Extension of Verification and Evaluation Method for Climate Mitigation Scenario: Considering Regional and Historical Information

気候緩和シナリオの検証と評価手法の拡張：地域と実績値を考慮した評価

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ATMOSPHERIC AND THERMAL ENVIRONMENTAL ENGINEERING LAB

ENVIRONMENTAL ENGINEERING COURSE,

DEPARTMENT OF GLOBAL ENGINEERING

B4 HENRY CHAN

Background

Current Situation of Climate Change

- The world's average annual CO_2 emissions recorded from 2010 to 2019 is all-time high
- Challenges in achieving climate target set in Paris Agreement: "well below 2°C…limit to 1.5°C"
- To avoid the surpassing of 2°C, **accelerating** implementation of mitigation measures is inevitable
- Integrated Assessment Models (IAMs) project mitigation scenarios, which allows evaluation of policies

(IPCC, 2022)

Validity & Feasibility of Scenarios

Besides traditional indicators (e.g., GDP loss), (1)**validity** & (2)**feasibility** are also important

(1) Validity: reproducibility of historical & near-future trend

**Vetting: Verification of scenarios' validity*

- assure the quality of scenarios to be evaluated

(2) Feasibility: "the degree to which scenarios lie within the boundaries of societal capacities for change in a given period" (Brutschin et al., 2021)

- provide practical information for decision making

Problems

- Concerns about the existing approach of vetting & feasibility assessment adopted by IPCC AR6 WGIII

(1) Only vetting at **global level**, yet increasing interest from policy makers & academic researchers on **regional** information (Byers et al., 2023; Wilson et al., 2021)

(2) Feasibility assessment indicators are set with thresholds deduced from literature review, but some **lacks strong justification** (Nishimoto & Fujimori, 2023)

e.g. emerging technologies like CCS scale-up

Objectives

- Extend the existing approach adopted by IPCC AR6 WGIII for evaluation of scenarios

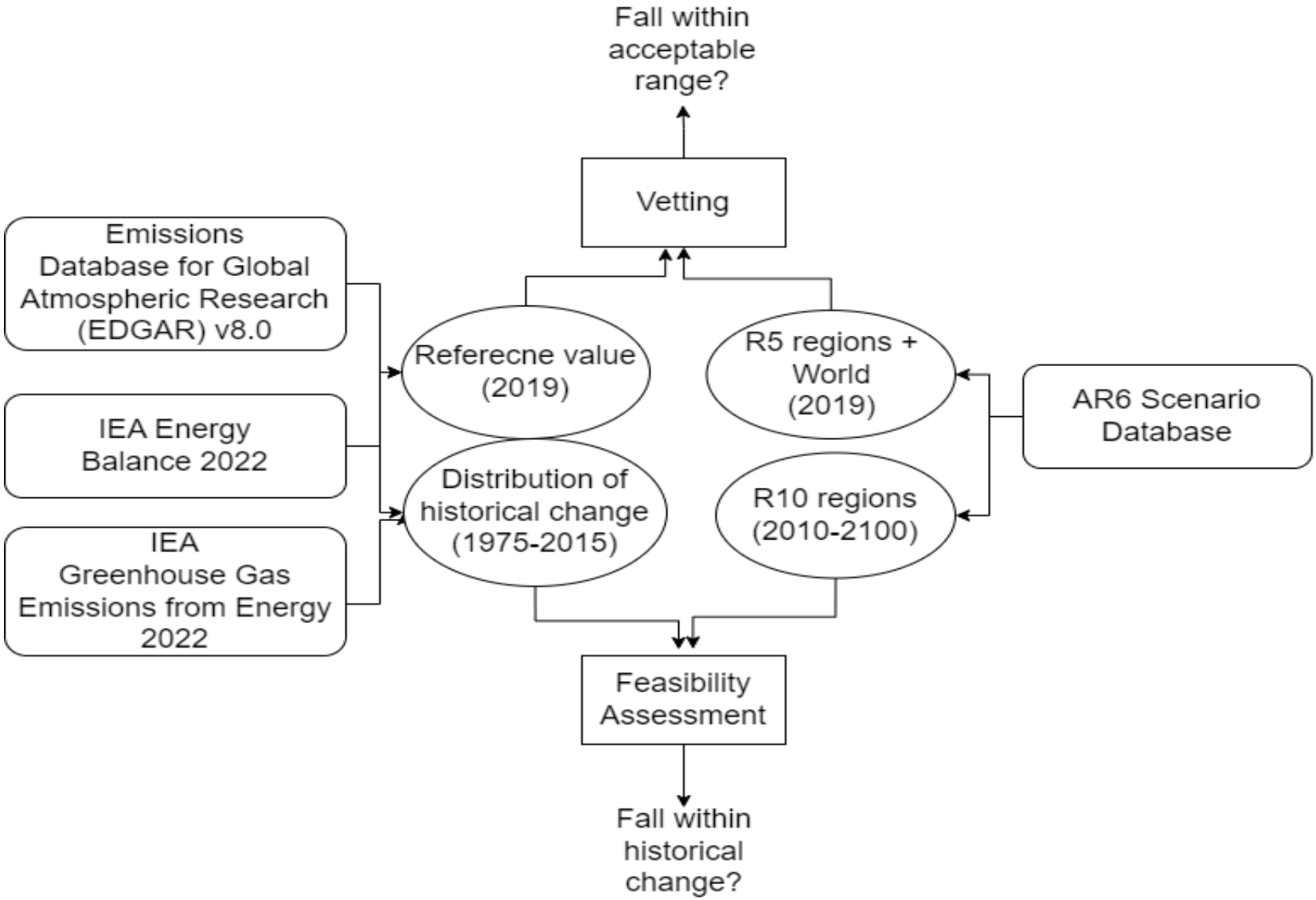
(1) Global vetting + **regional vetting**

(2) Feasibility Assessment based on **historical change**

- Comparing the results between extended & existing approach, the effectiveness of extension can be analyzed
  - Regional vetting might enhance the confidence of the use of global scenarios on regional context
  - Alternative feasibility assessment might reveal new dimension of feasibility concern that has not been focused on

Methodology

Overview


Fall within acceptable range?
Vetting
Emissions Database for Global Atmospheric Research (EDGAR) v8.0
IEA Energy Balance 2022
IEA Greenhouse Gas Emissions from Energy 2022
Referecne value (2019)
Distribution of historical change (1975-2015)
R5 regions + World (2019)
R10 regions (2010-2100)
AR6 Scenario Database
Feasibility Assessment
Fall within historical change?

Regional Vetting

- 6 Indicators of historical **emission** & **energy** production
- Reference year is 2019
- 5 regions (R5) defined by IPCC + World for comparison
  - OECD+EU, Asia, Latin America (LAM), Middle East & Africa (MEF), Reforming Economies (REF), World

Table 1 Indicators and acceptable ranges for vetting

Indicator	Acceptable range
CO2 emissions (EIP)	±10%
CO2 emissions (EIP) % change 2010-2019	±15%
CH4 emissions	±20%
Total primary energy supply	±10%
Electricity: nuclear	±20%
Electricity: solar & wind	±25%

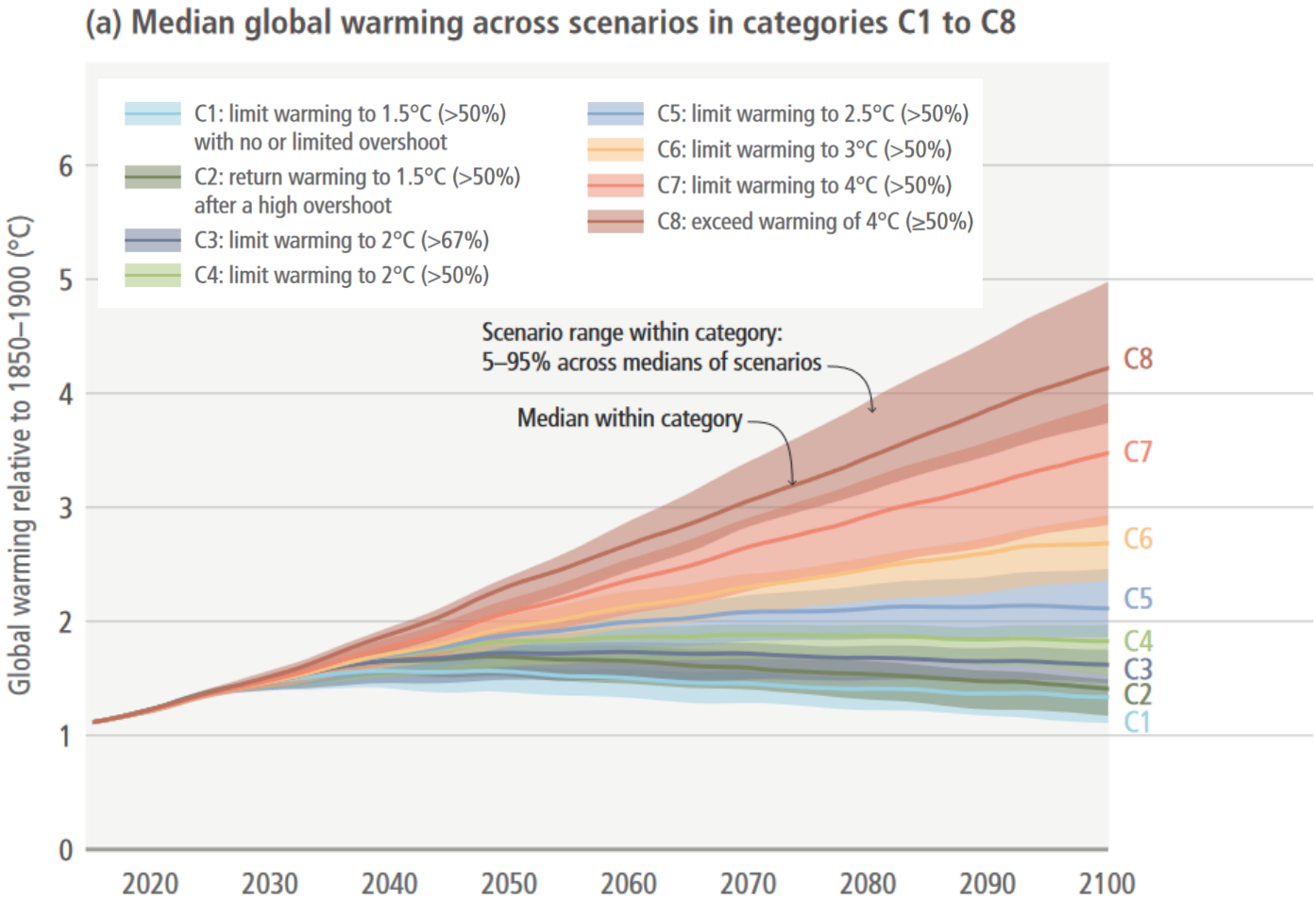
*EIP: Energy and Industrial Process

Feasibility Assessment Based on Historical Change

- Proposed by Nishimoto & Fujimori (2023) & showcased with scenarios projected from AIM/Hub
- **Energy intensity**, **carbon intensity**, **electrification rate**
- Indicator falls within (90% of) distribution of historical rates of changes -> feasible
- Apply to ensemble of scenarios (AR6 Scenario Database)

Climate Category

- Smaller number means lower temperature increase



*retrieved from Riahi et al. (2022) in IPCC (2022)

Results

Vetting-Deviation from Reference

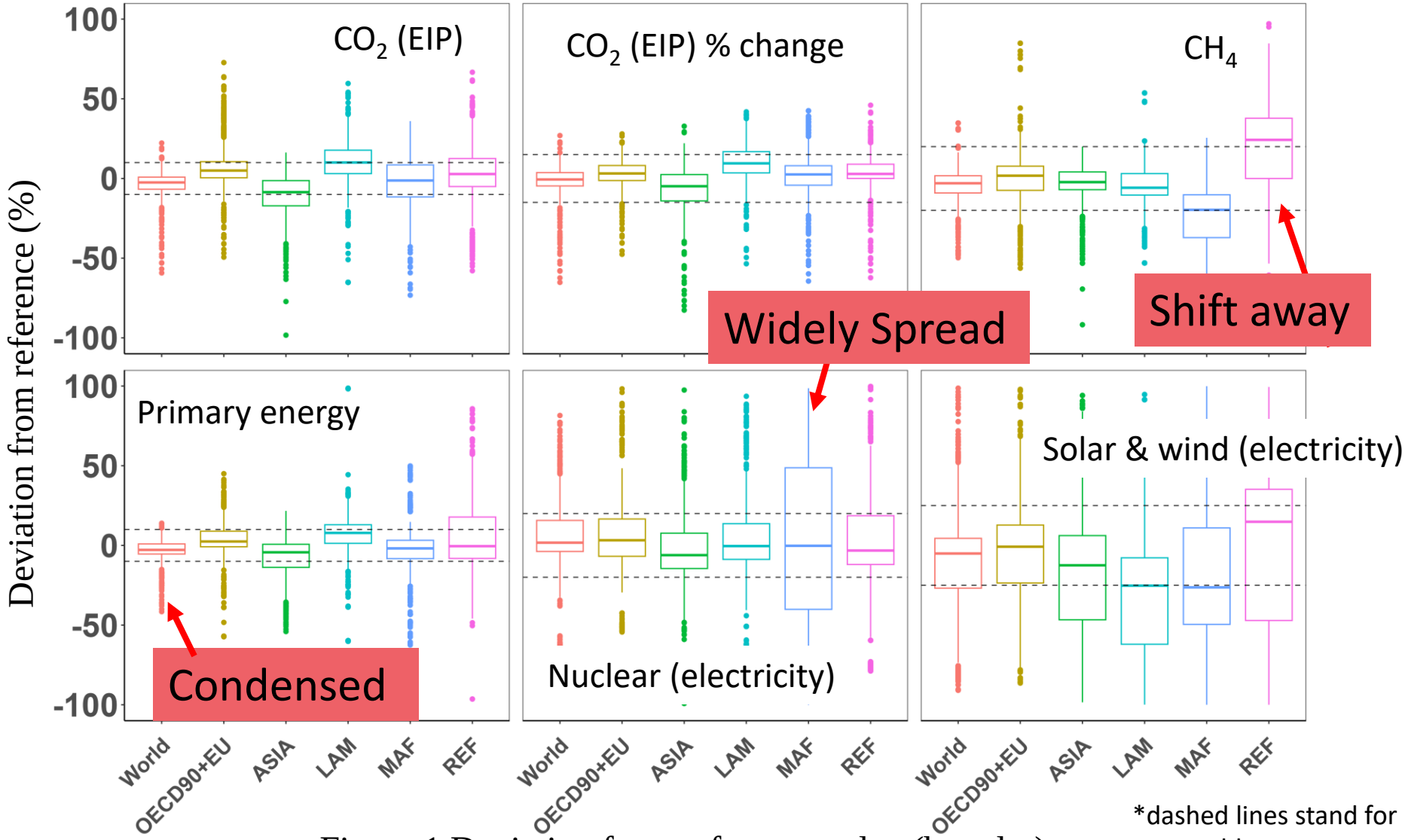


Figure 1 Deviation from reference value (boxplot)

*dashed lines stand for acceptable range

Vetting-Failing Rate

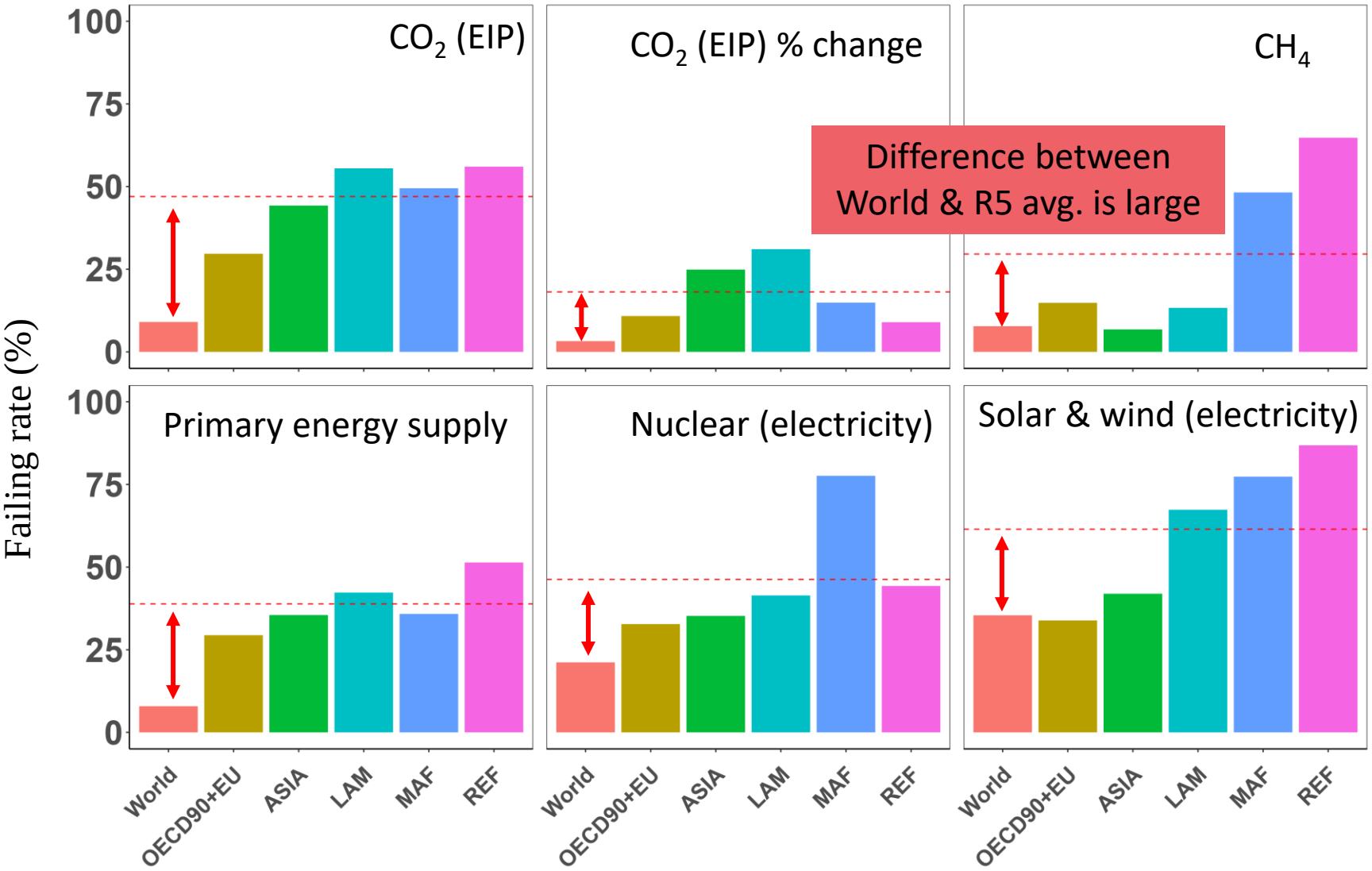


Figure 2 Failing rate of vetting

Feasibility Assessment-Trend

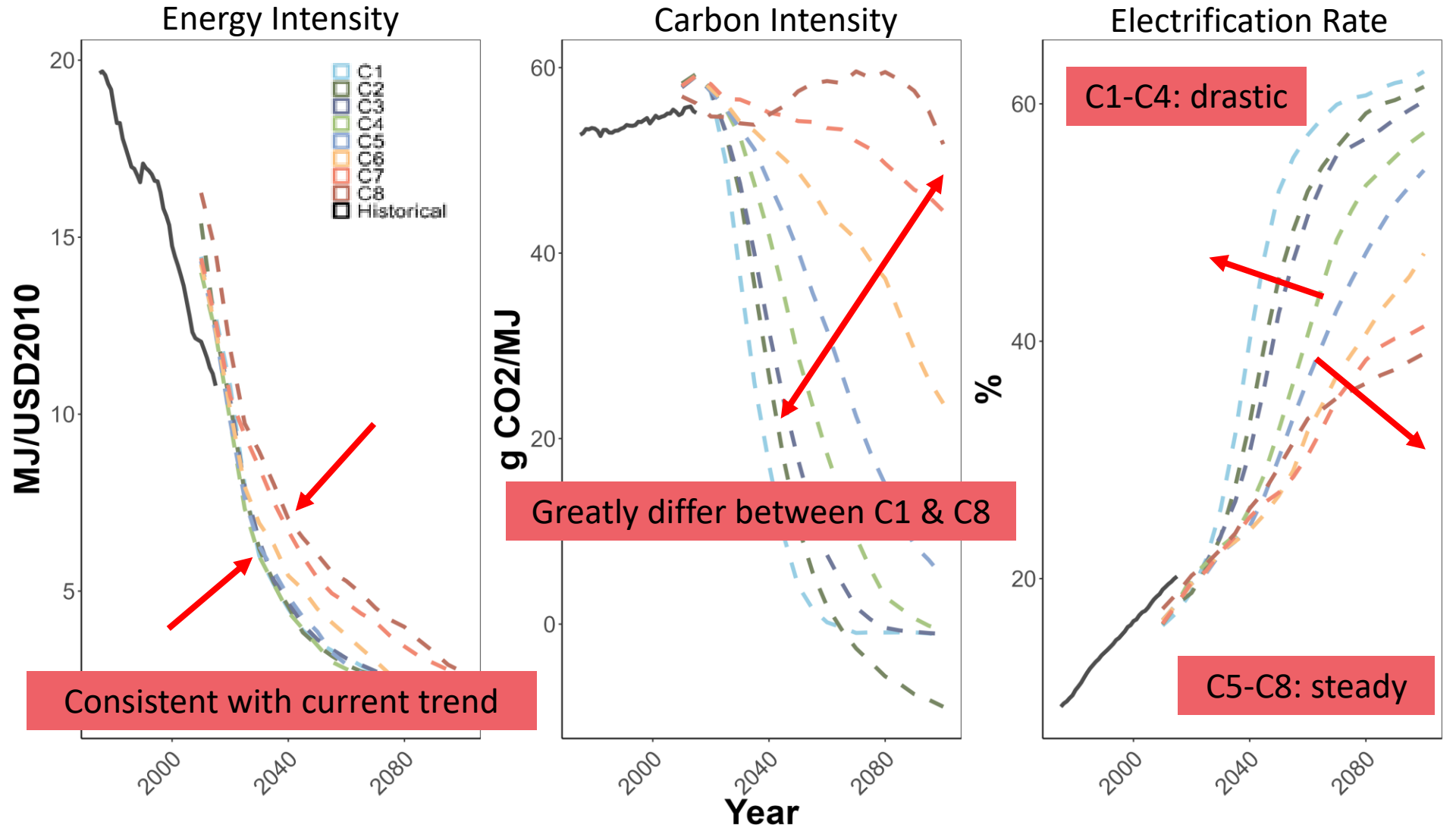


Figure 3 Trend & projection of indicators

*historical mean & projected median across R10 regions

Feasibility Assessment-Distribution

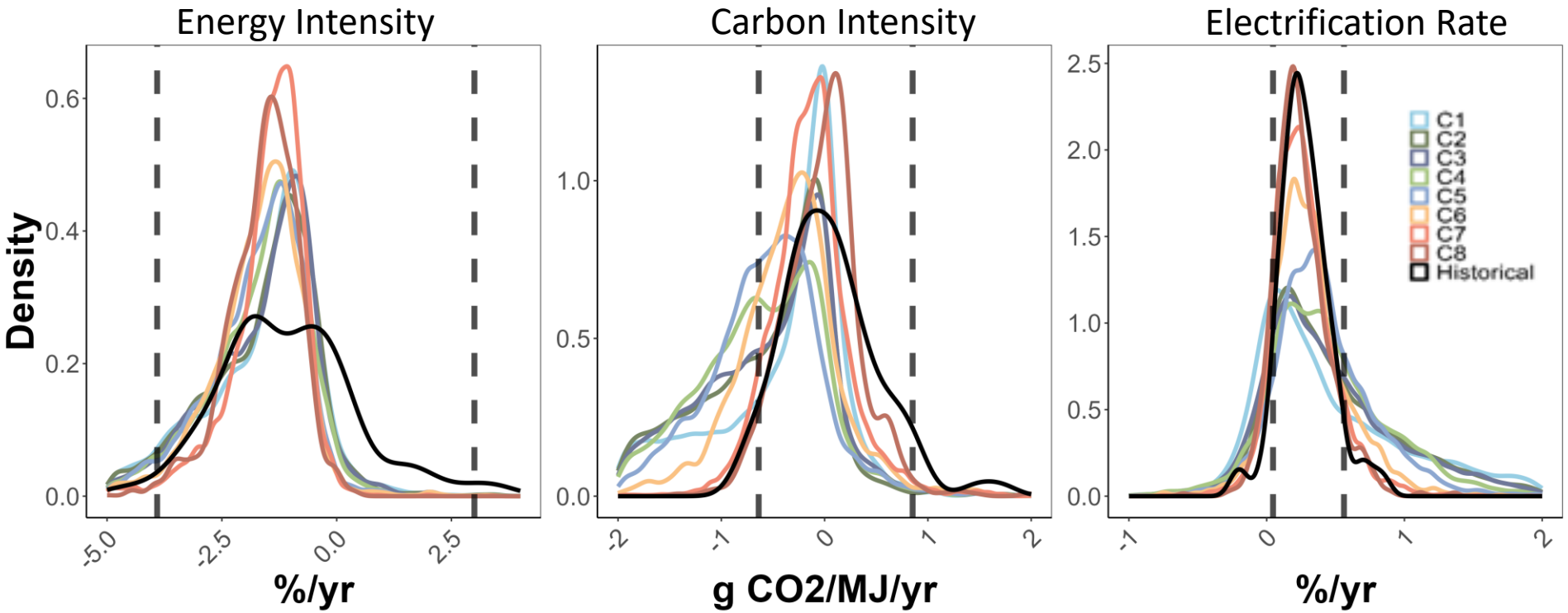


Figure 4 Density function for indicators' change

- **Carbon intensity** shifts towards **negative** side and **electrification rate** shifts towards **positive** side

➢ Scenarios require more **drastic change** than observation

*dashed lines stand for historical 5th & 95th percentile

Feasibility Concern

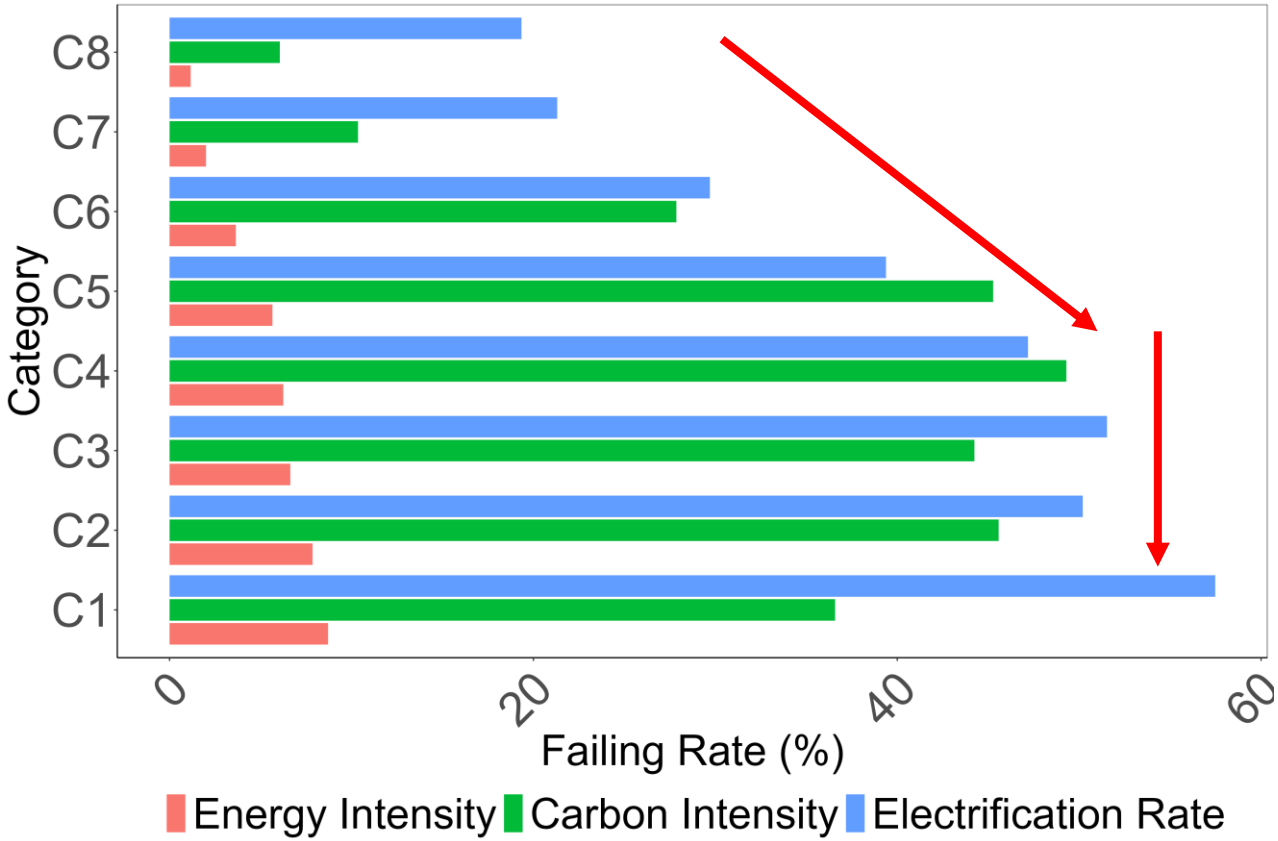


Figure 5 Feasibility concern of scenarios

- Electrification rate & carbon intensity are the main factors
- Significant increase from C8 to C4, but not for C4 to C1

Discussion

Difference between Global & Regional Vetting

- R5 regions are inferior to world in both deviation from reference & passing rates

➢ Global constraint couples with the uniform assumptions across region, which might not capture the variation & characteristics in regions properly (Köberle et al., 2022)

- Among R5, OECD+EU and Asia comparatively perform better than LAM, MAF and REF

➢ IAMs have been focusing more on major emission regions than other regions, possibly due to the lack of data and inconsistency in data quality in LDCs

Effectiveness of Feasibility Assessment Based on Historical Change

- Feasibility concerns from carbon intensity and electrification align with the result shown by IPCC AR6 WGIII, i.e. economic & technological concern in near term

➢ Prove the versality of the approach

- However, scenarios in C1-C4 do not continue the rising trend, with carbon intensity decreasing

➢ Contrast to IPCC AR6 WGIII's conclusion, i.e. C1 shows 2 times more in % of scenarios with concern than that of C3

Conclusion

Summary

- Regional vetting does not reproduce the same result as seen in global vetting, urging to review assumptions and mechanisms regulating regional projection
- Regions with significant figure tend to perform better than their counterparts, suggesting potential limitation of global scenario use case
- Feasibility assessment based on historical change shows a similar result as in literature, proving its versality
- However, it contrasts to result of AR6 on scenarios in C1 to C4, requiring adjustment of method to capture characteristics of scenarios

Limitations

- National vetting is not applied in this study, which might provide more relevant information for policy makers
- Difference between IAMs, in terms of model's structure & assumption, is not considered
  - Structural differences between models elaborate the different patterns of feasibility concern (van de Ven et al., 2023)
- Evaluation done on a 5-year interval, thus might fail to capture short-term drastic change

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Appendix

Conversion of Historical Energy & GDP

- Total primary energy supply from “physical energy content” method to “direct equivalent” method:

$$\mathrm{TES}_{\text{direct equivalent}} = \mathrm{TES}_{\text{physical energy content}} - 0.67\,(\mathrm{PE}_{\text{nuclear}}) - 0.9\,(\mathrm{PE}_{\text{geothermal}})$$

**TES = total energy supply; PE = primary energy*

- GDP constant year from USD2015 to USD2010:

$$\mathrm{GDP}_{\mathrm{USD2010}} = \mathrm{GDP}_{\mathrm{USD2015}} \times \frac{\mathrm{deflator}_{\mathrm{USD2015}}}{\mathrm{deflator}_{\mathrm{USD2010}}}$$

** GDP deflator from World Bank Dataset*

Calculation of Regional Vetting

- Scenario is considered “pass” if it falls within the range:

$$[Ref \times (1 - range), Ref \times (1 + range)]$$

- However, for CO_2 Emission (EIP) % change:

$$[Ref - range, Ref + range]$$

- On p.13, “Deviation from Reference” is calculated as:

$$Deviation = 100 \times \frac{Value_{scenairo} - Value_{reference}}{Value_{reference}}$$

- However, for CO_2 Emission (EIP) % change:

$$Deviation = Value_{scenairo} - Value_{reference}$$

Climate Categories

Category	Description	SSP
C1: Limit warming to 1.5°C (>50%) with no or limited overshoot	Reach or exceed 1.5°C during the 21st century with a likelihood of ≤67%, and limit warming to 1.5°C in 2100 with a likelihood >50%. Limited overshoot refers to exceeding 1.5°C by up to about 0.1°C and for up to several decades	SSP1-1.9
C2: Return warming to 1.5°C (>50%) after a high overshoot	Exceed warming of 1.5°C during the 21st century with a likelihood of >67%, and limit warming to 1.5°C in 2100 with a likelihood of >50%. High overshoot refers to temporarily exceeding 1.5°C global warming by 0.1°C–0.3°C for up to several decades.	-
C3: Limit warming to 2°C (>67%).	Limit peak warming to 2°C throughout the 21st century with a likelihood of >67%.	SSP1-2.6
C4: Limit warming to 2°C (>50%)	Limit peak warming to 2°C throughout the 21st century with a likelihood of >50%.	-
C5: Limit warming to 2.5°C (>50%)	Limit peak warming to 2.5°C throughout the 21st century with a likelihood of >50%.	-
C6: Limit warming to 3°C (>50%)	Limit peak warming to 3°C throughout the 21st century with a likelihood of >50%.	SSP2-4.5
C7: Limit warming to 4°C (>50%)	Limit peak warming to 4°C throughout the 21st century with a likelihood of >50%.	SSP3-7.0
C8: Exceed warming of 4°C (≥50%)	Exceed warming of 4°C during the 21st century with a likelihood of ≥50%.	SSP5-8.5

Indicators for Feasibility Assessment

Indicator	Definition	Equation
Energy Intensity	Energy consumption per unit of GDP.	$\frac{\text{Primary Energy Supply (TES)}}{\text{Activity Level (GDP)}}$
Carbon Intensity	Carbon emissions produced per unit of energy supplied	$\frac{\text{CO2 Emissions (from energy)}}{\text{Primary Energy Supply (TES)}}$
Electrification Rate	Proportion of energy consumed that comes from electricity sources.	$\frac{\text{Electricity (within TFC)}}{\text{Final Energy Consumption (TFC)}}$

Calculation of Feasibility Concern

- For energy intensity (EI), rate of change is used. For carbon intensity (CI) & electrification rate (ER), change is used.

$$\Delta EI = \frac{EI_t - EI_{t-\Delta t}}{EI_{t-\Delta t}}; \Delta \mathrm{CI} = \Delta CI_t - \Delta CI_{t-\Delta t}; \Delta \mathrm{ER} = \Delta ER_t - \Delta ER_{t-\Delta t}$$

- Note that calculation is performed with a 5-year interval
- On p.17, “feasibility concern” is expressed as failing rate, which is the percentage of scenarios does not fall within the 5^{th} & 95^{th} percentile of historical change per each indicator per climate categories.

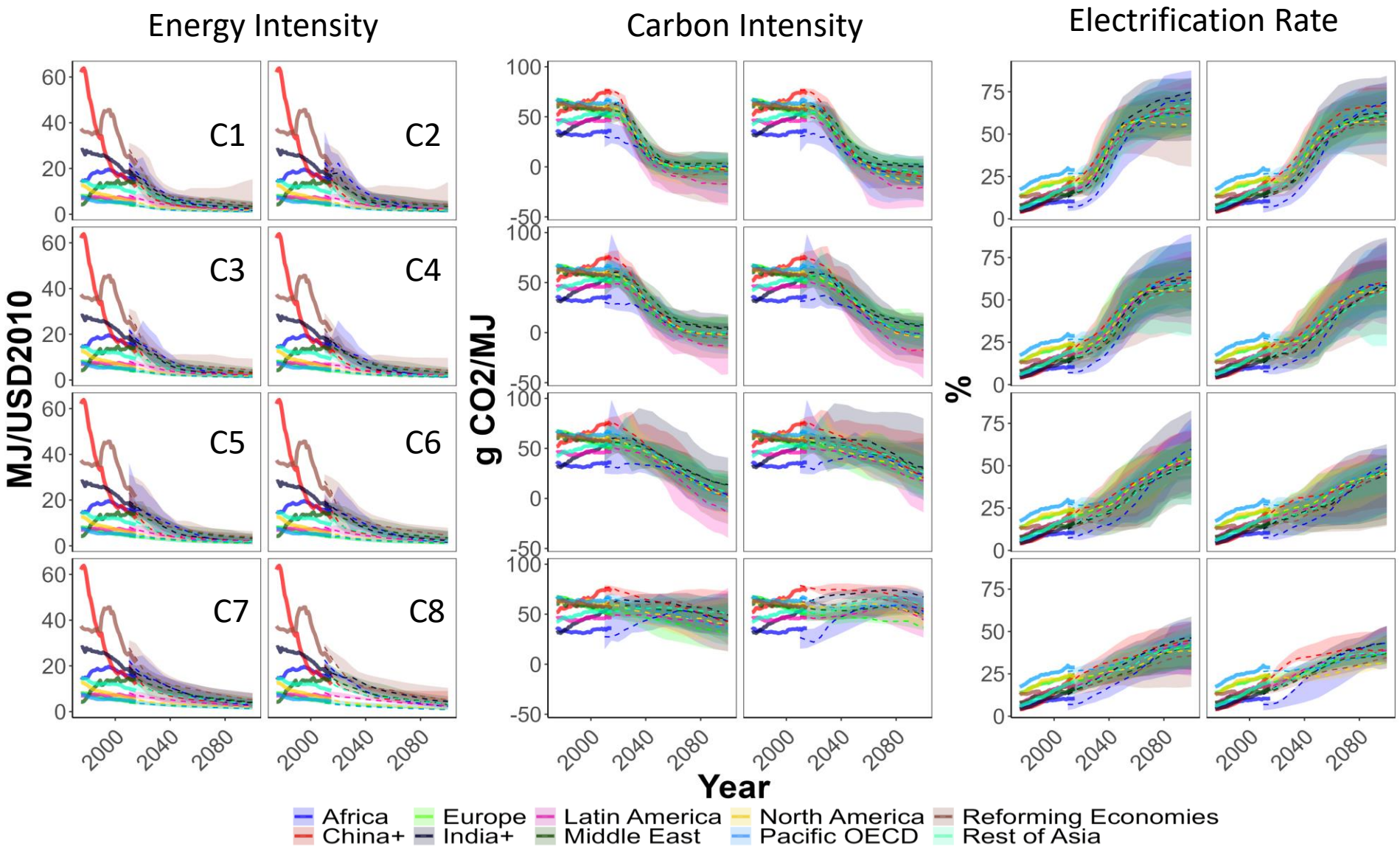

Figure 3 Trend & projection of indicators (in R10 regions)

*colored area stands for 90% coverage