Taiwan 2050 Net-zero Pathway

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Academia Sinica

Challenges of Decarbonization Polices and Technological Innovations toward Carbon Neutral Societies in East Asia

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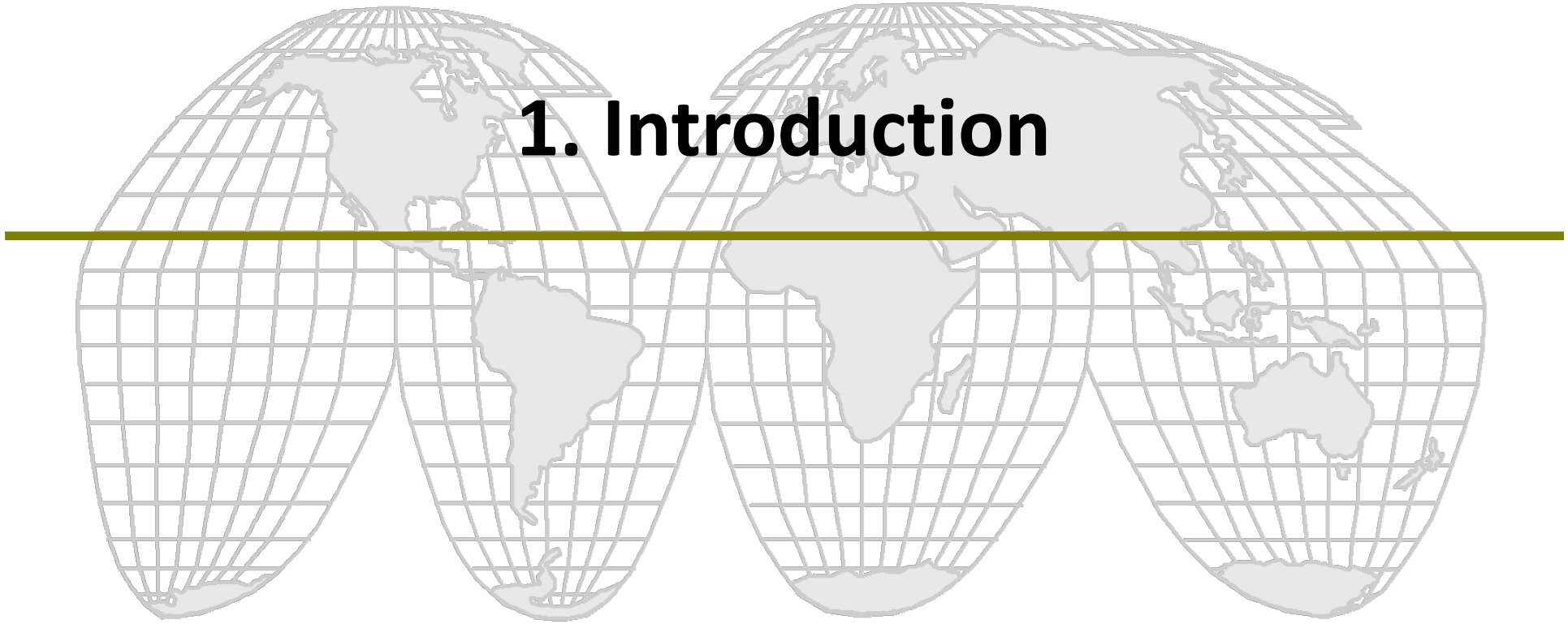
Preliminary results, please do not quote

Outline

1. Introduction
2. Methodology
3. Policy Scenarios
4. Modeling Results: Taiwan 2050 Net-zero Pathway
5. Conclusions

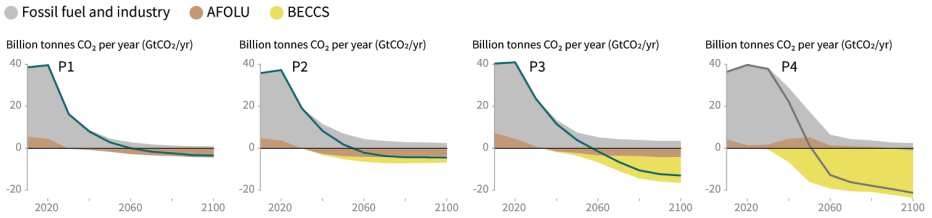


1. Introduction

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
↳ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
↳ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
↳ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
↳ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
↳ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
↳ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
↳ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
↳ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
↳ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
↳ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
↳ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km^2)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

FIGURE SPM.3B, IPCC, 2018, Special report Global Warming of 1.5°C.

Climate Crisis and 2050 Net-zero Target

- Climate change has now become **climate crisis**
- **2018**, IPCC indicated in the special report "**Global Warming of 1.5°C"**

  - **To avoid irreversible changes in systems, global warming must not exceed 1.5°C**
  - **Therefore, global net anthropogenic CO2 emissions must reach net-zero around 2050**
  - **On longer time scales, sustained net-negative global anthropogenic CO2 emissions are required to prevent further warming**
    - ➢ **Net-negative economy and society**

IPCC (2018) Special report Global Warming of 1.5°C

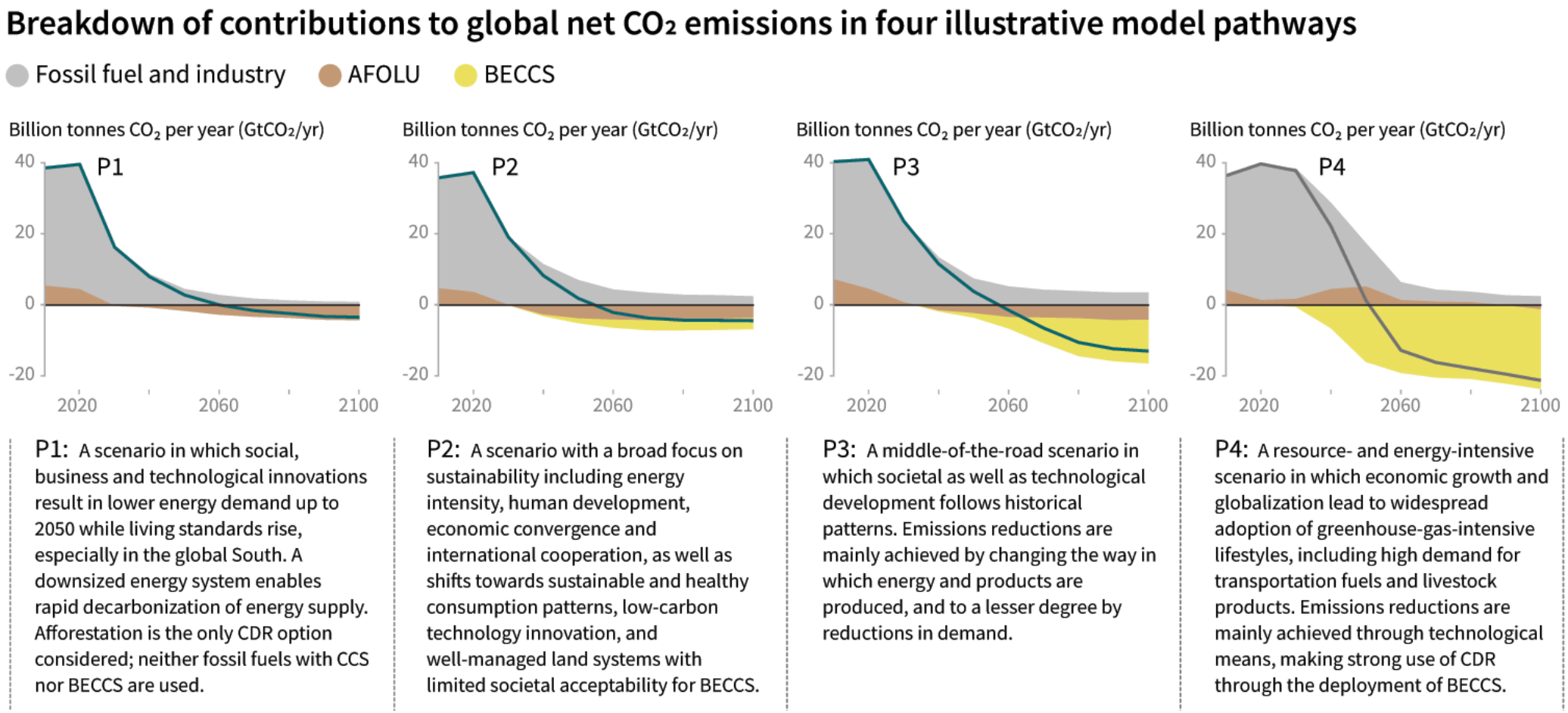


FIGURE SPM.3B, IPCC, 2018, Special report Global Warming of 1.5°C.

IPCC (2021) AR6
Climate Change 2021: The Physical Science Basis

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

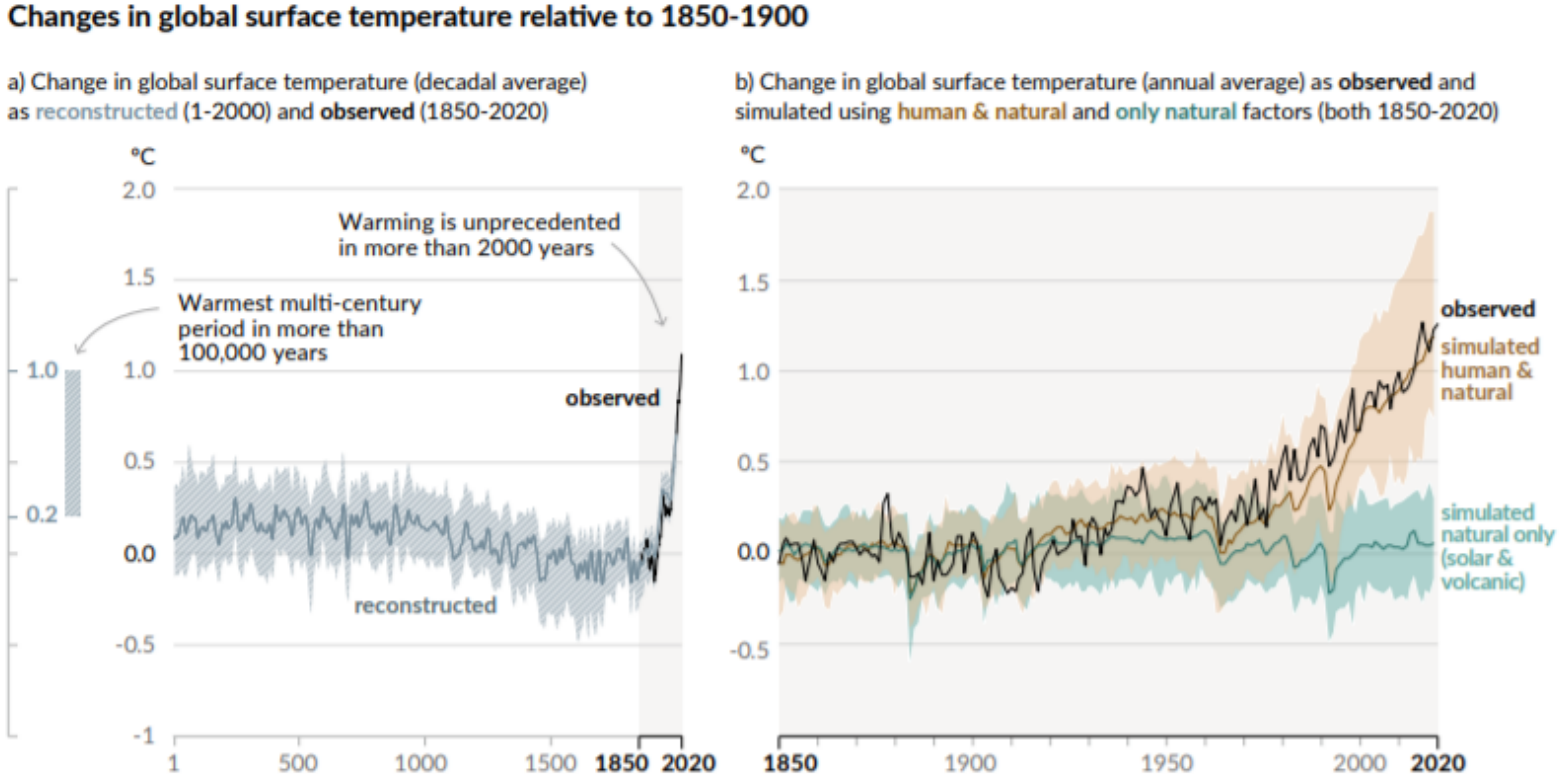


Figure SPM.1: History of global temperature change and causes of recent warming

This new assessment paints a devastating picture of a worsening global climate crisis that is now "**inevitable, unprecedented, and irreversible**."

(Guardian newspaper headline 10 August 2021)

Immediate, rapid and large-scale reductions of all greenhouse gases are needed to limit global warming to 1.5 degrees.

(IPCC news release, August 9, 2021)

Climate Crisis and 2050 Net-zero Target

- **Net Emissions:** GHG emissions released by humans minus GHG removal from the atmosphere within a period of time
- **Three groups of GHG removal (GGR) methods** (UK Royal Society, 2018, Greenhouse Gas Removal)
    1. **Increased biological uptake**

       Afforestation, reforestation and forest management; Habitat restorations; Soil carbon sequestration; Biochar; BECCS; Ocean fertilization; Building with biomass
    2. **Natural inorganic reactions**

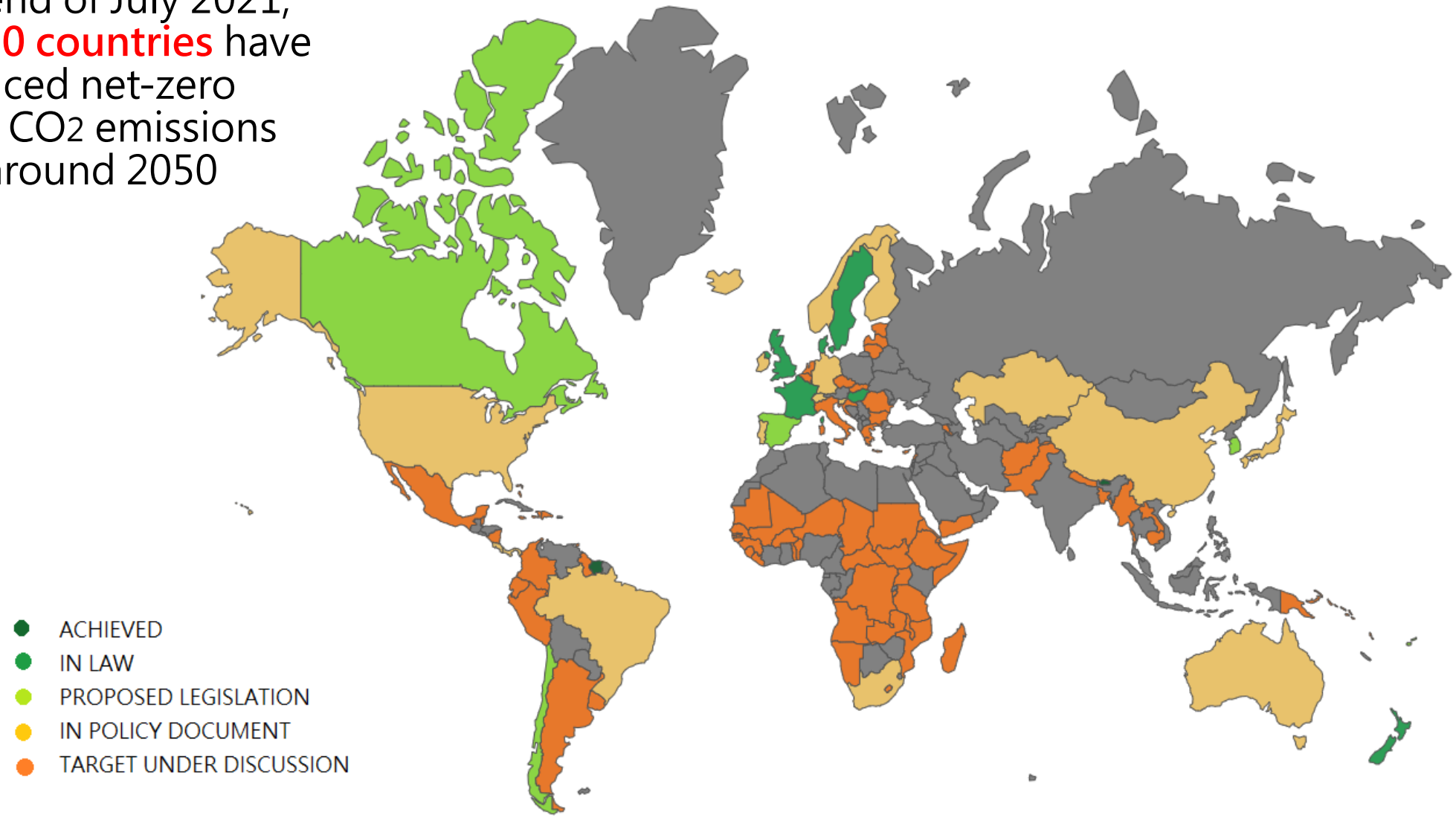
       Enhanced terrestrial weathering; Mineral carbonation at surface; Ocean alkalinity
    3. **Engineered removal**

       DACCS; Low-carbon concrete; and others

Net-zero GHG or CO2 Emissions Target Declarations

- At the end of July 2021, **over 130 countries** have announced net-zero GHG or CO2 emissions target around 2050
  - **June 2019**, **United Kingdom** was the first country legislated for 2050 net-zero GHG emissions
  - **December 2019**, **European Union**, as the leader of global GHG reduction, published "European Green Deal", announced the target to become the first climate-neutral continent by 2050
  - **September 2020, China** announced to reach carbon neutral by 2060
  - **October 26, 2020,** Japanese Prime Minister Yoshihide Suga declared that **Japan** would reach net-zero GHG emissions by 2050
  - **October 28, 2020,** President Moon Jae-in of **South Korea** announced that South Korea would reach net-zero CO2 emissions by 2050
  - **April 22-23, 2021**, President Joe Biden of **US** held Leaders Summit on Climate and announced goal of net-zero GHG emissions by 2050

At the end of July 2021, **over 130 countries** have announced net-zero GHG or CO_2 emissions target around 2050



Net-zero Emissions Race (by March 2021)

Source: Painted according to the data from Net Zero Tracker, The Energy & Climate Intelligence Unit (https://eciu.net/netzerotracker)

Net-zero in Taiwan

- **Net-zero Pathway Task Force,** November 2020- November 2021
  - Executive Yuan organizes the net-zero pathway task force
  - There are five working groups. Each one is joined by various responsible ministries, agencies, experts, and think tanks
    - Clean energy
    - Energy efficiency
    - Clean transportation
    - Negative emissions technology
    - Policies/Economic instruments
  - Executive Yuan is expected to finalize the net zero pathway by **November 2021**

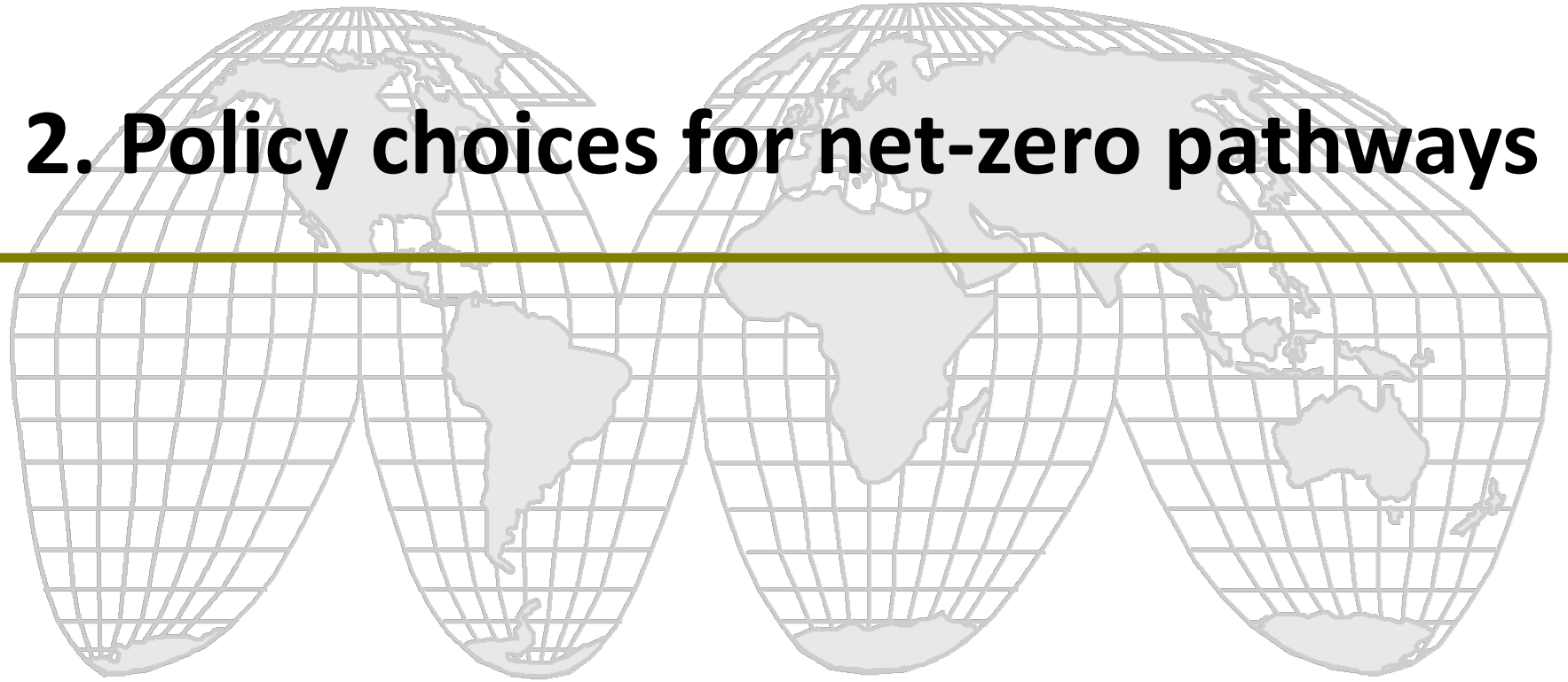
Net-zero in Taiwan

- On April 22, 2021, Earth Day, President Ing-Wen Tsai announced that **“The 2050 net-zero transformation is the goal of the whole world, and it is also the goal of Taiwan!”**
- **Taiwan is under pressure**
  - **Over 130 countries have announced net-zero GHG or CO2 emissions target around 2050 including our neighbors in East Asia,**
  - **A huge gap** between the international target and Taiwan’s current target
    - **Current GHG reduction target is written in “Greenhouse Gas Reduction and Management Act” since 2015**
    - **“Long-term national GHG emission reduction goal shall be to reduce GHG emissions to no more than 50% of 2005 GHG emission by 2050”**
- **Another critical pressure**
  - **EU CBAM** (carbon border adjustment mechanism) from 2026.
  - The government and industries in Taiwan all face serious pressure and incentives. Start to change their mind gradually

Net-zero in Taiwan

- Aug. 30, 2021, in a meeting of the National Council for Sustainable Development
  - Prime Minister Su made two important decisions concerning the revision of the Greenhouse Gas Reduction and Management Act
    - The target of 2050 net-zero should be specified in the ACT
    - EPA should consult with the Ministry of Economic Affairs about the carbon pricing policy to be adopted in the Act
      - In addition to the ETS in the Act, a carbon fee system earmarked for mitigating and adapting climate change is expected
        - The ETS has not been implemented yet
        - Interest groups (businesses, environmentalists) are lobbying hard against each other on the fee rate and the usage of revenue

2. Policy choices for net-zero pathways



Approaches to mitigate climate crisis

- To avoid irreversible changes in systems, global warming must not exceed 1.5°C
  - Therefore, global net anthropogenic CO2 emissions must reach **net-zero around 2050**
  - On longer time scales, **sustained net-negative** global anthropogenic CO2 emissions are required to prevent further warming
    - ➢ **Net-negative economy and society**
- Two major approaches to mitigate the climate crisis
  1. **To reduce GHG emissions**
     - Emission reduction
  2. **To remove GHG stocks** in the atmosphere, GHG removal (GGR)
     - Using **negative emissions technologies (NETs)** to remove GHG from the atmosphere
       - Natural: forestry, agriculture
       - Technological: energy, industry
       - Combined: BECCS

All available Strategies and Policies

- To reach net zero by 2050, we need **all available and correct strategies and policies**
  - **Proactive GHG reduction and removal policies**
  - **R&D of low-carbon and GGR technologies**
  - **Transforming to become a net-negative economy and society**

Economic Strategies and Policies

- **Economic incentives**
  - To reduce GHG emissions
    - Carbon pricing (**carbon tax and ETS**) and **energy tax** based on GHG emissions or fossil fuels
      - **Tax-fund system:** Tax revenue to be disbursed to citizens and to form a **GGR fund**
  - To remove GHG stocks
    - Using the interests of the GGR fund
      - To pay the **carbon removal price** based on GGR
        - Reverse auction of GGR
      - To invest in GGR R&D
    - **Dynamic cap-and-trade system** with banking and borrowing
      - Emission allowances
      - Carbon removal obligations
      - See Bednar, et al. "Operationalizing the net-negative carbon economy." Nature (2021)

Economic Strategies and Policies

- To overcome free-riding in international climate agreements and to encourage other countries to join a **climate club**, such as EU
  - **Tariff**
    - See Nordhaus. "Climate clubs: Overcoming free-riding in international climate policy." American Economic Review (2015)
  - **Carbon border adjustment mechanism (CBAM)**
  - **Green carbon fund**
    - See Shaw and Fu. "Climate clubs with tax revenue recycling, tariffs, and transfers." Climate Change Economics (2020)

Economic Strategies and Policies

- **Sustainable consumption and production policies**
  - Huge investments for transforming the system of consumption and production are needed
    - Government investments in infrastructure
    - Private investments: households and industries
  - Related policies
    - Greening government budgeting and procurement
    - Greening finance
      - Loans, bonds, investment, financing
    - Green financing: Green carbon fund
    - Systems of green consumption and production
      - Green value chain
      - Extended producer responsibility to cover the whole value chain

3. Methodology

Cambridge Econometrics

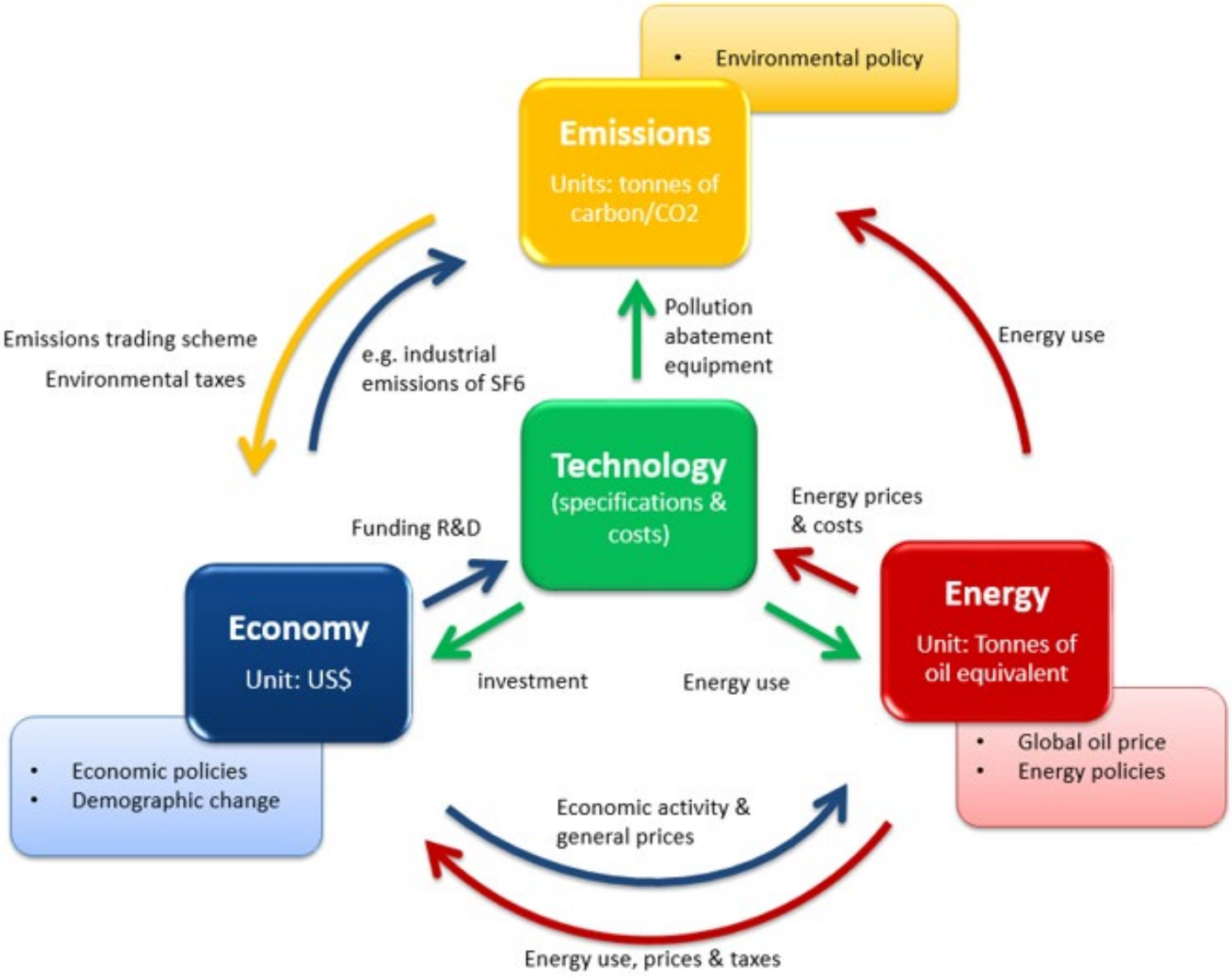
- Cambridge Econometrics founded in 1978
- A commercial spin-off from the University of Cambridge
- Take forward the pioneering work of Professor Sir Richard Stone
  - 1984 Nobel Laureate in Economics
- Research fields: applied economic analysis
- Models: E3ME, MDM-E3, LEFM, CHELMER
- Projects
  - New Climate Economy – unlocking the inclusive growth story of the 21st Century
  - Modelling global renewables targets
  - Fueling Europe's Future: How the transition from oil strengthens the economy

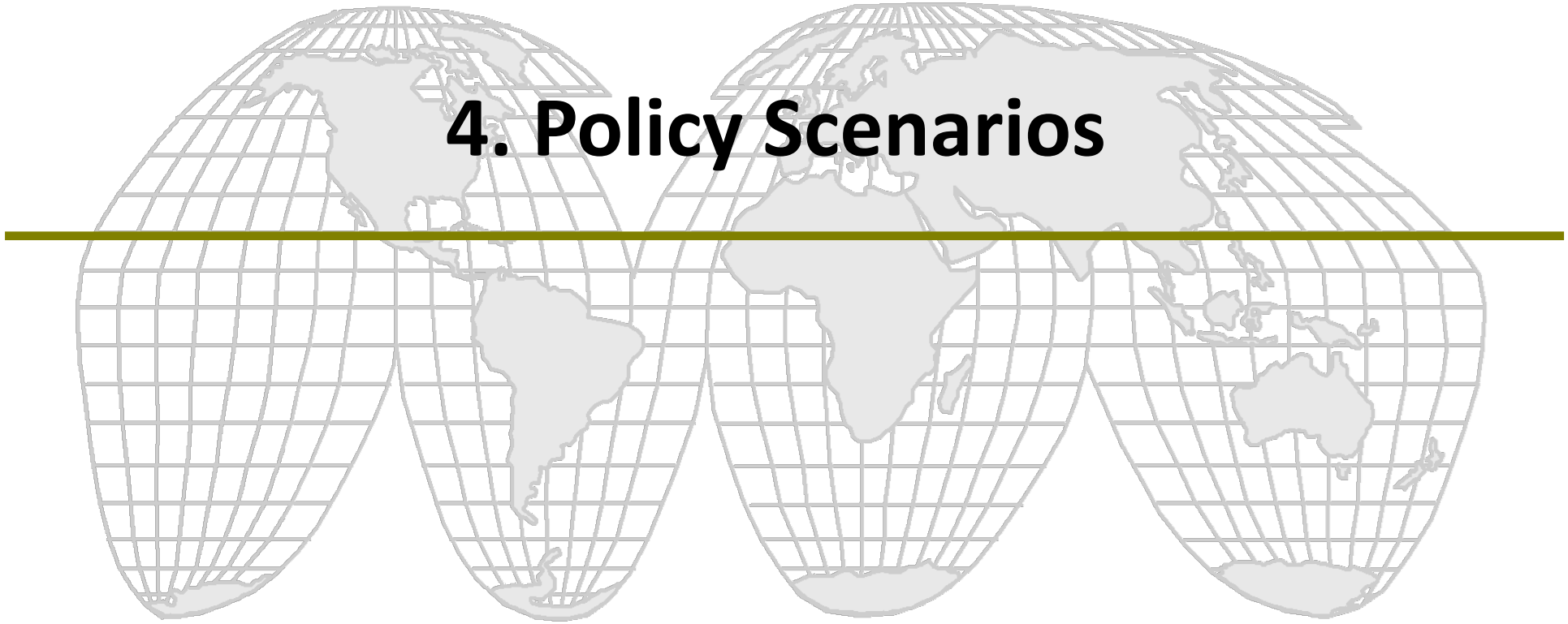
E3ME: Global Macro-econometric Model

- To analyze the short-, medium- and long-term impacts of **Energy-Environment-Economy (E3)** policies
- E3ME is a dynamic, computer-based, global macroeconomic model. The econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- The first version of the E3ME model was built by an international European team under a succession of European Commission research projects, which were completed in 1999
- E3ME's origins lie in **post-Keynesian economic theory**. **E3ME includes a realistic representation of the financial system and pays particular attention to unemployment and the labor market**
- Features
  - **Covers 59 global regions and 43 economic sectors in each region**, with additional detail in Europe
  - Its econometric specification addresses concerns about conventional macroeconomic models and provides a strong empirical basis for analysis. It can fully assess both short and long-term impacts and is not limited by many of the restrictive assumptions common to Computable General Equilibrium (CGE) models
  - **Integrated treatment of the world's economies, energy systems, emissions and material demands**. To capture two-way linkages and feedbacks between these components.
- Timeframe: **1970-2050** on an annual basis. Version 6

Future Technology Transformations (FTT)

- FTT is a group of sectoral models of technological change
  - power, road transport, household heating and steel
- **Dynamic selection and diffusion of innovations**
  - Lotka-Volterra equation



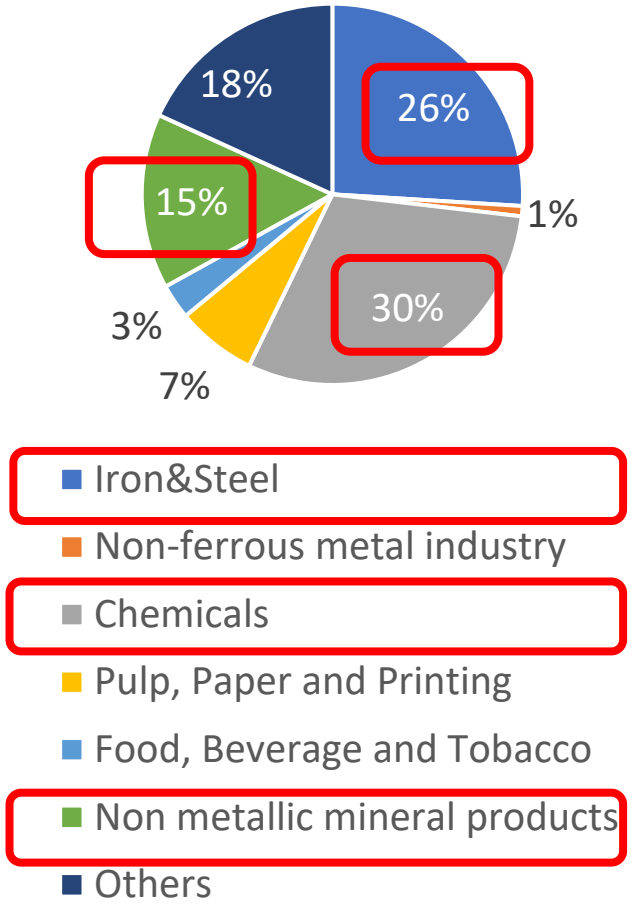


4. Policy Scenarios

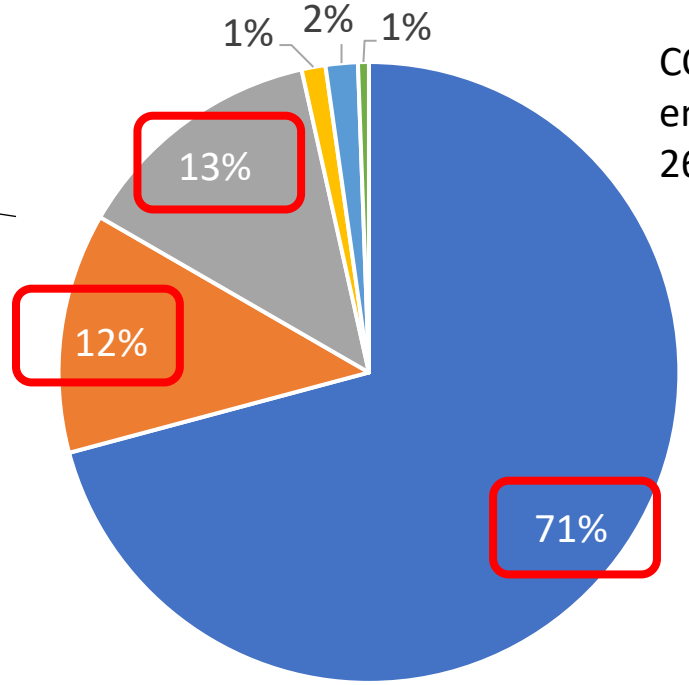
CO2 emissions by sectors in Taiwan

- To reach the 2050 net-zero target, need all possible and correct strategies to **induce transformation of all sectors**
- Total CO2 emissions: 283 MtCO2 (2018), 289 MtCO2 (2019)
  - Removal by LULUCF: 22 MtCO2 CO2
- Emissions by sectors in 2018
  - **Energy sector (94%** of total CO2 emissions**)**
    - **Energy Industry** (**71%** of CO2 emissions from energy sectors)
    - **Transportation** (**13%** of CO2 emissions from energy sectors)
    - **Manufacturing Industry and Construction** (**12%** of CO2 emissions from energy sectors)
      - **Chemicals**
      - **Iron & Steel**
      - **Non-metallic mineral products**

CO_2 emissions from Manufacturing Industry and Construction



Taiwan CO_2 emissions in 2018 from energy sector



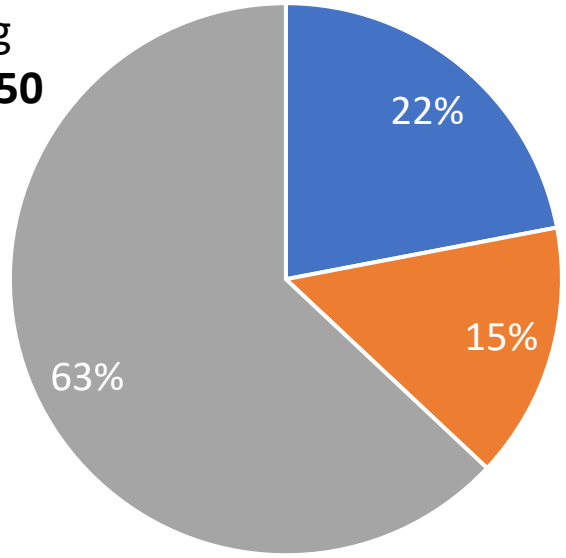
CO_2 emissions from the energy sector are 267 $MtCO_2$

Note: Total CO2 emissions in 2018 are 283 MtCO2, removal from LULUCF are 22 MtCO2

Four emission intensive industries in Taiwan

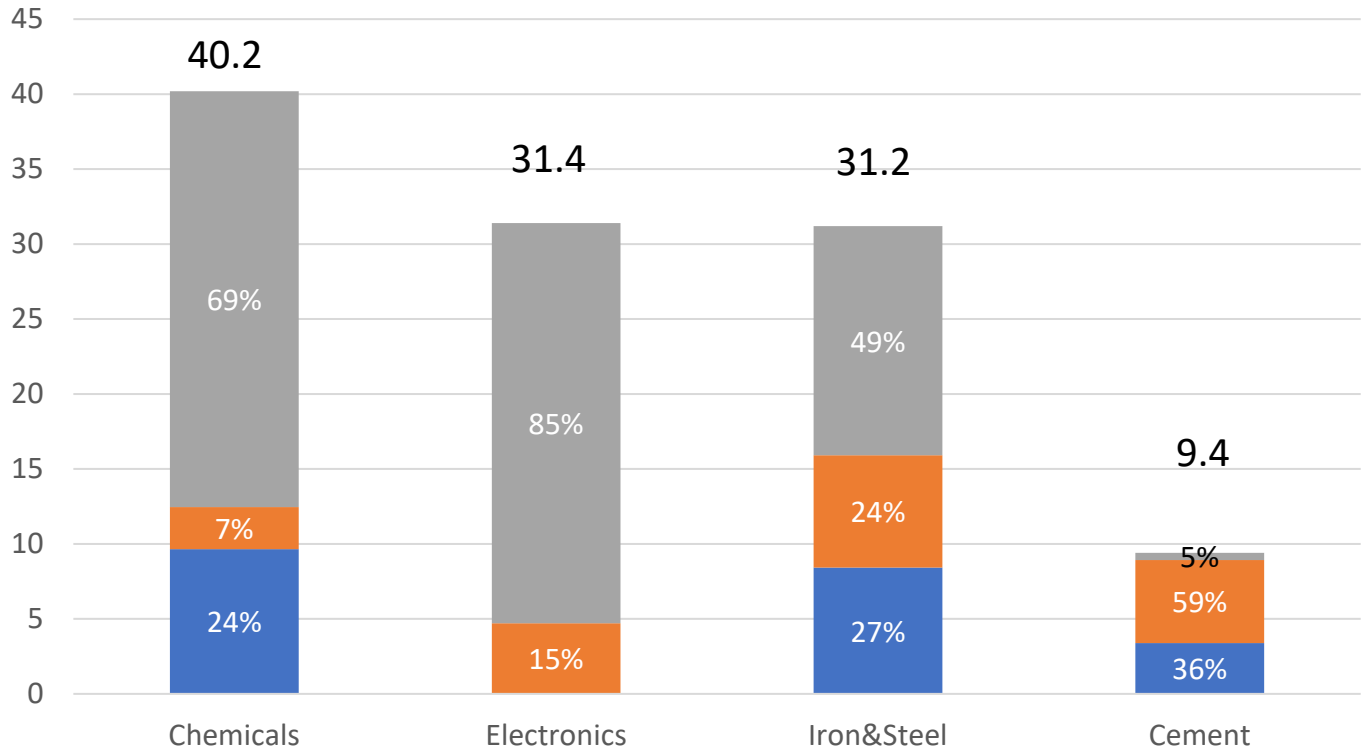
GHG Emissions from Manufacturing Industry in 2019

GHG emissions from manufacturing industry are **150 MtCO2e**



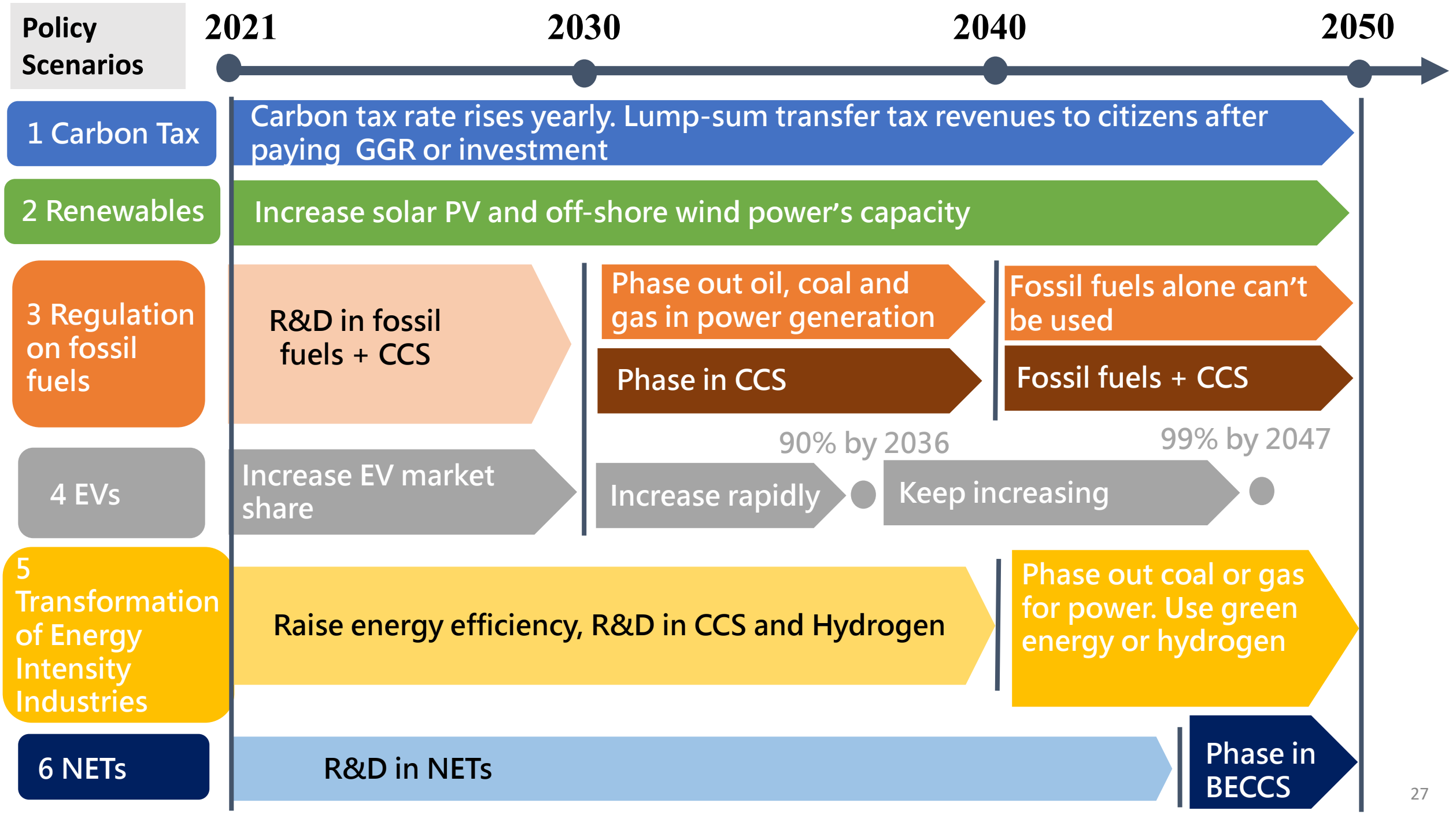
Emissions from fuel combustion
Emissions from industrial processes
Emissions from electricity consumption

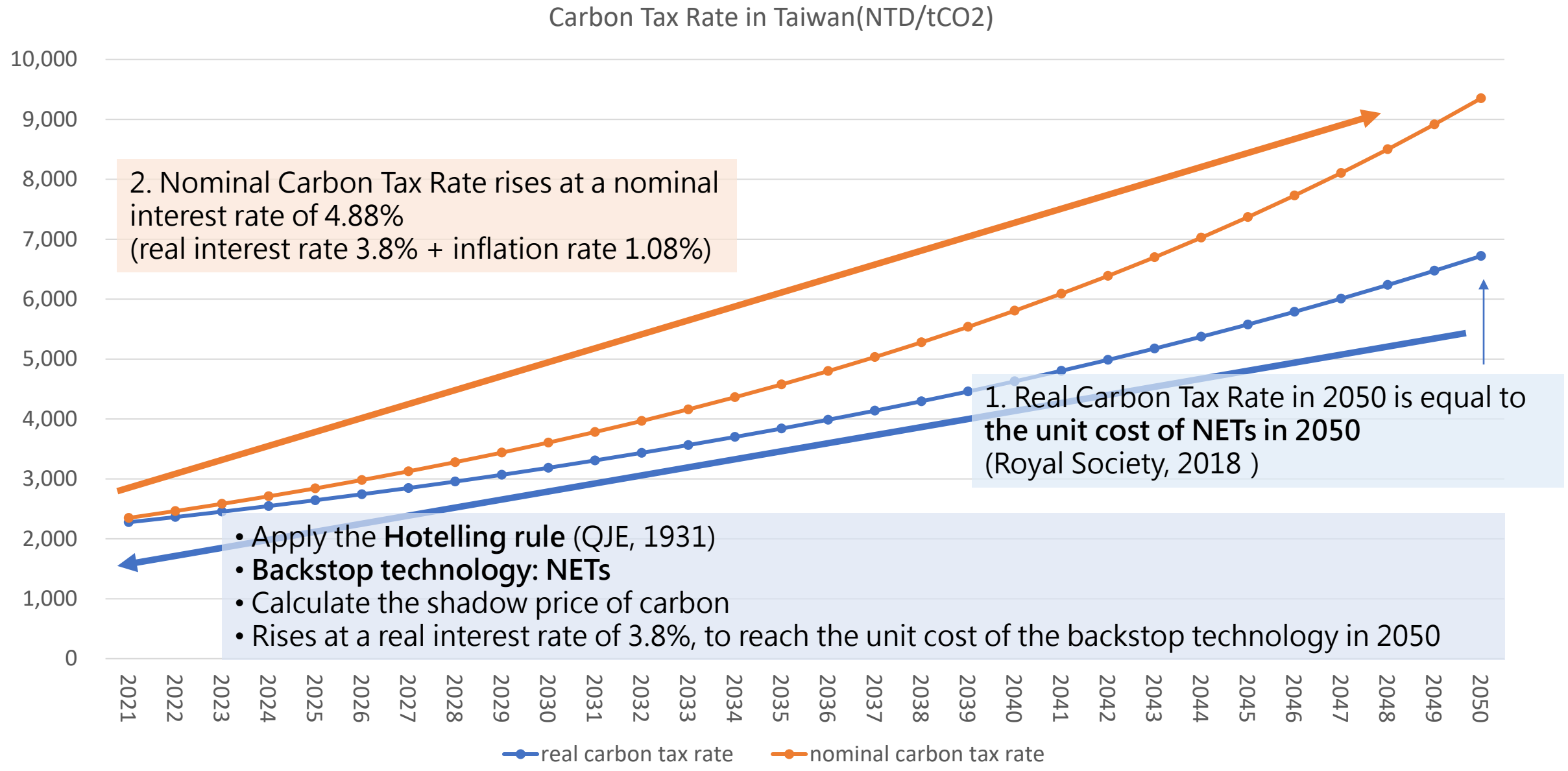
GHG Emissions in 2019



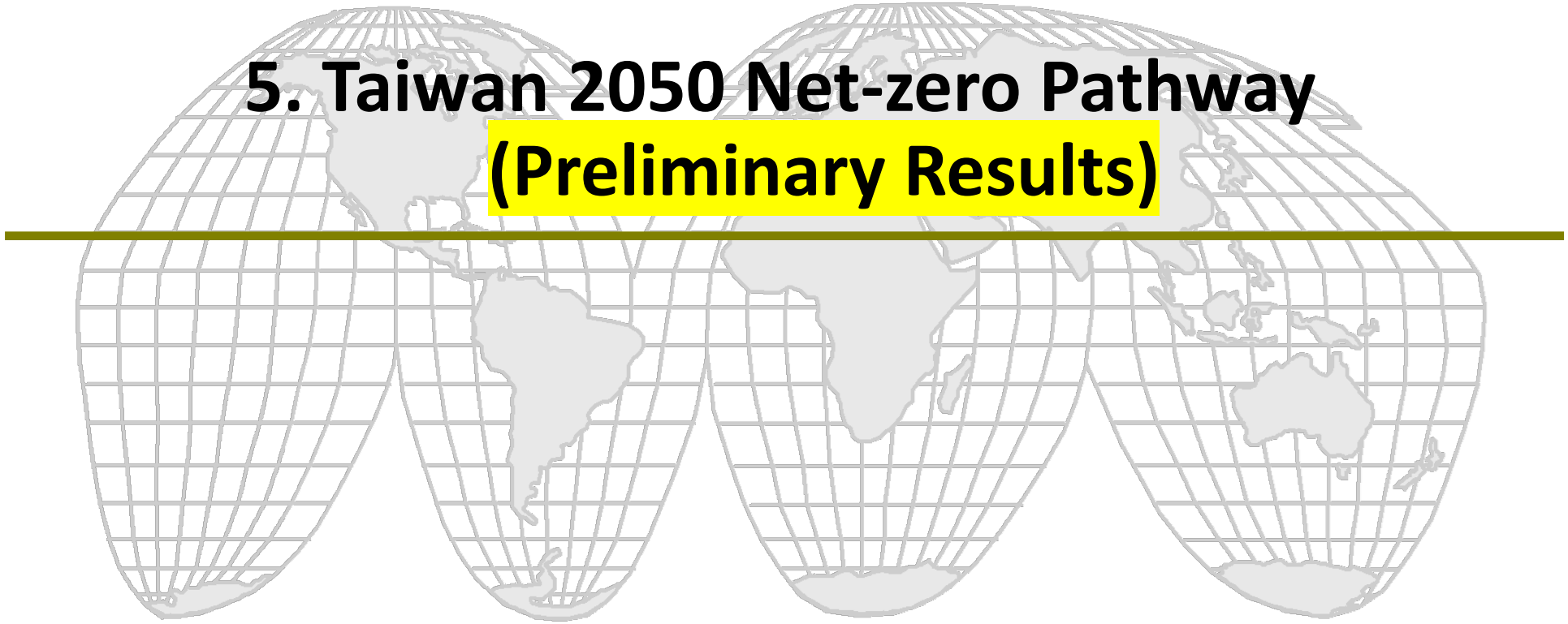
Emissions from fuel combustion
Emissions from industrial processes
Emissions from electricity consumption

Note: Total GHG emissions in 2019 are **289 MtCO2e**

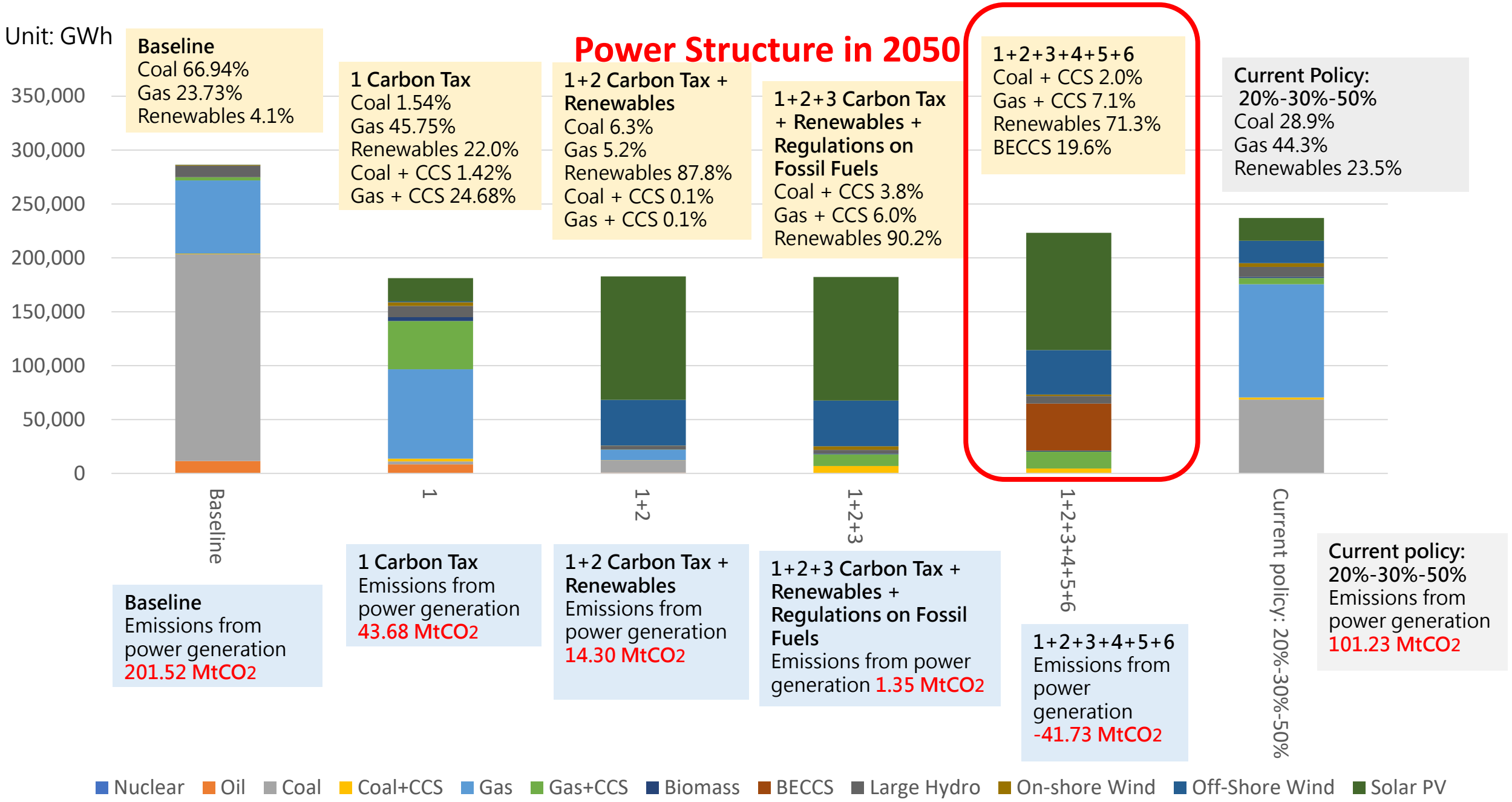

Policy Scenarios
2021
2030
2040
2050
1 Carbon Tax
Carbon tax rate rises yearly. Lump-sum transfer tax revenues to citizens after paying GGR or investment
2 Renewables
Increase solar PV and off-shore wind power's capacity
3 Regulation on fossil fuels
R&D in fossil fuels + CCS
Phase out oil, coal and gas in power generation
Phase in CCS
Fossil fuels alone can't be used
Fossil fuels + CCS
4 EVs
Increase EV market share
90% by 2036
Increase rapidly
99% by 2047
Keep increasing
5 Transformation of Energy Intensity Industries
Raise energy efficiency, R&D in CCS and Hydrogen
Phase out coal or gas for power. Use green energy or hydrogen
6 NETs
R&D in NETs
Phase in BECCS


Carbon Tax Rate in Taiwan(NTD/tCO2)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
real carbon tax rate
nominal carbon tax rate
2. Nominal Carbon Tax Rate rises at a nominal interest rate of 4.88%
(real interest rate 3.8% + inflation rate 1.08%)
1. Real Carbon Tax Rate in 2050 is equal to **the unit cost of NETs in 2050**
(Royal Society, 2018)
• Apply the **Hotelling rule** (QJE, 1931)
• **Backstop technology: NETs**
• Calculate the shadow price of carbon
• Rises at a real interest rate of 3.8%, to reach the unit cost of the backstop technology in 2050

5. Taiwan 2050 Net-zero Pathway
(Preliminary Results)



Power Structure in 2050



Baseline
Coal 66.94%
Gas 23.73%
Renewables 4.1%

Baseline
Emissions from power generation
201.52 MtCO2

1 Carbon Tax
Coal 1.54%
Gas 45.75%
Renewables 22.0%
Coal + CCS 1.42%
Gas + CCS 24.68%

1 Carbon Tax
Emissions from power generation
43.68 MtCO2

1+2 Carbon Tax + Renewables
Coal 6.3%
Gas 5.2%
Renewables 87.8%
Coal + CCS 0.1%
Gas + CCS 0.1%

1+2 Carbon Tax + Renewables
Emissions from power generation
14.30 MtCO2

1+2+3 Carbon Tax + Renewables + Regulations on Fossil Fuels
Coal + CCS 3.8%
Gas + CCS 6.0%
Renewables 90.2%

1+2+3 Carbon Tax + Renewables + Regulations on Fossil Fuels
Emissions from power generation 1.35 MtCO2

1+2+3+4+5+6
Coal + CCS 2.0%
Gas + CCS 7.1%
Renewables 71.3%
BECCS 19.6%

1+2+3+4+5+6
Emissions from power generation
-41.73 MtCO2

Current Policy: 20%-30%-50%
Coal 28.9%
Gas 44.3%
Renewables 23.5%

Current policy: 20%-30%-50%
Emissions from power generation
101.23 MtCO2

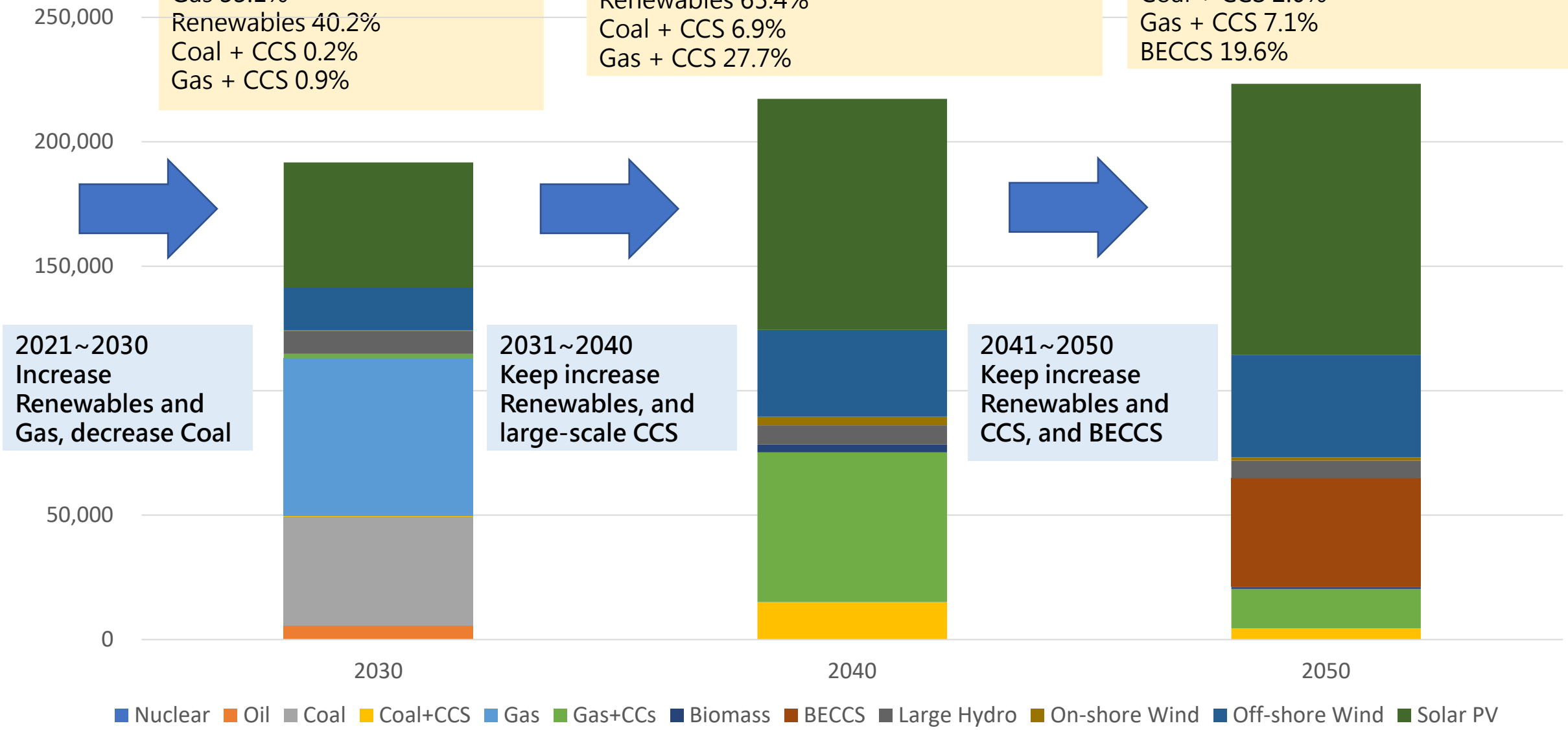
Note: Because EV and Transformation of energy intensive (EI) industries do not make much difference on power mix, we did not present power mix of those scenarios

Transformation of Power Structure

2030s
Mostly Gas and Renewables
Coal 22.8%
Gas 33.1%
Renewables 40.2%
Coal + CCS 0.2%
Gas + CCS 0.9%

2040s
Mostly Renewables, with some Gas + CCS
Renewables 65.4%
Coal + CCS 6.9%
Gas + CCS 27.7%

2050s
Mostly Renewables, with some BECCS
Renewables 71.3%
Coal + CCS 2.0%
Gas + CCS 7.1%
BECCS 19.6%

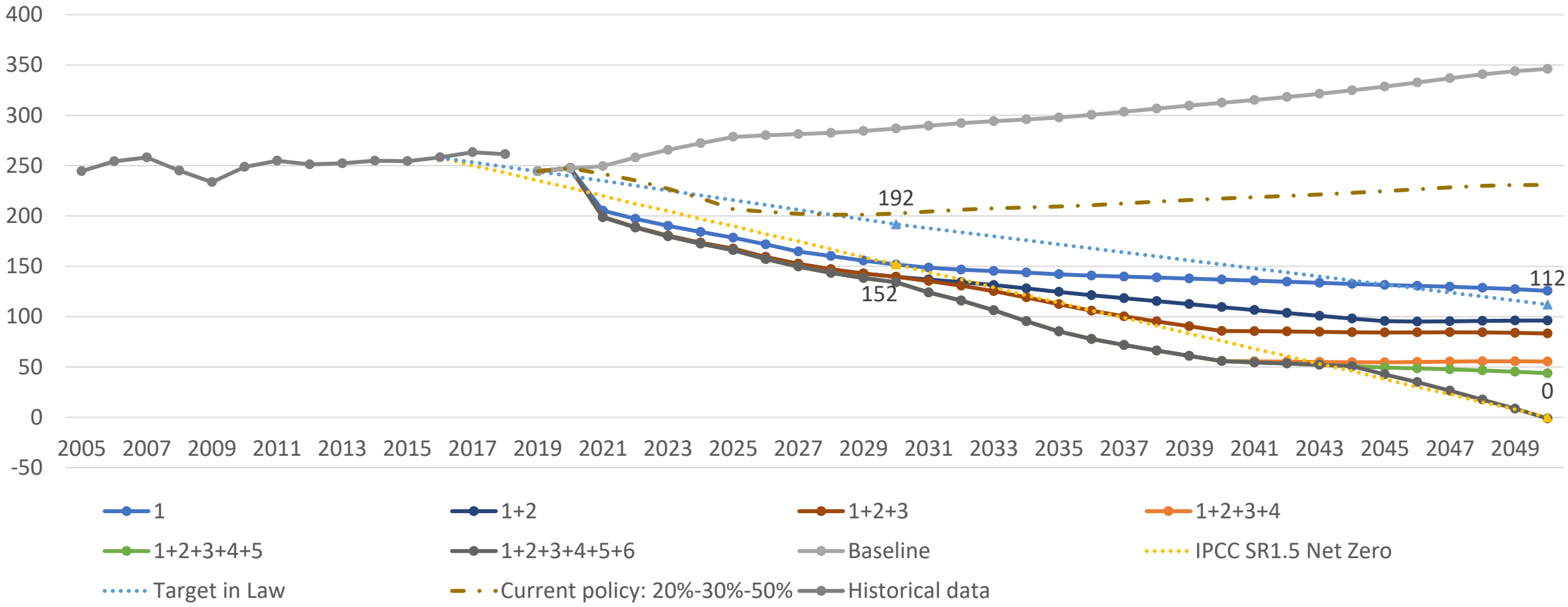


2021~2030
Increase Renewables and Gas, decrease Coal

2031~2040
Keep increase Renewables, and large-scale CCS

2041~2050
Keep increase Renewables and CCS, and BECCS

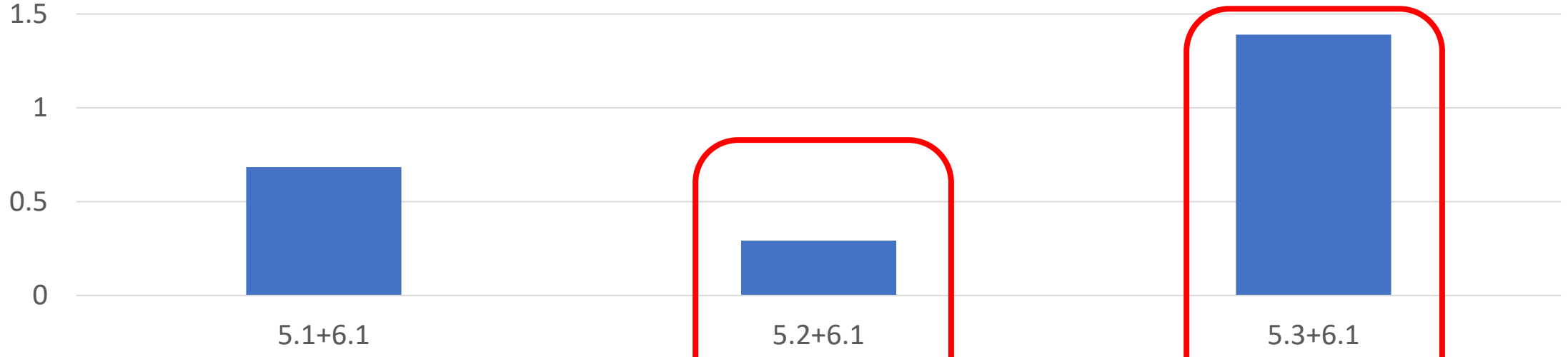
Net CO2 Emissions (mt CO2)



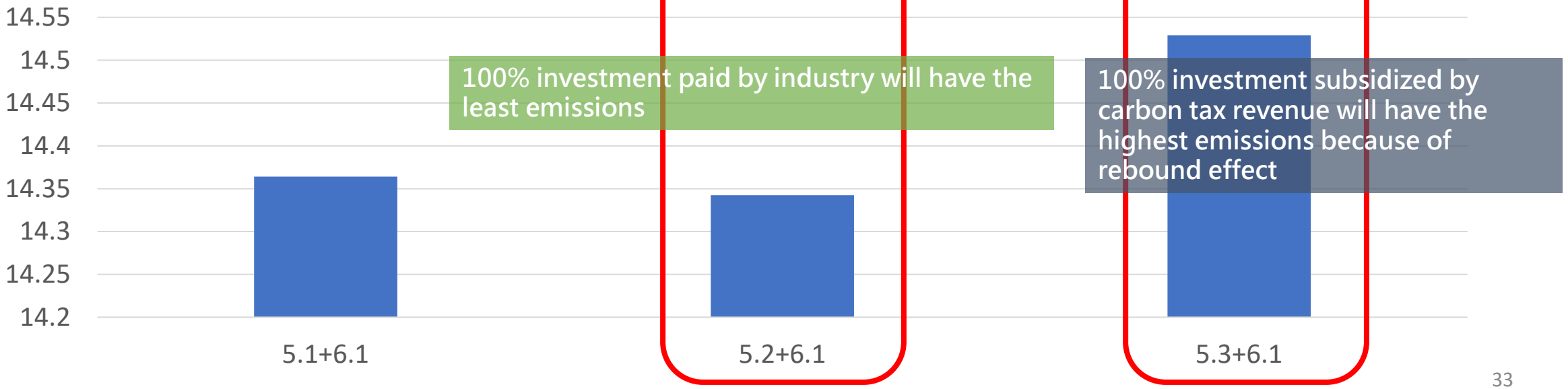
Note:

1. We use total CO_2 emissions minus CO_2 removals to get the historical data from 2005 to 2018
2. Net CO_2 emissions after 2019 are the difference between the total CO_2 emissions simulated by E3ME and 21 $MtCO_2$ from LULUCF
3. We only present the results of carbon tax with revenue recycling in this graph. The results without revenue recycling are a little bit smaller. Because the two curves almost coincide, thus we do not present in the graph.
4. We calculate the Target in Law using total GHG emissions reduction percentage as total CO_2 emission reduction percentage, and then subtract 21 $MtCO_2$ of LULUCF

CO2 emissions from Iron & Steel in 2050 (MtCO2)



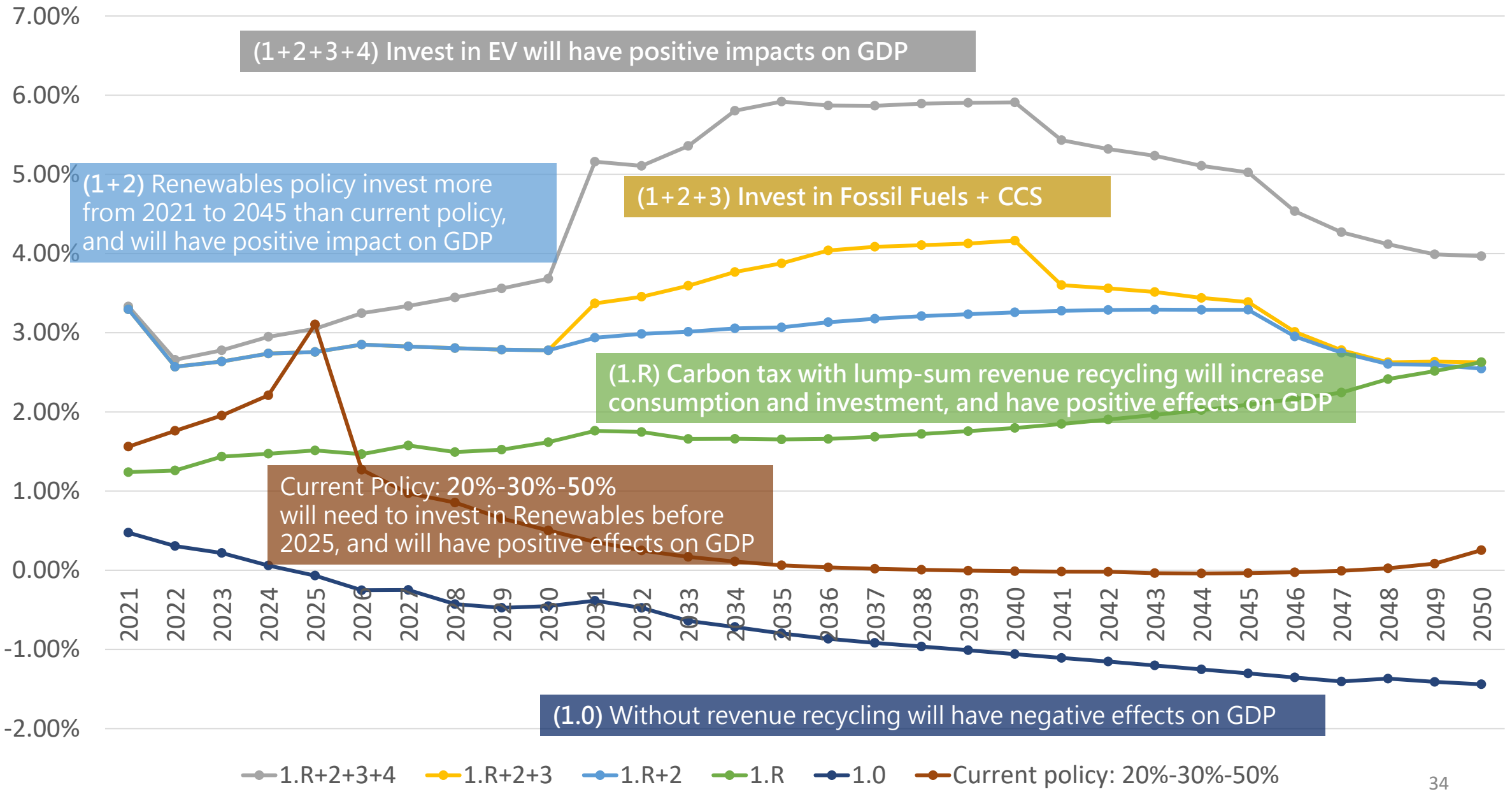
CO2 emissions from Chemicals in 2050 (MtCO2)



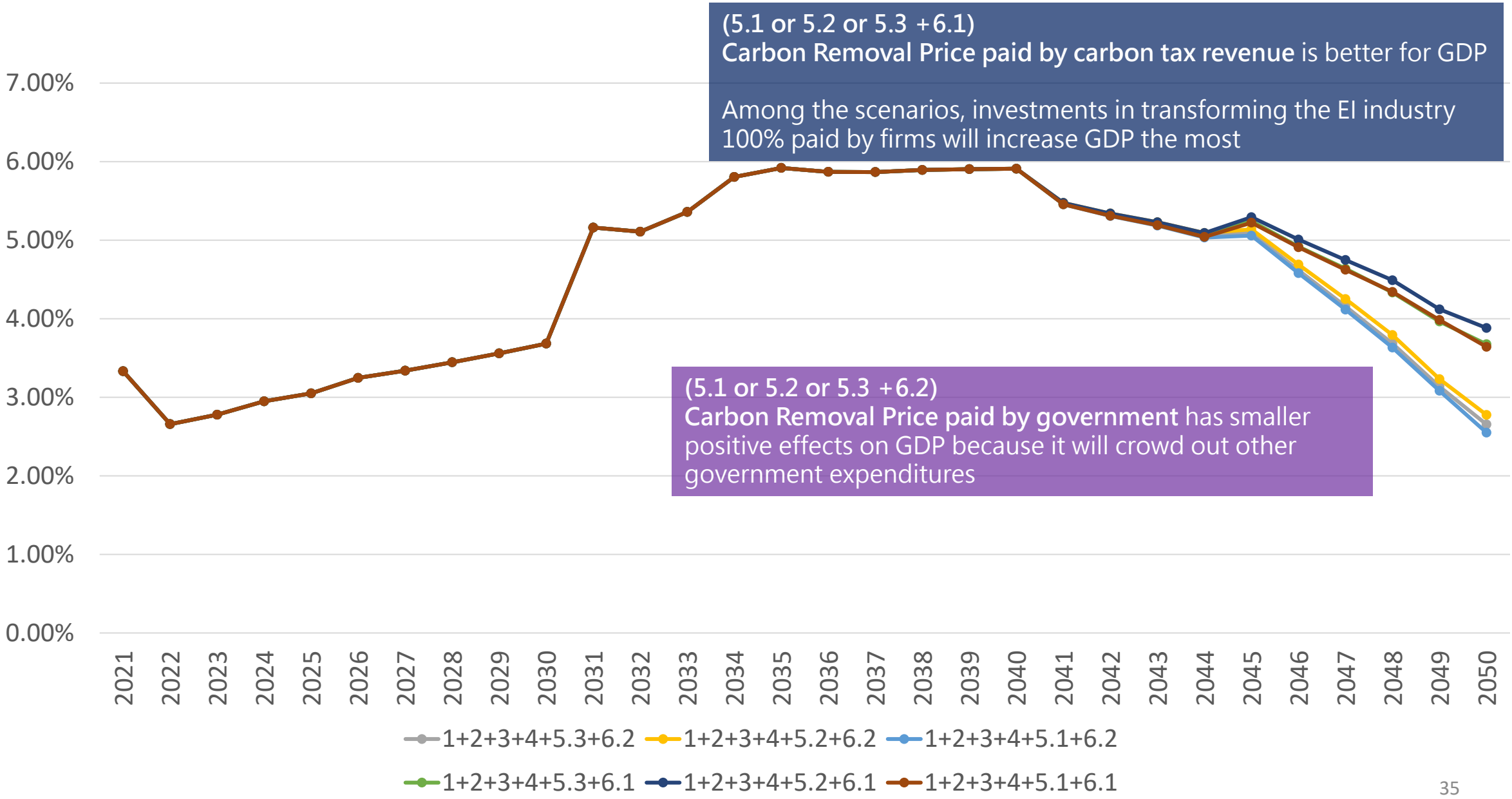
100% investment paid by industry will have the least emissions

100% investment subsidized by carbon tax revenue will have the highest emissions because of rebound effect

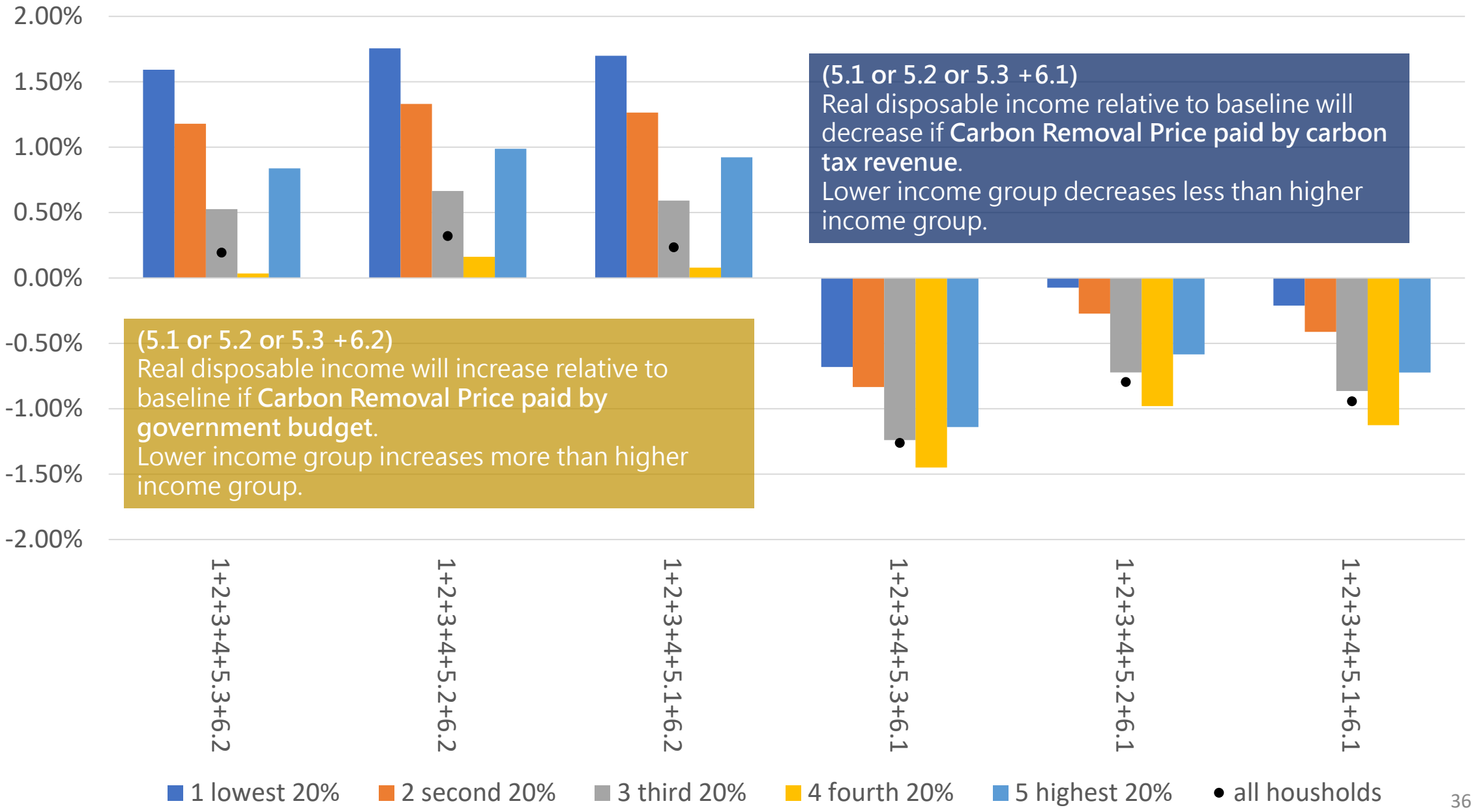
GDP relative to baseline (part.1)



GDP relative to baseline (part 2)

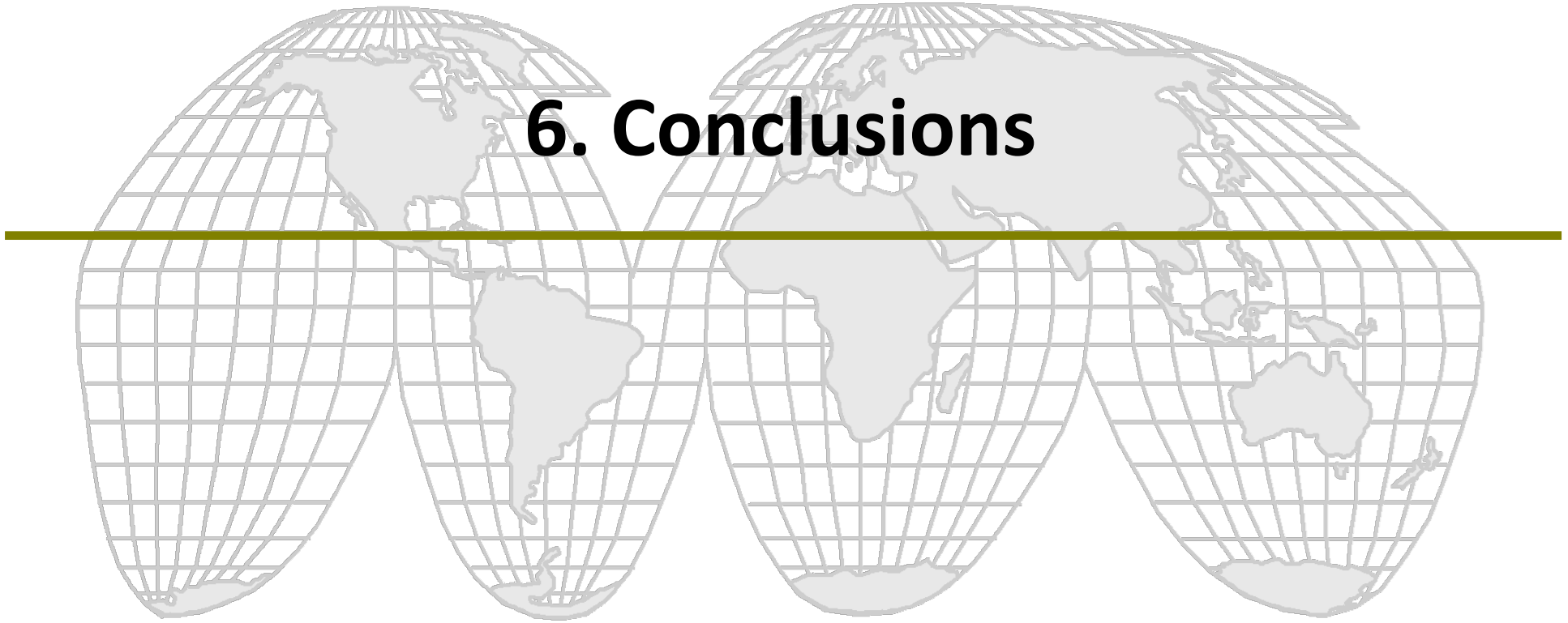


Income Redistribution (2050)



(5.1 or 5.2 or 5.3 +6.1)
Real disposable income relative to baseline will decrease if **Carbon Removal Price paid by carbon tax revenue**.
Lower income group decreases less than higher income group.

(5.1 or 5.2 or 5.3 +6.2)
Real disposable income will increase relative to baseline if **Carbon Removal Price paid by government budget**.
Lower income group increases more than higher income group.



6. Conclusions

Taiwan 2050 Net Zero Pathway

- Taiwan can meet the target of 2050 net-zero, and result in a win-win solution in terms of net-zero emissions, economic growth, and social equity
  - Need to adopt all possible and economically correct policies and strategies
    - Polluter pays principle
  - And avoid those unsound policies
    - Subsidize polluters

Thank you for your attention!