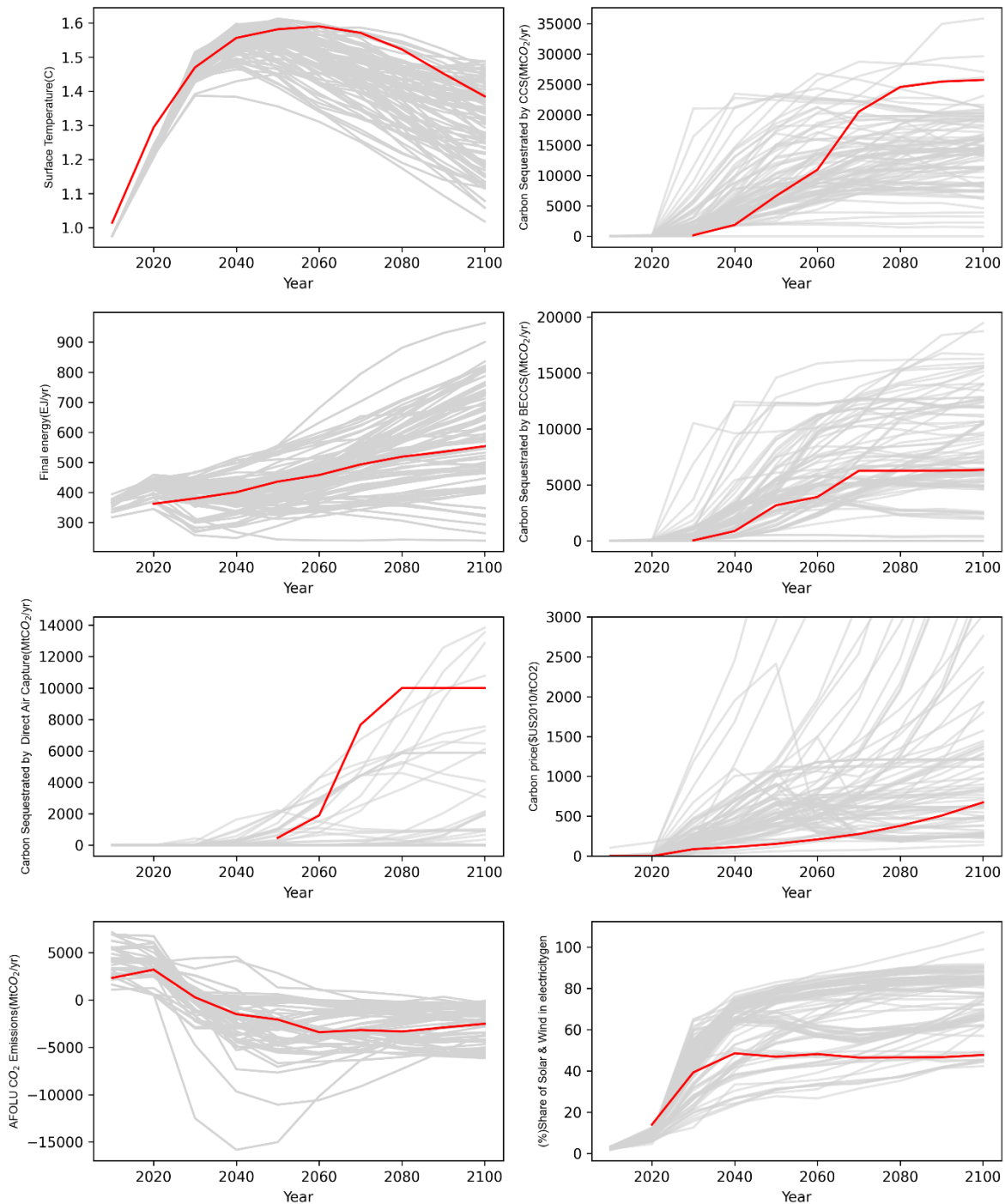


Scenario	Cumulative CO ₂ (2020-2050)
1p5_ref_dr1	543
1p5_limBundle_30_dr1	413
1p5_ref_dr2	589
1p5_limBundle_30_dr2	425
1p5_ref_dr3	648
1p5_limBundle_30_dr3	439
1p5_ref_dr5	750
1p5_limBundle_30_dr5	448

Supplementary Figure 7: Mitigation pathways with different system discount rates. Top figure shows fossil fuel and industry global CO₂ emissions in 1p5_ref and 1p5_limBundle_30 scenarios, for a range of discount rates 1%, 2%, 3%, 5%. Bottom panel shows cumulative CO₂ from all emissions, including land use, for the period 2020-2050.

S7 Emissions pathways with different system discount rates

The TIAM-Grantham Integrated Assessment Model's outputs on key variables of interest in this study (for the 1p5_Ref scenario) are compared to those across the range of similar temperature pathway scenarios in the IPCC AR6 database⁶ for no and low overshoot (i.e. category "C1") scenarios (Supplementary Figure 8). In general, the TIAM-Grantham model is not an outlier compared to the range, which is itself a limited representation of the future possibility space. However, the range is large, so model-specific results on any single technology do not represent the only possibility.



Supplementary Figure 8: Key variables in 1.5°C scenarios. IPCC AR6 database of "C1" category (i.e. 1.5°C with no or low overshoot) scenarios (grey lines) with overlay of this study's 1.5°C reference scenario (red line), for key variables analysed in this study.

Supplementary References

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