Adjusting net zero emissions pledges can improve equity and welfare under global emissions permit trade

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1.Background

Global net zero emissions pledges (NZEPs)

Countries	Regions
137	116
Cities	**Companies**
240	728

Out of 198 countries, 713 regions, 1,177 cities and 2,000 companies.

Source: https://zerotracker.net/

- ✓ Existing NZEPs are effectively emissions caps

Global carbon pricing Initiatives

68	Carbon pricing initiatives selected
46	National jurisdictions are covered by the initiatives selected
36	Subnational jurisdictions are covered by the initiatives selected

Source: https://carbonpricingdashboard.worldbank.org/

- ✓ Countries are willing to use carbon pricings

- ➢ Global emissions permit trade is more efficient than single-country carbon pricing
- ➢ Why is it not happening?

sources accessed: 19/07/2022

2. Literature review

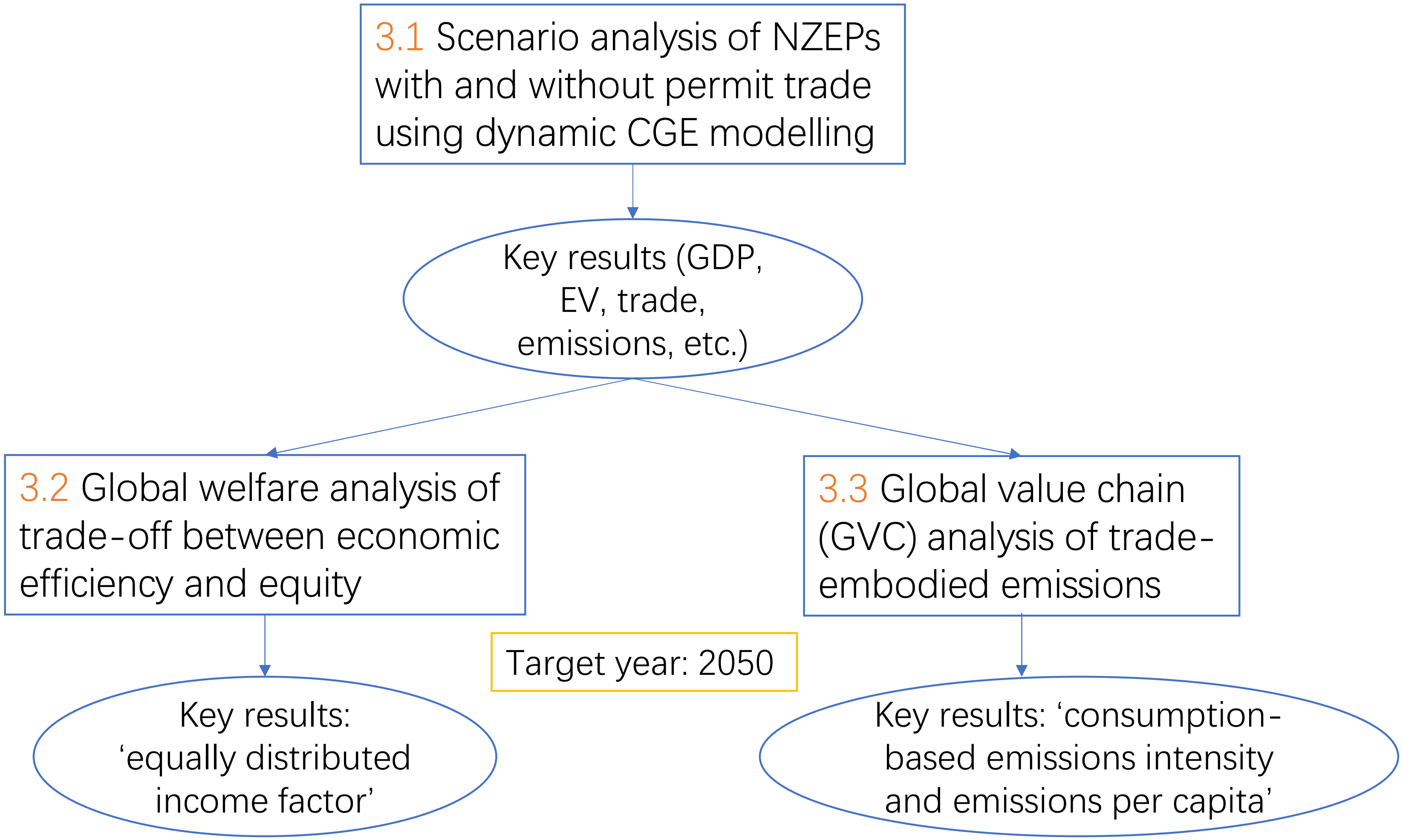
Key findings from existing studies – equity and welfare concerns

- International permit trade is more efficient than no-trade [***consensus*** (Flachsland et al., 2009)], but
  - Poorer regions tend to lose from permit trade, and this may increase inequality [***generally agree*** (Babiker et al., 2002, Fujimori et al 2016), with a few **exceptions** (Li and Duan, 2020)]
  - If a global welfare index weights both equity and efficiency, the increased inequality may harm global welfare despite higher efficiencies (Feng et al, 2018)
- Existing net-zero emissions pledges are production-based pledges (PBPs)
  - Consumption-based emissions (CBEs) account for trade embodied emissions [Meng, 2018]
  - Using CBEs, developed regions tend to be net emissions importers [Wen and Wang, 2020]

Contributions/policy questions

- What are the equity and efficiency implications of NZEPs with/without global permit trade
- Whether adjusting NZEPs can enhance global welfare under global permit trade
- What are implications to emissions intensity and emissions per capita using consumption-based emissions accountings

3. Methods


3.1 Scenario analysis of NZEPs with and without permit trade using dynamic CGE modelling
Key results (GDP, EV, trade, emissions, etc.)
3.2 Global welfare analysis of trade-off between economic efficiency and equity
3.3 Global value chain (GVC) analysis of trade-embodied emissions
Target year: 2050
Key results: ‘equally distributed income factor’
Key results: ‘consumption-based emissions intensity and emissions per capita’

3.1 CGE modelling

3.1.1 Database

From GTAP-power database (V10, base year 2014): region, sector and factor aggregations

Region (11)	Sector (24)	
1. United States of America (USA)	1. Agriculture (agr)	13. Other manufacturing (omf)
2. Central South America (CSA)	2. Coal (coa)	14. Power transmission distribution (tnd)
3. European Union (EUR)	3. Oil (oil)	15. Solar power (slp)
4. Africa (AFR)	4. Gas (gas)	16. Wind power (wdp)
5. Mid-East (MED)	5. Other mining (oxt)	17. Nuclear hydropower (nhp)
6. Russia (RUS)	6. Petroleum products (p_c)	18. Other power (otp)
7. China (CHN)	7. Chemical rubber plastic (crp)	19. Coal-fired power (cfp)
8. India (IND)	8. Non-metallic mineral (nmm)	20. Gas-fired power (gfp)
9. Japan (JPN)	9. Iorn steel (i_s)	21. Oil-fired power (ofp)
10. Southeast Asia (SEA)	10. Non-ferrous metal (nfm)	22. Construction (cns)
11. Rest of the World (ROW)	11. Electronics (ele)	23. Transport (tsp)
	12. Motor vehicles and parts (mvh)	24. Services (srv)
Factors (2)	1. Labour 2. Capital	

3.1.2. Modelling techniques

Basic model: **GTAP-E**, with the followings added

- ✓ MONASH-style dynamisms (Dixson and Rimmer, 2002)
- ✓ Fuel-factor nesting structure and CES parameters (Feng et al 2021a)
- ✓ Carbon capture and storage (CCS) modelling mechanisms (Feng et al 2021b)

3.1.3 (a) Scenarios overview

Name	Description	References
BAU	Business as usual	STEPS (IEA, 2021)
NZEP_NT	Net zero emissions pledges without global emissions permit trade	APS (IEA, 2021)
NZEP_TR	Net zero emissions pledges with global emissions permit trade	APS (IEA, 2021)
AEP	Adjusting emissions pledges with global emissions permit trade	Author's assumption

3.1.3 (b) BAU settings

	GDP (CAAGR%)			POP (CAAGR%)			Fossil Fuel (PJ)						Net CO_2 ($mtCO_2$)	
							coal		oil		gas			
	2021-25	2026-30	2031-50	2021-25	2026-30	2031-50	2020	2050	2020	2050	2020	2050	2020	2050
USA	3.3	2.2	1.9	0.6	0.5	0.4	9329	1361	29590	25041	30427	27936	4207	2938
CSA	3.1	2.7	2.6	0.8	0.7	0.4	1295	1437	9618	12093	5230	6714	1010	1220
EUR	3.0	2.0	1.3	0.0	-0.1	-0.2	5976	1393	17706	7879	13642	10119	2355	1085
AFR	4.0	4.2	4.2	2.3	2.2	1.9	4560	4657	7308	16164	5702	11085	1176	2000
MDE	2.9	2.7	3.1	1.1	0.9	0.6	129	449	12434	18036	19429	29249	1732	2480
RUS	2.6	2.1	1.1	-0.1	-0.2	-0.3	4911	4300	5873	5903	16631	18398	1536	1532
CHN	5.8	5.1	2.9	0.3	0.1	-0.2	87501	58019	27595	25494	11138	17414	10009	7385
IND	7.4	6.9	4.4	0.9	0.8	0.4	16323	20254	9021	17848	2290	7465	2140	3359
JPN	1.7	1.0	0.7	-0.4	-0.5	-0.7	4475	2106	6021	3569	3682	2208	961	483
SEA	4.9	4.9	3.2	0.9	0.8	0.4	7535	11451	9268	14869	5703	11633	1544	2511
ROW	3.8	3.5	2.7	1.2	1.1	0.8	13766	12296	36966	51355	25226	33331	4949	6214

	Power generation (TWH)													
	slp		wdp		nhp		otp		cfp		gfp		ofp	
	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050
USA	117	1300	340	1178	1116	877	92	210	858	42	1676	1558	38	7
CSA	22	346	78	392	719	1229	76	200	66	21	242	234	73	11
EUR	142	540	398	1363	1028	936	194	357	386	15	556	356	47	5
AFR	10	370	17	271	149	588	10	211	241	175	329	707	69	62
MDE	11	445	2	261	20	141	0	128	3	29	844	1583	308	188
RUS	1	19	1	99	405	490	3	99	167	127	471	653	8	1
CHN	270	3147	471	2632	1701	2901	146	667	4958	3338	230	545	11	1
IND	64	2108	68	916	220	679	55	179	1127	948	69	172	7	1
JPN	79	188	8	205	127	293	62	143	316	65	366	140	26	2
SEA	18	348	7	201	164	371	66	224	479	822	360	858	17	11
ROW	97	861	205	1281	1390	1950	112	415	867	628	1115	1639	112	20

Consulted Stated-policy Scenario (STEPS) in World Energy Outlook (IEA 2021)

BAU case reflects built-in ***changes*** to energy-using efficiency and productivity

The same ***changes*** are applied in the policy cases

3.1.3 (c) NZEP scenarios

	Net emissions commitments (mtCO_2)							CCS coverage rate (%)						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
USA	4207	3496	2786	1697	1068	678	426	0.00	0.04	0.08	0.51	0.84	0.92	0.97
CSA	1010	973	937	907	880	848	795	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUR	2354	1859	1363	854	463	240	123	0.00	0.00	0.00	0.08	0.54	0.98	0.99
AFR	1176	1270	1364	1408	1460	1595	1757	0.00	0.00	0.00	0.00	0.02	0.02	0.02
MDE	1732	1875	2019	2202	2312	2439	2477	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RUS	1536	1583	1630	1603	1582	1552	1512	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHN	10008	9912	9815	7809	5887	3621	1781	0.00	0.00	0.00	0.11	0.20	0.35	0.65
IND	2140	2603	3066	3383	3499	3449	3330	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JPN	961	801	641	452	291	155	87	0.00	0.04	0.08	0.51	0.84	0.92	0.97
SEA	1544	1818	2092	2314	2414	2494	2518	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ROW	4949	5021	5093	4971	4950	4960	4970	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WLD	31617	31211	30806	27600	24806	22031	19776							

Exogenously Given

Consulted Announced pledges Scenario (APS) in World Energy Outlook (IEA 2021)

Cumulative, 2021-50	USA	CSA	EUR	AFR	MDE	RUS	CHN	IND	JPN	SEA	ROW	WLD
BAU (btCO_2)	107	34	47	48	65	48	270	94	20	66	173	971
NZEP (btCO2)	58	27	29	43	65	47	211	94	14	66	150	805
NZEP-BAU (btCO2)	-48	-7	-18	-4	0	0	-59	0	-7	0	-23	-166
NZEP-BAU (rate)	-45%	-20%	-38%	-9%	0.1%	-1%	-22%	0.2%	-32%	0.4%	-13%	-17%

Endogenized carbon price

NZEP_NT: each region has own carbon price

NZEP_TR: global permit trade initiated while pledges are retained, a uniformed global carbon price

3.2 Global welfare

Equally distributed income (EDI) factor e_k

$$W_{NT\_TR}\left(\left(1+e_{NT\_TR}/100\right)\times C_{r,NZEP-NT}\right)=W_{NZEP-TR}\left(C_{r,NZEP-TR}\right)$$

- e_{NT_TR} : percentage change in per capita household consumption in no permit trade scenario needed to reach those in trade scenarios
- Positive ***e*** indicates improvement in welfare

Combined equity-adjusted welfare (Atkinson's welfare) of the world under scenario s

$$W_s=\frac{\sum_r\left(POP_r\times U_{r,s}\right)}{\sum_r POP_r}$$

- POP: population

Welfare of region r in scenario s as Ur,s,

$$U_{r,s}=\frac{1}{1-\varepsilon}C_{r,s}^{1-\varepsilon},\quad \varepsilon\neq 1$$

$$U_{r,s}=\ln\left(C_{r,s}\right),\quad \varepsilon=1$$

- ε is an aversion to inequality parameter,
- higher ε: more dislike for inequality,
- C: per capita real household consumption. → Obtained from CGE modelling results

3.3 Consumption-based emissions pledges (CBPs)

PBPs: production-based emissions pledges → existing pledges

CBPs: **consumption-based emissions pledges** → ‘real’ pledges

$$CBPs^s = PBPs^s - NCT^s$$

Following Meng et al. (2018), **Embodied Emissions Exports** (EEX) is emissions generated in production to satisfy foreign final demand.

$$EEX^{sr} = F^s \sum_{t \neq s,r}^{G} B^{st} Y^{tr}$$

- s is the producing country
- r is the destination country,
- F^s is the direct carbon emission intensity vector of s,
- B is the Leontief inverse matrix,
- Y is final demand vector.

Obtained from CGE modelling results

Embodied emissions export of s: $EEX^s = \sum_{r \neq s}^{G} EEX^{sr}$

Embodied emissions import of s: $EEI^s = \sum_{s \neq r}^{G} EEX^{rs}$

Net carbon transfer(export) of s: $NCT^s = EEX^s - EEI^s$ → Net emissions for others

4. Results

4.1 Macroeconomic results

4.2 Adjusting emissions pledges (AEP) scenario and results

4.3 Global welfare results

4.4 Consumption-based emissions pledges (CBP) results

4.1 Macroeconomic results

	Carbon price in 2050 (USD/tCO_2)		Net permit import (cumulative 2021-50, $btCO_2$)		Real GDP, cumulative (%) deviation from BAU, 2050		Equivalent variation, USD per capita, cumulative deviation from BAU (2050)		
	NT	TR	NT	TR	NT	TR	NT	TR	TR - NT
USA	653	46	0	28	-3.20	-0.54	-3098	-503	2594
CSA	140	46	0	4	-1.69	-0.70	-218	-90	128
EUR	2692	46	0	14	-4.78	-0.27	-2548	-117	2431
AFR	14	46	0	-3	-0.87	-1.14	-8	-25	-17
MDE	5	46	0	-11	-2.94	-1.60	-239	-260	-20
RUS	7	46	0	-5	-2.58	-3.54	-430	-422	8
CHN	190	46	0	-3	-1.51	-0.59	-125	-37	88
IND	1	46	0	-13	-0.09	-1.91	59	-14	-73
JPN	297	46	0	1	-1.49	-0.34	-1155	-140	1015
SEA	1	46	0	-18	-0.23	-1.14	36	-3	-39
ROW	44	46	0	6	-1.05	-0.93	-96	-114	-18
WLD		46	0	0	-2.06	-0.77	-295	-78	217

	Carbon price		Permit trade		GDP and EV		
	Developed	**Least developed**	**Developed**	**Least developed**	**Developed**	**Least developed**	**World**
No permit trade (NT)	Very high	Low			Large loss	Small loss/gain	Bigger loss
Permit trade (TR)	same	same	Net importer	Net exporter	Smaller loss	Bigger loss	Smaller loss
NoTrd to Trade ()	Fall	Rise			Better off	Worse off	Better off

4.2 (a) Adjusting emissions pledges (AEP) scenario setting

Cumulative, 2021-50	USA	CSA	EUR	AFR	MDE	RUS	CHN	IND	JPN	SEA	ROW	WLD
AEP (btCO2)	-2	27	-46	96	65	47	211	138	-6	87	188	805
AEP-BAU (btCO2)	-109	-7	-93	48	0	0	-59	44	-26	21	15	-166
AEP-BAU (rate)	-102%	-20%	-197%	101%	0.1%	-1%	-22%	46%	-128%	32%	9%	-17%
AEP-NZEP (btCO2)	-61	0	-75	52	0	0	0	44	-20	21	38	0

Moving from NZEP to AEP:

- Redistributing a total of 155 billion tonnes of CO_2 ($btCO_2$) mitigation pledges from three more developed regions (USA, EUR, JPN) to four less developed regions (AFR, IND, SEA and ROW) throughout the 30 years (2021-50);
- Total world emissions levels are the same;
- The 155 btCO2 are redistributed proportional to countries' population.
- World carbon price between NZEP_TR and AEP are the same

4.2 (b) AEP macroeconomic results

Cumulative deviations from BAU by 2050								
	Permit trade revenues (billion USD)		EV (billion USD)		EV differences (billion USD)		Per capita EV differences (USD)	
	NZEP_TR	AEP	NZEP_TR	AEP	TR-NT	AEP-NT	TR-NT	AEP-NT
USA	-60	-238	-190	-472	981	700	2594	1850
CSA	-9	-9	-55	-50	78	83	128	136
EUR	-29	-248	-49	-361	1032	720	2431	1697
AFR	15	169	-59	196	-40	216	-17	90
MDE	38	38	-81	-71	-6	4	-20	12
RUS	16	16	-57	-51	1	7	8	52
CHN	-74	-74	-51	-31	122	141	88	103
IND	52	179	-24	174	-120	78	-73	47
JPN	-4	-62	-15	-88	107	33	1015	315
SEA	52	114	-3	83	-31	55	-39	69
ROW	4	115	-172	12	-27	156	-18	103

Pareto Improvement

From NZEP_TR to AEP

- USA, EUR, and JPN spend much more on permit import
- AFR, IND, SEA and ROW earn much more on permit export

Compared to NZEP_NT

EV/EV per capita	**USA, EUR, JPN**	**AFR, IND, SEA, ROW**
NZEP_TR	Rise more	Fall
AEP	Rise less	Rise

4.3 Global welfare

Values of e (equally distributed income)							
	From NZEP_NT to NZEP_TR (e_{NT_TR})						
ε	2021	2025	2030	2035	2040	2045	2050
0	0.0	0.1	0.2	0.4	0.6	0.8	1.0
1	0.0	0.0	0.0	0.0	0.1	0.1	0.1
2	0.0	0.0	-0.1	-0.1	-0.1	-0.2	-0.7
	From NZEP_NT to AEP (e_{NT_AP})						
ε	2021	2025	2030	2035	2040	2045	2050
0	0.0	0.1	0.2	0.4	0.6	0.9	1.1
1	0.0	0.0	0.1	0.2	0.4	0.7	1.0
2	0.0	0.0	0.1	0.3	0.6	1.0	1.4

From No-trade to **Trade**: global welfare **worsens** as aversion to inequality increases

From No-trade to **AEP**: global welfare **improves** as aversion to inequality increases

4.4(a) emissions intensity

	Cumulative, CO_2/Y 2021-50 (tCO_2/USD)								Change CO_2/Y 2021-50							
	PBP				CBP				PBP				CBP			
	BAU	NZEP_NT	NZEP_TR	AEP	BAU	NZEP_NT	NZEP_TR	AEP	BAU	NZEP_NT	NZEP_TR	AEP	BAU	NZEP_NT	NZEP_TR	AEP
USA	0.12	0.07	0.07	0.00	0.16	0.11	0.10	0.03	-68%	-95%	-95%	-143%	-58%	-80%	-87%	-127%
CSA	0.14	0.11	0.11	0.11	0.17	0.14	0.13	0.13	-56%	-70%	-71%	-71%	-54%	-68%	-71%	-71%
EUR	0.08	0.05	0.05	-0.07	0.12	0.10	0.08	-0.04	-72%	-96%	-97%	-240%	-62%	-78%	-85%	-189%
AFR	0.27	0.25	0.25	0.54	0.28	0.24	0.25	0.54	-60%	-66%	-65%	-11%	-64%	-72%	-70%	-17%
MDE	0.55	0.55	0.55	0.55	0.53	0.50	0.52	0.52	-52%	-52%	-51%	-52%	-61%	-66%	-61%	-61%
RUS	0.73	0.74	0.74	0.74	0.52	0.50	0.53	0.53	-26%	-24%	-23%	-24%	-44%	-50%	-39%	-40%
CHN	0.31	0.24	0.24	0.24	0.27	0.21	0.21	0.21	-76%	-94%	-94%	-94%	-74%	-91%	-93%	-93%
IND	0.43	0.42	0.43	0.62	0.39	0.38	0.40	0.59	-67%	-68%	-67%	-44%	-70%	-71%	-67%	-41%
JPN	0.15	0.10	0.10	-0.04	0.18	0.14	0.14	-0.01	-60%	-92%	-92%	-211%	-59%	-85%	-87%	-186%
SEA	0.36	0.35	0.36	0.47	0.30	0.27	0.32	0.43	-57%	-58%	-58%	-38%	-67%	-74%	-60%	-38%
ROW	0.23	0.20	0.20	0.25	0.24	0.20	0.20	0.25	-57%	-66%	-65%	-50%	-56%	-66%	-66%	-50%
WLD	0.23	0.19	0.19	0.19	0.23	0.19	0.19	0.19	-61%	-75%	-75%	-75%	-61%	-75%	-75%	-75%

PBP: production-based emissions pledges

CBP: consumption-based emissions pledges

CO_2/Y		BAU	NZEP	AEP
PBP	Absolute	IND>CHN>USA	IND>CHN>USA	IND>CHN>USA
CBP	Absolute	Gaps are smaller	Gaps are smaller	Gaps are smaller
PBP	%change	CHN fall most	USA,CHN fall most	USA fall most
CBP	%change	Gaps are larger	CHN fall most	USA fall most

Richer countries always have lower CO_2/Y, but CBPs show gaps are not as big

USA should move towards AEP

4.4(b) emissions per capita

	Cumulative, CO_2/Pop 2021-50 (tCO_2/person)								Change CO_2/Pop 2021-50 (%)							
	PBP				CBP				PBP				CBP			
	BAU	NZEP_ NT	NZEP TR	AEP	BAU	NZEP _NT	NZEP _TR	AEP	BAU	NZEP _NT	NZEP _TR	AEP	BAU	NZEP _NT	NZEP _TR	AEP
USA	9.65	5.28	5.28	-0.22	12.72	8.43	7.67	2.13	-39%	-91%	-91%	-178%	-21%	-65%	-76%	-149%
CSA	1.88	1.51	1.51	1.51	2.21	1.81	1.74	1.74	5%	-31%	-31%	-31%	9%	-26%	-32%	-32%
EUR	3.46	2.13	2.13	-3.35	5.47	4.30	3.85	-1.66	-51%	-94%	-94%	-336%	-34%	-65%	-75%	-250%
AFR	0.83	0.76	0.76	1.67	0.84	0.74	0.75	1.67	-4%	-17%	-17%	123%	-13%	-31%	-27%	108%
MDE	7.32	7.33	7.33	7.33	7.06	6.64	6.92	6.91	16%	15%	15%	15%	-6%	-19%	-8%	-8%
RUS	11.03	10.96	10.96	10.96	7.87	7.35	7.84	7.84	6%	5%	5%	5%	-20%	-31%	-17%	-17%
CHN	6.14	4.79	4.79	4.79	5.22	4.11	4.13	4.12	-25%	-82%	-82%	-82%	-20%	-73%	-79%	-79%
IND	1.98	1.98	1.98	2.89	1.78	1.77	1.84	2.77	28%	27%	27%	124%	18%	15%	29%	139%
JPN	5.67	3.86	3.86	-1.61	6.91	5.26	5.18	-0.32	-41%	-89%	-89%	-259%	-40%	-79%	-80%	-223%
SEA	2.87	2.88	2.88	3.79	2.40	2.22	2.60	3.52	34%	34%	34%	100%	3%	-16%	26%	97%
ROW	4.16	3.61	3.61	4.53	4.27	3.69	3.64	4.55	-5%	-23%	-23%	13%	-3%	-23%	-25%	11%
WLD	3.56	2.95	2.95	2.95	3.56	2.95	2.95	2.95	-21%	-49%	-49%	-49%	-21%	-49%	-49%	-49%

PBP: production-based emissions pledges

CBP: consumption-based emissions pledges

CO_2/pop		BAU	NZEP	AEP
PBP	Absolute	USA>CHN>IND	USA>CHN>IND	CHN>IND>USA
CBP	Absolute	Gaps are larger	Gaps are larger	Gaps are smaller
PBP	%change	USA fall most	USA fall most	USA fall most
CBP	%change	USA, CHN fall most	CHN fall most	USA fall most

- USA has the higher CO2/pop but fall less
- USA should move towards AEP

5. Final remarks

Global permit trade enhances global abatement efficiency

With global permit trade

- Under existing NZEPs, moving from no-trade to trade
  - Developed regions would yield most of the benefits
  - Some less developed regions would be worse off
  - Global welfare may fall
  - Using consumption-based emissions pledges (CBPs), China's emissions intensity and emissions per capita would fall more than USA
- Shifting more mitigation responsibilities to the more developed regions
  - It is possible to improve global welfare
  - It is possible to lead to Pareto Improvement
  - Using CBPs, it is possible for USA to achieve more reduction in emissions intensity and emissions per capita than China

THE END

Thank you very much for your time and attention!

Comments and questions are appreciated!

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4.1 Energy results: primary energy

	Primary energy consumption (Exajoule, 10^{18} joule, EJ), cumulative 2021-50														
	BAU					NZEP_NT					NZEP_TR				
	coal	oil	gas	NFF	Total	coal	oil	gas	NFF	Total	coal	oil	gas	NFF	Total
USA	124	858	905	595	2482	100	692	610	730	2131	119	839	847	609	2414
CSA	39	340	178	257	813	25	307	148	286	765	33	331	168	265	798
EUR	74	369	367	496	1307	42	308	197	578	1125	69	365	347	501	1282
AFR	139	346	248	98	831	125	344	243	103	815	116	329	236	106	786
MDE	10	470	748	155	1383	10	486	754	159	1409	8	447	698	169	1323
RUS	139	189	550	106	984	134	185	552	106	978	109	182	517	106	914
CHN	2240	856	470	1279	4845	1851	825	399	1358	4434	1851	835	395	1334	4416
IND	627	453	167	359	1607	626	457	167	358	1608	521	439	159	371	1489
JPN	94	145	81	99	419	82	139	72	101	394	89	144	78	100	411
SEA	312	403	265	56	1036	324	413	268	56	1061	214	394	265	57	929
ROW	384	1414	878	609	3284	312	1329	820	645	3106	335	1359	836	634	3164
WLD	4182	5843	4856	4111	18991	3631	5486	4229	4480	17826	3465	5664	4546	4252	17927

From No-trade
to Trade

Developed countries' total energy consumption increase, fossil fuel energy consumption increase, non-fossil fuel energy fall

Least developed countries' total energy consumption fall, fossil fuel energy consumption fall, non-fossil fuel energy increase

4.3 Trade results: trade at the sector level

2050 cumulative deviations of sectors' trade from no-trade to trade

	USA	CSA	EUR	AFR	MDE	RUS	CHN	IND	JPN	SEA	ROW
agr	-1.9	1.1	-0.5	5.8	2.5	8.1	-1.6	11.1	-0.9	7.4	2.9
oxt	13.0	3.9	1.1	-0.7	-2.3	-2.0	-2.2	1.1	4.5	1.7	1.5
crp	-7.1	7.7	4.2	1.7	-0.7	-17.9	6.4	1.3	1.4	3.1	4.0
nmm	6.7	16.1	27.9	-1.8	-0.5	-26.5	16.0	-28.1	15.4	-28.2	-0.4
i_s	3.7	19.9	21.7	-13.6	-8.2	-27.2	7.4	-45.8	3.0	-16.8	-1.3
nfm	-2.6	9.8	19.4	-16.9	-26.5	-36.7	8.5	-27.0	-8.6	-25.7	-8.7
ele	-5.1	5.1	-1.8	1.5	-10.8	-4.7	2.8	5.5	0.7	3.0	2.2
mvh	-4.5	3.4	1.8	4.5	-1.2	-6.4	5.3	2.4	0.4	2.7	3.8
omf	-9.0	3.0	2.6	3.8	-5.0	-1.4	6.4	1.5	2.4	0.5	1.4
cns	-6.8	2.8	-3.6	7.2	6.1	9.6	5.4	13.0	1.1	5.8	5.3
tsp	41.0	-6.6	27.6	-31.9	-32.1	-29.3	-14.4	-24.4	-6.6	-21.8	-14.1
srv	-6.3	2.9	-3.9	7.5	1.1	11.4	4.0	11.0	0.7	7.3	6.0

(a) export

	USA	CSA	EUR	AFR	MDE	RUS	CHN	IND	JPN	SEA	ROW
agr	4.6	2.6	5.2	-1.7	-2.4	-3.1	1.9	-5.9	3.4	-2.2	-0.3
oxt	-3.2	3.8	8.4	-3.0	-1.5	-10.7	3.3	-5.5	1.0	-7.9	-0.3
crp	6.0	0.6	4.6	-0.4	-0.2	0.8	1.0	-0.9	2.9	-0.2	0.6
nmm	0.0	-2.3	-1.4	1.6	-1.0	12.8	-6.9	25.3	1.2	13.4	1.1
i_s	-0.2	-3.5	3.1	1.7	0.1	6.7	0.3	29.6	1.8	1.8	1.7
nfm	2.0	2.1	5.2	0.3	-2.4	5.9	0.5	-1.6	3.0	0.8	-0.1
ele	4.8	1.4	4.5	-1.7	0.8	-3.0	1.4	-2.7	2.4	0.7	0.6
mvh	5.7	1.7	4.6	-1.9	-1.9	-1.8	-1.0	-2.5	2.5	-1.2	0.2
omf	7.4	2.2	5.4	-1.0	0.1	-2.1	-0.8	-1.4	2.6	-0.7	0.6
cns	8.8	1.9	8.7	-4.7	-3.9	-9.3	-1.0	-9.1	2.9	-4.9	-1.8
tsp	-25.1	9.8	-4.0	13.2	8.3	10.8	10.6	14.4	12.8	11.7	12.9
srv	6.5	0.4	7.6	-4.5	-3.9	-7.5	-0.8	-7.6	0.8	-4.8	-2.6

(b) import

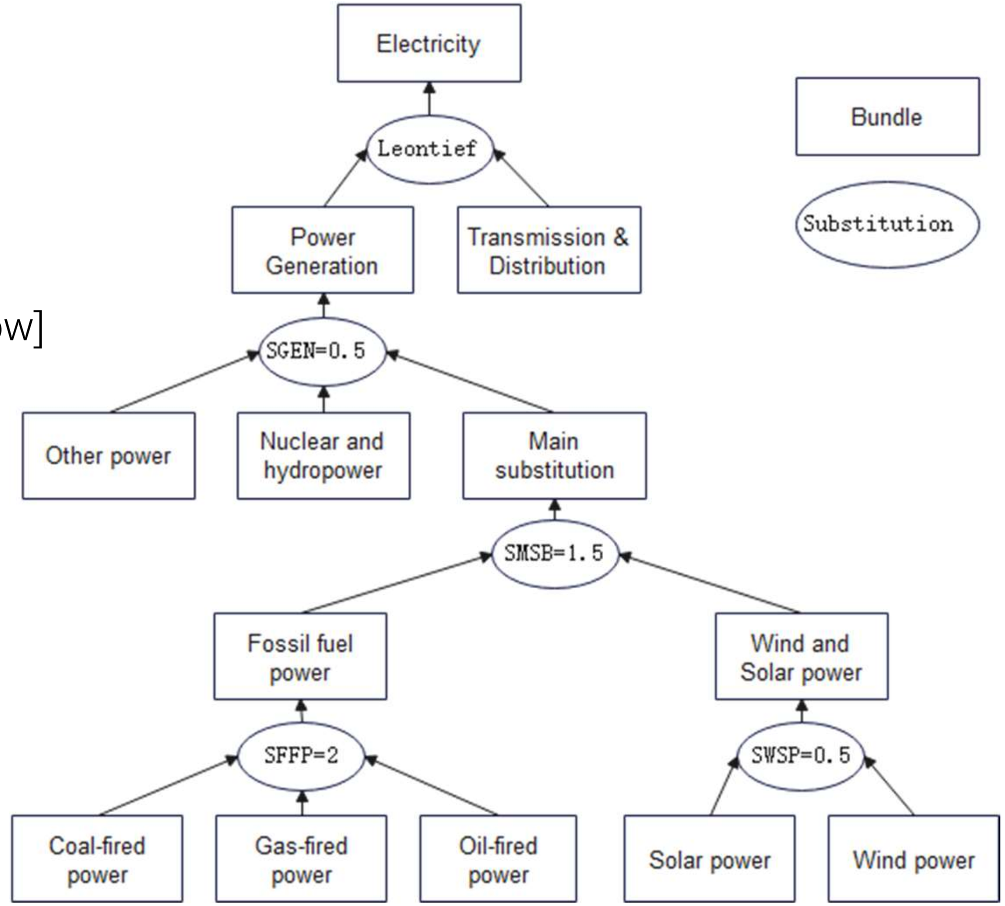
3.1.2. Modelling techniques

Basic model: **GTAP-E**, with the followings added

- ✓ GTAP-power database (v.10)
- ✓ MONASH-style dynamisms (Dixson and Rimmer, 2002)
- ✓ Fuel-factor nesting structure and CES parameters [right]
- ✓ Carbon capture and storage (CCS) modelling mechanisms [below]

$$NetCO_2(f,i) = CO_2(f,i) + CCS(f,i) \quad COV(f,i) = \frac{-CCS(f,i)}{CO_2(f,i)}$$

- ➢ $NetCO_2$: net emissions
  - *f* stands for fuel [coal, oil, gas]
  - *i* stands for stationary emitters [Chemicals, Cement, Steel, Power generation]
- ➢ CO_2(f,i) is the total amount of emissions before CCS
- ➢ Create a separate account for CCS: CCS(f,i) [this is negative]
- ➢ Introduce the CCS coverage rate: COV(f,i)



4.8 Systematic sensitivity analysis (SSA) results

	Cumulative % deviation in real GDP from BAU, 2050					Cumulative change in EV (mUSD) from BAU, 2050				
	NZEP_NT	SSA_M	SSA_SD	93.75% C.I.		NZEP_NT	SSA_M	SSA_SD	93.75% C.I.	
				lower	upper				lower	upper
USA	-3.20	-3.17	0.03	-3.28	-3.06	-1172	-1161	22	-1247	-1074
CSA	-1.69	-1.67	0.19	-2.43	-0.91	-133	-132	10	-170	-93
EUR	-4.78	-4.75	0.05	-4.93	-4.57	-1081	-1077	7	-1107	-1048
AFR	-0.87	-0.87	0.05	-1.06	-0.68	-19	-19	3	-31	-6
MDE	-2.94	-2.96	0.12	-3.42	-2.49	-75	-74	4	-88	-60
RUS	-2.58	-2.61	0.08	-2.92	-2.31	-58	-58	2	-66	-49
CHN	-1.51	-1.51	0.01	-1.56	-1.46	-172	-173	5	-194	-152
IND	-0.09	-0.09	0.03	-0.21	0.03	96	95	5	77	114
JPN	-1.49	-1.49	0.04	-1.67	-1.32	-121	-121	2	-128	-115
SEA	-0.23	-0.24	0.02	-0.32	-0.15	28	29	1	24	33
ROW	-1.05	-1.05	0.05	-1.23	-0.86	-145	-145	13	-195	-94
WLD	-2.06	-2.05	0.01	-2.09	-2.01	-2852	-2836	21	-2922	-2750

50% variations in tested parameters

- The SSA means are close to their original solutions
- The standard deviations are all small
- The confidence intervals (C.I.) are small and encompass all original solutions

4.7 GVC analysis results (a): bilateral emissions trade

2021-50 cumulative change of carbon flow ($MtCO_2$)，From NZEP_NT to NZEP_TR

	USA	CSA	EUR	AFR	MDE	RUS	CHN	IND	JPN	SEA	ROW	TOX
USA		252.3	472.4	100.6	141.6	39.2	499.2	91.5	104.6	191.4	1031.2	2924.0
CSA	106.3		57.8	24.1	35.1	7.5	113.1	158.0	17.2	35.2	110.0	664.2
EUR	410.3	179.5		227.1	190.3	97.9	391.6	131.1	68.3	148.0	976.2	2820.2
AFR	-131.5	-67.1	-207.9		-58.7	-6.5	-115.4	-95.3	-13.9	-19.6	-168.0	-883.8
MDE	-274.6	-156.0	-230.6	-133.7		-15.4	-271.7	-803.2	-16.4	-109.0	-622.2	-2632.7
RUS	-429.8	-99.7	-658.5	-45.9	-41.1		-125.2	-52.1	-11.2	-42.7	-405.2	-1911.3
CHN	-732.5	-150.9	-987.3	22.9	53.9	0.2		34.5	-6.1	82.6	-149.2	-1832.0
IND	-517.3	-191.6	-630.1	-372.3	-619.2	-38.8	-363.4		-51.3	-232.2	-891.3	-3907.6
JPN	60.2	9.9	31.5	7.3	13.3	4.0	87.3	5.5		33.0	66.6	318.6
SEA	-4250.6	-302.3	-1364.9	-182.0	-172.6	-38.9	-691.5	-280.6	-144.4		-820.1	-8247.9
ROW	202.7	15.6	86.5	44.1	130.4	29.8	150.4	142.5	41.4	52.6		896.0
TOI	-5556.7	-510.2	-3431.2	-307.9	-327.1	79.2	-325.7	-668.2	-11.8	139.4	-872.1	

TOX → Total carbon export

TOI → Total carbon import

From No-trade to Trade	TOX	TOI	NCT (net emissions for others)
Developed regions	Increase	Decrease	Increase
Least developed regions	Decrease	Decrease	Decrease