# New metric quantifies climate adaptation feedback on future global warming



A recent study published in Nature presents a comprehensive methodology to quantify the feedback effects that arise when future energy consumption changes in response to adaptation efforts addressing anthropogenic climate change (ACC), and how these changes in energy use in turn influence greenhouse gas (GHG) emissions and subsequent climate outcomes. The authors introduce a novel metric termed the Climate Adaptation Feedback (CAF), which measures the difference in global mean surface temperature (GMST) at a specified future horizon with and without the inclusion of adaptation-induced energy consumption.

The CAF is formally defined by comparing two future climate projections: one that includes adaptive energy use changes due to warming, and one that does not. Using a baseline combination of Representative Concentration Pathway (RCP) 8.5 and Shared Socioeconomic Pathway (SSP) 2 scenarios to fix assumptions about emissions and socioeconomic factors, the CAF at time horizon τ (measured from 2020 as year zero) is expressed as:

[ CAF\_\tau = \Delta \overline{T}^A\_\tau - \Delta \overline{T}^N\_\tau ]

Here, (\Delta \overline{T}^A\_\tau) denotes the change in GMST when adaptive energy use is accounted for, and (\Delta \overline{T}^N\_\tau) the change without such adaptation. A positive CAF indicates that adaptation leads to increased warming globally, while a negative value suggests that adaptation dampens warming.

To calculate the CAF, the researchers first determined the changes in global carbon dioxide (CO₂) emissions attributable to adaptive energy use at country-level granularity, acknowledging significant spatial heterogeneity in temperature changes, energy demand responses, and carbon intensities of energy consumption. For each country i and year t, the additional emissions from adaptation were modelled as:

[ E\_{i,t} = \sum\_h F\_i^h \sum\_{p \in i} \left[ J^h(\mathbf{T}*{p,t}^N, \mathbf{X}*) - J^h(\mathbf{T}*{p,0}^N, \mathbf{X}*) \right] ]

where (h) indexes final energy consumption types (electricity and other fuels), (F\_i^h) is the CO₂ emissions factor for energy type h in country i, and (J^h) represents the "dose-response" functions relating energy use to daily temperature and socioeconomic covariates at ~25,000 subnational regions (p). The differences ([J^h(\mathbf{T}*{p,t}^N, \mathbf{X}*) - J^h(\mathbf{T}*{p,0}^N, \mathbf{X}*)]) quantify the additional energy consumption induced by climate change relative to a baseline stable climate of 2020.

These dose-response functions were estimated empirically using historical energy consumption and temperature data with econometric methods, capturing nonlinear and heterogeneous responses that vary by income and climate, thereby integrating both intensive (variations on a daily basis) and extensive (long-term behavioural and technological adjustments) margins of adaptation. The modelling framework accounted for uncertainties arising from climate model projections (33 General Circulation Models from the CMIP5 archive) and statistical estimation, combining them to produce probabilistic projections of emissions changes.

Summing across all countries and the years from 2020 to τ gives the cumulative CO₂ emissions change induced by adaptation:

[ \mathcal{E}*\tau = \sum*^\tau \sum\_i E\_{i,t} ]

To translate these emissions changes into corresponding GMST changes, the study estimated an empirical linear relationship between cumulative CO₂ emissions and warming from the ensemble of climate models. This relationship, denoted by the coefficient (\beta), incorporates not only direct CO₂ effects but also co-varying impacts of other GHGs, leading to a slightly higher sensitivity coefficient than the well-known Transient Climate Response to Cumulative Carbon Emissions (TCRE). Formally, the adaptation-driven temperature change contribution is:

[ \Delta T\_\tau^A = \Delta T\_\tau^N + \beta \mathcal{E}\_\tau ]

which leads to an expression for the Climate Adaptation Feedback:

[ CAF\_\tau = \beta \mathcal{E}\_\tau ]

The study provides point estimates and 90% confidence intervals for the CAF under various SSP-RCP scenarios, enabling quantification of how adaptation-driven energy consumption influences future global temperatures.

In terms of the economic valuation of the climate adaptation feedback, the authors employed the Climate Impact Lab's Data-driven Spatial Climate Impact Model (DSCIM), which estimates climate-induced damages including mortality, coastal storms, sea-level rise, labour productivity, energy, and agriculture impacts. Monetization of mortality risk used the U.S. Environmental Protection Agency's Value of Statistical Life adjusted by life years lost and income elasticity. Avoided economic damages due to the negative CAF were calculated by comparing baseline damage projections against those reflecting adaptation-induced emissions scenarios, discounted back to 2019 using a stochastic discount factor based on the Ramsey rule with specified parameters for risk aversion and pure time preference.

This data-driven approach contrasts with prior analyses based on Integrated Assessment Models (IAMs), such as the WITCH IAM framework, which simulate agents optimising welfare balancing consumption, savings, and energy use, often conceptualising adaptation in terms of productivity shocks and relative prices. The present study avoids the structural assumptions inherent in IAMs and instead relies on empirical historical energy use-temperature relationships, allowing finer spatial resolution (~25,000 regions) and explicitly incorporating statistical and climate model uncertainties. However, it does not model general equilibrium effects or future policy-induced changes in behaviour or technology beyond historical adaptation patterns.

The researchers utilised a range of data sources. Projections of adaptation-induced energy use were sourced from previous studies [ref. 8], with energy intensities for CO₂ emissions compiled from the International Energy Agency's Emissions Intensities Report and World Energy Balances. Socioeconomic pathways were based on averaged outputs from IIASA and OECD models. Country-specific fuel mixes were accounted for to reflect realistic emissions intensities; for example, electricity produced predominantly from coal in Poland versus renewable sources in Costa Rica were distinctly treated. Baseline emissions pathways and Nationally Determined Contributions (NDCs) were integrated from additional datasets.

An important aspect of the study was dealing with limitations in GHG emissions data, particularly beyond CO₂. By estimating an empirical regression of GMST changes on cumulative CO₂ emissions across climate model combinations, they derived an effective coefficient (\beta) capturing both direct effects and co-varying other GHGs. The authors found (\beta = 2.2 \times 10^{-3} \degree C \, \text{per GtC}), which is about 1.4 times greater than median TCRE estimates but consistent with positive covariance between CO₂ and other greenhouse gases.

Beyond static estimates, the researchers also developed a dynamic CAF model that iteratively updates temperature projections each year by considering how emissions changes caused by adaptation feedback into temperature pathways, which then influence future adaptive emissions. This iterative process called for constructing impulse response functions relating emissions changes to GMST deviations, and updating emissions projections accordingly over each year through 2099. Importantly, results demonstrated that this dynamic feedback mechanism yielded negligible differences from the static CAF estimates; for example, by 2099, the static CAF was approximately −0.1206°C, while the dynamic CAF was −0.1196°C.

In summary, this work rigorously estimates the feedback loop whereby adaptive responses to climate change influence energy consumption, altering emissions and subsequently climate outcomes. Their data-driven, empirically grounded model underlines the importance of spatial heterogeneity, socioeconomic context, and the nuanced interplay between energy use and warming. The Climate Adaptation Feedback metric defined constitutes a potentially valuable tool for considering the net effects of adaptation on climate trajectories and for informing climate impact valuation and policy assessments.

Source: [Noah Wire Services](https://www.noahwire.com)