Kyoto University Seminar

E3ME-FTTs: Modelling of Japan Net Zero

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clarity from complexity

Overview

- E3ME and FTTs Overview
- Modelling Japan Net Zero in E3ME – step by step

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E3ME and FTTs

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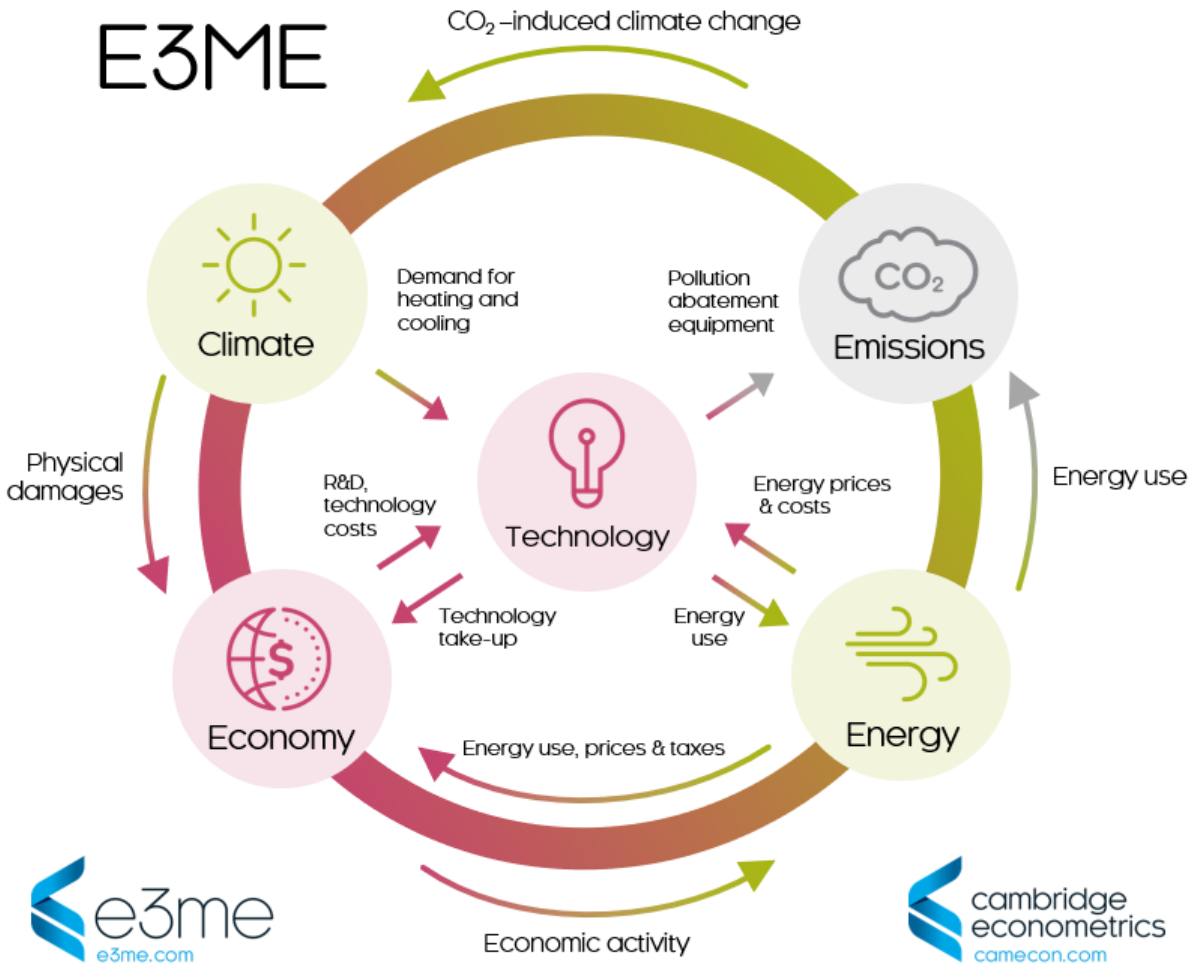
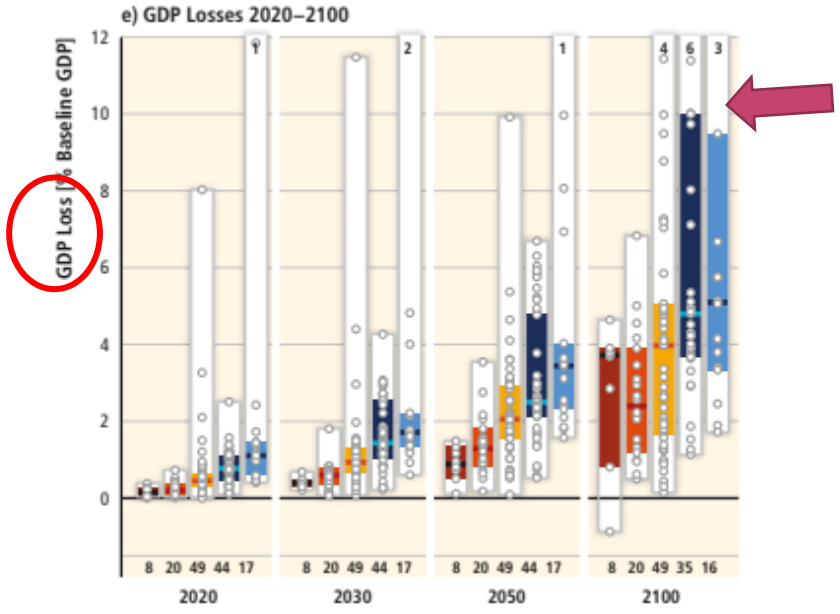


E3ME is a macro-econometric model designed to assess global policy challenges.

Following the Cambridge tradition*, it is the most model of its type. It is widely used for policy assessment, forecasting and research purposes.

*Post-Keynesian, non-optimisation, accept real world behaviours and uncertainties

Optimisation vs Simulation approach



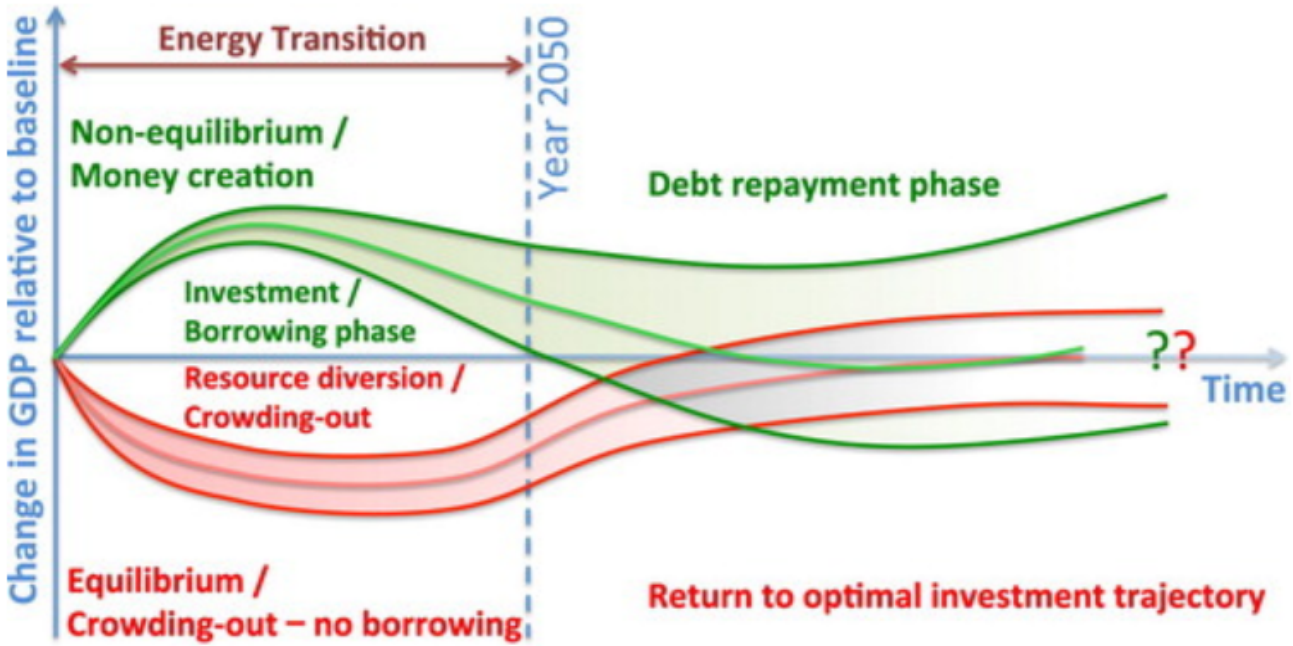
Costs!

Costs!

Costs!

Costs!

IPCC mainstream model
Source: Clarke et al (2014)



Mercure et al (2018)
https://www.tandfonline.com/doi/full/10.1080/14693062.2019.1617665

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Key Features of FTTs in E3ME

	FTT-Power	FTT-Transport	FTT-Heat	FTT-Steel
Technologies	24	25	13	26
Inputs from E3ME	Electricity demand	Fleet/ car demand	Heat demand	Steel demand
Output to E3ME	• Fuel demand and emissions • Electricity price • Electricity investment • Detailed PG employment	• Fuel demand and emissions • Average car price	• Fuel demand and emissions • Costs of boilers	• Fuel demand and emissions • Steel investment • Steel price • Detailed steel employment
Policies	• Tax (carbon, fuel, vehicle, boiler) • Subsidy • Regulations (phase out, limits) • Turnover time • Discount rate • Feeds in tariff • Demonstration technology • Demand side policies e.g. building energy efficiency			

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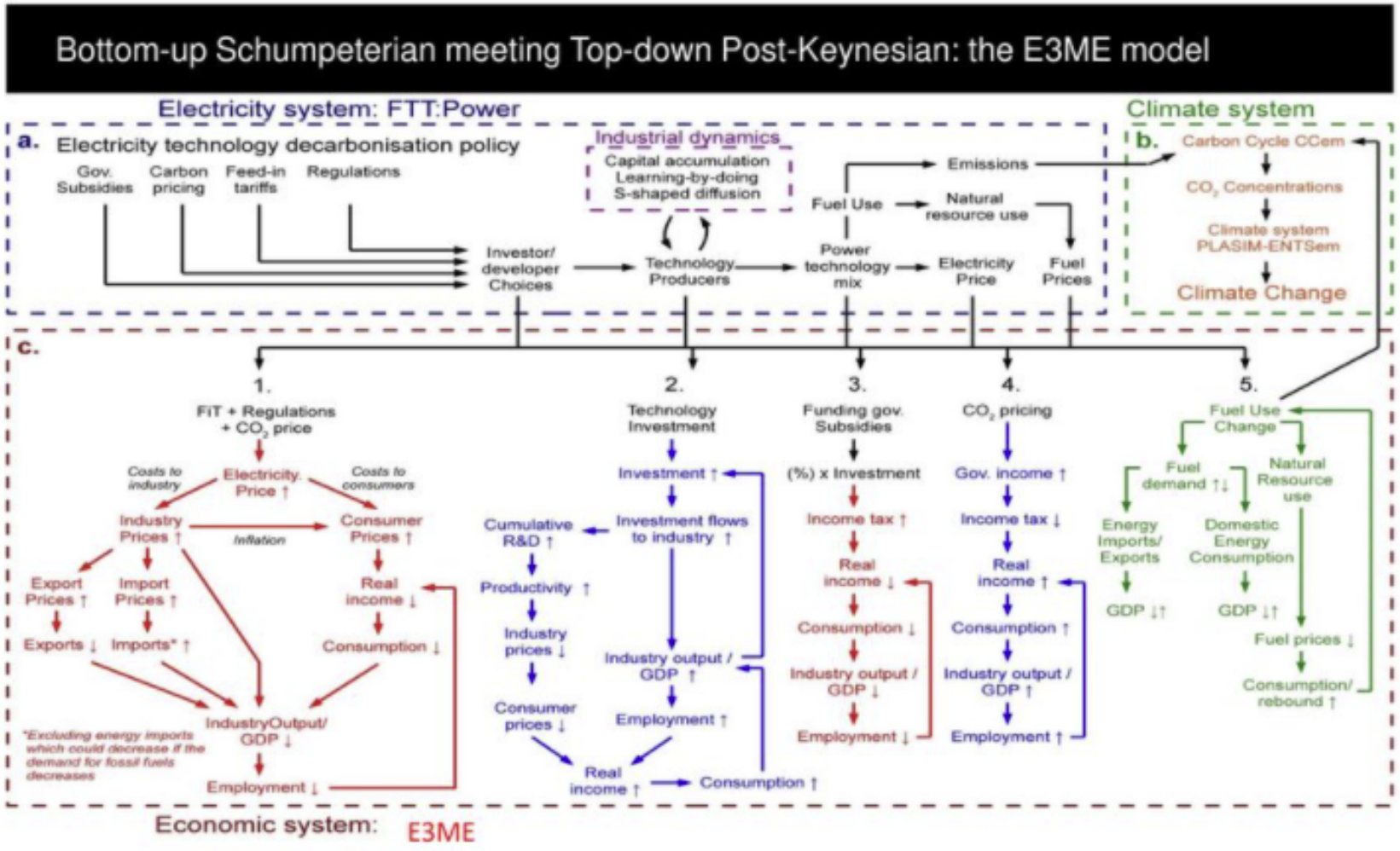
Example: FTT Policy Impacts in E3ME



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Modelling Japan Net Zero in E3ME

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Step 1: Define Scenarios

- Baseline – E3ME existing baseline (IEEJ2021)
- Net Zero Scenario by 2050 with nuclear
- Net Zero Scenario by 2050 without nuclear

Assumptions

- Revenue neutrality (including policy costs and revenues), remaining amount used to reduce income tax, VAT, and social security contribution
- Include energy + processed CO2 emissions only
- Assuming small remaining emissions can be absorbed by LULUCF
- No action in Rest of World
- Net Zero can be achieved via combination of polices based on existing technologies in E3ME
- Allow for Biomass plus CCS technology

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Step 2: Define Policies

Table 3-1: Policy inputs

	Sectors	Net-Zero	Net-Zero without Nuclear
Carbon tax (from 2025 onward)	All sectors	Carbon tax gradually increasing from \$50/tCO_2 in 2021 to reach around \$400/tCO_2 in 2040 (2010 prices). Fixed rate after 2040.	
Coal phase out regulation	Power	Phase out by 2040	
Nuclear phase out regulation	Power	As IEEJ2021	Phase out with operating age reduced to 40 years
Renewable subsidies and Feed-in-Tariffs	Power	Subsidies for expensive renewable technologies (biomass+CCS) between 2021-2035 Feed-in-Tariff for onshore and offshore winds between 2021-2035 Solar is excluded as already competitive.	
Kick start for biomass+CCS	Power	A programme to support biomass+CCS plants by setting up a small size demonstration plant in the first year	
Ban on petrol & diesel engines by regulation	Road transport	Ban sales from 2035 onward	
Biofuel mandate	Freight and air transport	Increase share of biofuels in fuel mix	
EV subsidies	Road transport	Subsidies given to EVs in the first few years	
Energy efficiency investment	Buildings and industry	Similar level of investment under the IEA Sustainable Development Scenario	
Coal, gas and oil boiler regulations	Buildings	Gradual ban of fossil fuel boilers by 2050	
Steel sector	Steel	Regulation of blast furnace to gradually reduced to zero by 2050 (switch to recycled steel + EAF)	
Processed emissions	Industry	Assume processed emission intensity reduced by 4% pa in the net zero scenario	

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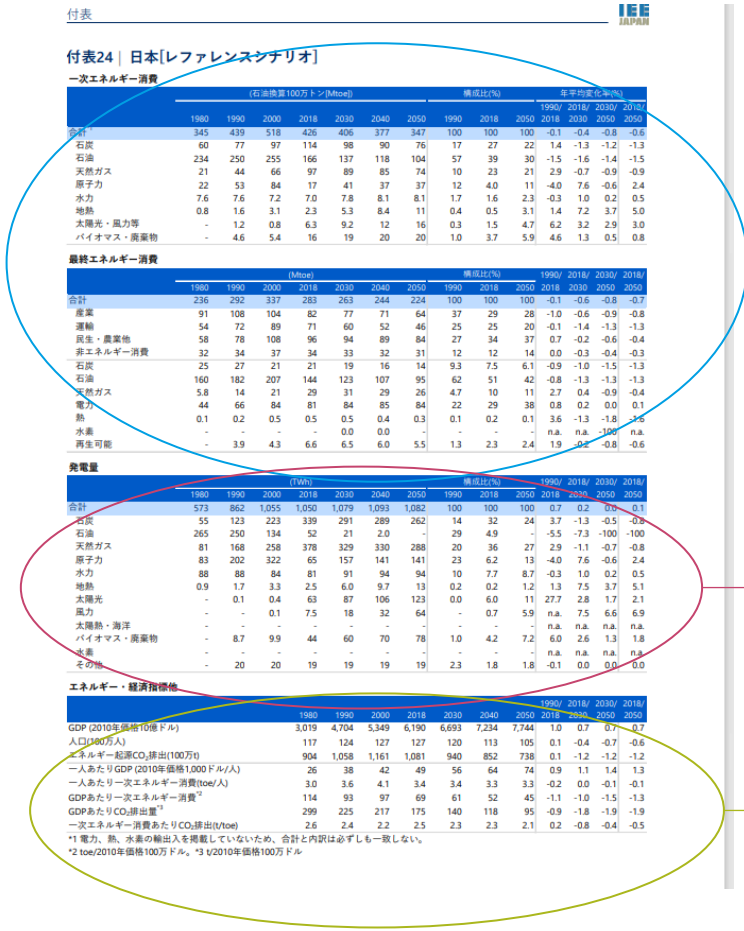
Step 2: Calibrate E3ME Baseline for Japan to IEEJ21


付表

付表24｜日本[レファレンスシナリオ]

一次エネルギー消費

	(石油換算100万トン[Mtoe])							構成比(%)			年平均変化率(%)			
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050	1990/2018	2018/2030	2030/2050	2018/2050
合計[1]	345	439	518	426	406	377	347	100	100	100	-0.1	-0.4	-0.8	-0.6
石炭	60	77	97	114	98	90	76	17	27	22	1.4	-1.3	-1.2	-1.3
石油	234	250	255	166	137	118	104	57	39	30	-1.5	-1.6	-1.4	-1.5
天然ガス	21	44	66	97	89	85	74	10	23	21	2.9	-0.7	-0.9	-0.9
原子力	22	53	84	17	41	37	37	12	4.0	11	-4.0	7.6	-0.6	2.4
水力	7.6	7.6	7.2	7.0	7.8	8.1	8.1	1.7	1.6	2.3	-0.3	1.0	0.2	0.5
地熱	0.8	1.6	3.1	2.3	5.3	8.4	11	0.4	0.5	3.1	1.4	7.2	3.7	5.0
太陽光・風力等	-	1.2	0.8	6.3	9.2	12	16	0.3	1.5	4.7	6.2	3.2	2.9	3.0
バイオマス・廃棄物	-	4.6	5.4	16	19	20	20	1.0	3.7	5.9	4.6	1.3	0.5	0.8

最終エネルギー消費

	(Mtoe)							構成比(%)			1990/2018	2018/2030	2030/2050	2018/2050
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050				
合計	236	292	337	283	263	244	224	100	100	100	-0.1	-0.6	-0.8	-0.7
産業	91	108	104	82	77	71	64	37	29	28	-1.0	-0.6	-0.9	-0.8
運輸	54	72	89	71	60	52	46	25	25	20	-0.1	-1.4	-1.3	-1.3
民生・農業他	58	78	108	96	94	89	84	27	34	37	0.7	-0.2	-0.6	-0.4
非エネルギー消費	32	34	37	34	33	32	31	12	12	14	0.0	-0.3	-0.4	-0.3
石炭	25	27	21	21	19	16	14	9.3	7.5	6.1	-0.9	-1.0	-1.5	-1.3
石油	160	182	207	144	123	107	95	62	51	42	-0.8	-1.3	-1.3	-1.3
天然ガス	5.8	14	21	29	31	29	26	4.7	10	11	2.7	0.4	-0.9	-0.4
電力	44	66	84	81	84	85	84	22	29	38	0.8	0.2	0.0	0.1
熱	0.1	0.2	0.5	0.5	0.5	0.4	0.3	0.1	0.2	0.1	3.6	-1.3	-1.8	-1.6
水素	-	-	-	-	0.0	0.0	-	-	-	-	n.a.	n.a.	-100	n.a.
再生可能	-	3.9	4.3	6.6	6.5	6.0	5.5	1.3	2.3	2.4	1.9	-0.2	-0.8	-0.6

発電量

	(TWh)							構成比(%)			1990/2018	2018/2030	2030/2050	2018/2050
	1980	1990	2000	2018	2030	2040	2050	1990	2018	2050				
合計	573	862	1,055	1,050	1,079	1,093	1,082	100	100	100	0.7	0.2	0.0	0.1
石炭	55	123	223	339	291	289	262	14	32	24	3.7	-1.3	-0.5	-0.8
石油	265	250	134	52	21	2.0	-	29	4.9	-	-5.5	-7.3	-100	-100
天然ガス	81	168	258	378	329	330	288	20	36	27	2.9	-1.1	-0.7	-0.8
原子力	83	202	322	65	157	141	141	23	6.2	13	-4.0	7.6	-0.6	2.4
水力	88	88	84	81	91	94	94	10	7.7	8.7	-0.3	1.0	0.2	0.5
地熱	0.9	1.7	3.3	2.5	6.0	9.7	13	0.2	0.2	1.2	1.3	7.5	3.7	5.1
太陽光	-	0.1	0.4	63	87	106	123	0.0	6.0	11	27.7	2.8	1.7	2.1
風力	-	-	0.1	7.5	18	32	64	-	0.7	5.9	n.a.	7.5	6.6	6.9
太陽熱・海洋	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
バイオマス・廃棄物	-	8.7	9.9	44	60	70	78	1.0	4.2	7.2	6.0	2.6	1.3	1.8
水素	-	-	-	-	-	-	-	-	-	-	n.a.	n.a.	n.a.	n.a.
その他	-	20	20	19	19	19	19	2.3	1.8	1.8	-0.1	0.0	0.0	0.0

エネルギー・経済指標他

	1980	1990	2000	2018	2030	2040	2050	1990/2018	2018/2030	2030/2050	2018/2050
GDP (2010年価格10億ドル)	3,019	4,704	5,349	6,190	6,693	7,234	7,744	1.0	0.7	0.7	0.7
人口(100万人)	117	124	127	127	120	113	105	0.1	-0.4	-0.7	-0.6
エネルギー起源CO_2排出(100万t)	904	1,058	1,161	1,081	940	852	738	0.1	-1.2	-1.2	-1.2
一人あたりGDP (2010年価格1,000ドル/人)	26	38	42	49	56	64	74	0.9	1.1	1.4	1.3
一人あたり一次エネルギー消費(toe/人)	3.0	3.6	4.1	3.4	3.4	3.3	3.3	-0.2	0.0	-0.1	-0.1
GDPあたり一次エネルギー消費[2]	114	93	97	69	61	52	45	-1.1	-1.0	-1.5	-1.3
GDPあたりCO_2排出量[3]	299	225	217	175	140	118	95	-0.9	-1.8	-1.9	-1.9
一次エネルギー消費あたりCO_2排出(t/toe)	2.6	2.4	2.2	2.5	2.3	2.3	2.1	0.2	-0.8	-0.4	-0.5

*1 電力、熱、水素の輸出入を掲載していないため、合計と内訳は必ずしも一致しない。
*2 toe/2010年価格100万ドル。*3 t/2010年価格100万ドル

Final energy demand

Power mix

Economic (GDP components and sectors) and demographic

- Process to E3ME classification
- Interpolate between years
- Using RAS to obtain fuel users by fuels
- Using shift/share (based on historical and trends) apply growth rates while matching totals
- Create consistent projections for other variables e.g. GDP components, energy sector outlooks
- Save numbers on databank
- Run the model to create residuals
- Apply residuals to endogenous solutions (baseline and scenarios)

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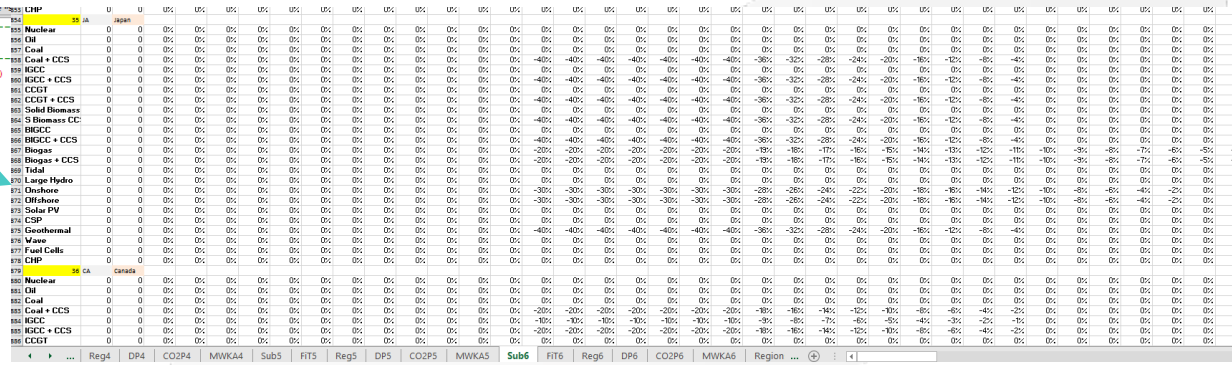
Step 3: Set up Scenario Files with Policy Inputs

```
COMM-----------------------------------------------------
COMM 1.FTT-Power policies (nuclear and hydro fixed in baselin
COMM-----------------------------------------------------
SELECT INPUT 21 DB1 |Z.DB1
IF YEAR GT 2020; DO
  COMM FTT exogenous capacity if any
  COMM GET MWKA(?:35) 31123501,C(YEAR-2000)
  COMM FTT technology subsidies
  GET MEWT(?:35) 31103501,C(YEAR-2000)
  COMM FTT feed-in tariffs
  GET MEFI(?:35) 31113501,C(YEAR-2000)
  COMM FTT regulations
  GET MEWR(?:35) 31093501,C(YEAR-2000)
  LET MEWR(10,35) = 10.0
  LET MEWR(12,35) = 10.0
  LET MEWR(19,35) = 300.0
 END


COMM Coal regulation from previous Kyoto project
COMM IF YEAR EQ 2020 LET MWKA(3,35) = 47.52
 IF YEAR EQ 2021 LET MWKA(3,35) = 46.95
 IF YEAR EQ 2022 LET MWKA(3,35) = 46.27
 IF YEAR EQ 2023 LET MWKA(3,35) = 43.90
 IF YEAR EQ 2024 LET MWKA(3,35) = 40.24
 IF YEAR EQ 2025 LET MWKA(3,35) = 36.04
 IF YEAR EQ 2026 LET MWKA(3,35) = 32.04
 IF YEAR EQ 2027 LET MWKA(3,35) = 28.32
 IF YEAR EQ 2028 LET MWKA(3,35) = 23.62
 IF YEAR EQ 2029 LET MWKA(3,35) = 18.76
 IF YEAR EQ 2030 LET MWKA(3,35) = 16.46
 IF YEAR EQ 2031 LET MWKA(3,35) = 14.16
 IF YEAR EQ 2032 LET MWKA(3,35) = 11.76
 IF YEAR EQ 2033 LET MWKA(3,35) = 9.91
 IF YEAR EQ 2034 LET MWKA(3,35) = 8.15
 IF YEAR EQ 2035 LET MWKA(3,35) = 6.36
 IF YEAR EQ 2036 LET MWKA(3,35) = 4.52
 IF YEAR EQ 2037 LET MWKA(3,35) = 2.45
 IF YEAR EQ 2038 LET MWKA(3,35) = 1.15
 IF YEAR EQ 2039 LET MWKA(3,35) = 0.00
 IF YEAR EQ 2040 LET MWKA(3,35) = 0.00
 IF YEAR EQ 2041 LET MWKA(3,35) = 0.00
 IF YEAR EQ 2042 LET MWKA(3,35) = 0.00
 IF YEAR EQ 2043 LET MWKA(3,35) = 0.00
 IF YEAR EQ 2044 LET MWKA(3,35) = 0.00
 IF YEAR EQ 2045 LET MWKA(3,35) = 0.00
```

```
COMM-----------------------------------------------------
COMM 2.FTT-Transport policies
COMM-----------------------------------------------------
 IF YEAR GT 2020;  DO
   COMM Exogenous policies
   GET REMB 32130001,C(YEAR-2000)
   LET RTCO(35) = REMB(35)
   GET REMB 32150001,C(YEAR-2000)
   LET RBFM(35) = REMB(35)
   GET REMB 32140001,C(YEAR-2000)
   LET RTFT(35) = REMB(35)
   GET TTVT(?:35) 32023501,C(YEAR-2000)
   GET TTRT(?:35) 32033501,C(YEAR-2000)
   GET TREG(?:35) 32043501,C(YEAR-2000)
   COMM Exogenous capacities if any
   GET TWSA(?:35) 32053501,C(YEAR-2000)
 END IF

COMM-----------------------------------------------------
COMM 3.FTT-Heating policies
COMM-----------------------------------------------------
 IF YEAR GT 2020; DO
  GET REMB 33170001,C(YEAR-2000)
  LET RHUD(35) = REMB(35)
  GET HTVS(?:35) 33063501,C(YEAR-2000)
  GET HTRT(?:35) 33073501,C(YEAR-2000)
  GET HREG(?:35) 33083501,C(YEAR-2000)
  GET HWSA(?:35) 33093501,C(YEAR-2000)
  GET HEFI(?:35) 33103501,C(YEAR-2000)
  GET HETR(?:35) 33113501,C(YEAR-2000)
  GET HFIN(?:35) 33123501,C(YEAR-2000)
  COMM GET HFFC(?:35) 33143501,C(YEAR-2000)
 END IF

COMM-----------------------------------------------------
COMM 4.FTT-Steel policies
COMM-----------------------------------------------------
 IF YEAR GT 2020; DO
  GET SKST(?:35) 34163501,C(YEAR-2017)
  GET SWKA(?:35) 34173501,C(YEAR-2017)
  GET SEWT(?:35) 34183501,C(YEAR-2017)
  GET SEWR(?:35) 34193501,C(YEAR-2017)
  GET SRDI(?:35) 34203501,C(YEAR-2017)
  GET SEEI(?:35) 34213501,C(YEAR-2017)
  GET STRT(?:35) 34223501,C(YEAR-2017)
```

```
COMM-----------------------------------------------
COMM 5. Energy efficiency
COMM-----------------------------------------------
 IF YEAR GT 2020; DO
  SELECT INPUT 21 DB1
  GET FRCH(?:35) 30013501,C(YEAR-2002)
  GET FR2H(?:35) 30023501,C(YEAR-2002)
  GET FR3H(?:35) 30033501,C(YEAR-2002)
  GET FROH(?:35) 30043501,C(YEAR-2002)
  GET FR5H(?:35) 30053501,C(YEAR-2002)
  GET FR6H(?:35) 30063501,C(YEAR-2002)
  GET FRGH(?:35) 30073501,C(YEAR-2002)
  GET FREH(?:35) 30083501,C(YEAR-2002)
  GET FR9H(?:35) 30093501,C(YEAR-2002)
  GET FRWH(?:35) 30103501,C(YEAR-2002)
  GET FRBH(?:35) 30113501,C(YEAR-2002)
COMM COMM-----------------------------------------------
COMM COMM 6.Carbon price and energy price
COMM COMM-----------------------------------------------
 IF YEAR GT 2020 LET FETS(0,35) = FETS(0,35)*0.0+ 1.0
 COMM tax rate euro/tC
 IF YEAR EQ 2021 LET REPX(35,21) =164
 IF YEAR EQ 2022 LET REPX(35,22) =261
 IF YEAR EQ 2023 LET REPX(35,23) =357
 IF YEAR EQ 2024 LET REPX(35,24) =453
 IF YEAR EQ 2025 LET REPX(35,25) =550
 IF YEAR EQ 2026 LET REPX(35,26) =646
 IF YEAR EQ 2027 LET REPX(35,27) =742
 IF YEAR EQ 2028 LET REPX(35,28) =839
 IF YEAR EQ 2029 LET REPX(35,29) =935
 IF YEAR EQ 2030 LET REPX(35,30) =1032
 IF YEAR EQ 2031 LET REPX(35,31) =1128
 IF YEAR EQ 2032 LET REPX(35,32) =1224
 IF YEAR EQ 2033 LET REPX(35,33) =1321
 IF YEAR EQ 2034 LET REPX(35,34) =1417
 IF YEAR EQ 2035 LET REPX(35,35) =1513
 IF YEAR EQ 2036 LET REPX(35,36) =1610
 IF YEAR EQ 2037 LET REPX(35,37) =1706
 IF YEAR EQ 2038 LET REPX(35,38) =1802
 IF YEAR EQ 2039 LET REPX(35,39) =1899
 IF YEAR EQ 2040 LET REPX(35,40) =1995
 IF YEAR EQ 2041 LET REPX(35,41) =1995
 IF YEAR EQ 2042 LET REPX(35,42) =1995
 IF YEAR EQ 2043 LET REPX(35,43) =1995
 IF YEAR EQ 2044 LET REPX(35,44) =1995
 IF YEAR EQ 2045 LET REPX(35,45) =1995
 IF YEAR EQ 2046 LET REPX(35,46) =1995
 IF YEAR EQ 2047 LET REPX(35,47) =1995
 IF YEAR EQ 2048 LET REPX(35,48) =1995
 IF YEAR EQ 2049 LET REPX(35,49) =1995
 IF YEAR EQ 2050 LET REPX(35,50) =1995


COMM energy tax on transport
 IF YEAR GT 2020 ; DO
 LET FEDS(16,35) = 1
  FOR JJ = 1 TO 12
   LET JEDS(JJ,35) = 0.0
  LOOP JJ
  LET JEDS(5,35) = 1.0
 END IF
 COMM tax rate euro/toe
 IF YEAR EQ 2021 LET RTEA(35,21) = 1176.47
 IF YEAR EQ 2022 LET RTEA(35,22) = 1176.47
```

- A lot of policies!
- Some policies are saved in databank due to dimension (region, sector/technologies, time)



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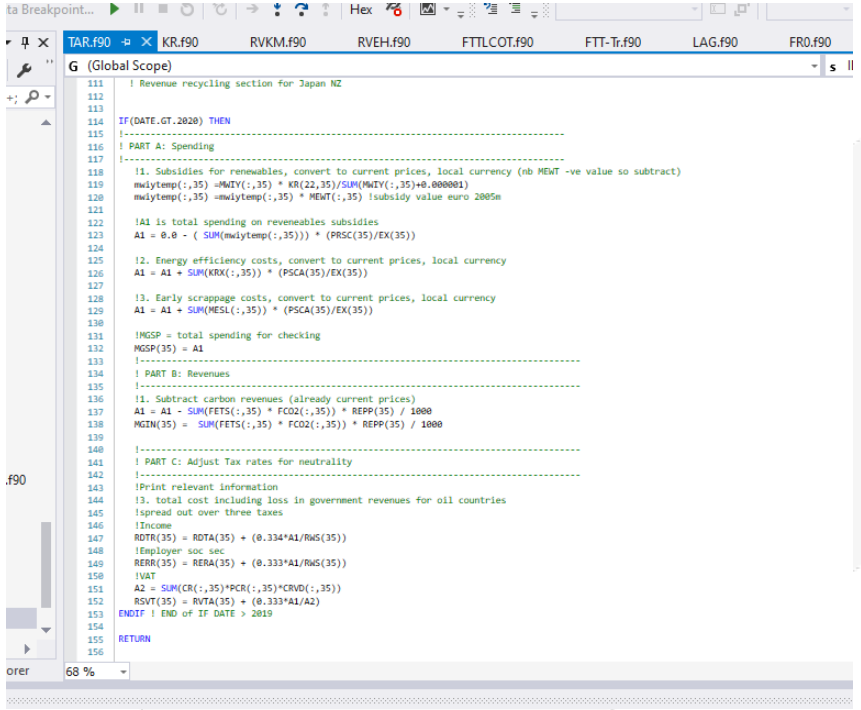
Step 4: Set Up Revenue Recycling Code in E3ME

- Policy revenues = carbon tax revenues
- Policy costs = energy efficiency investment, renewables subsidies, stranded power plants (including nuclear)
- Leftover revenues = adjust tax rates (income tax, VAT, social security contribution)
- Automated process to take into accounts of rebounds in emissions



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Step 5: Run Baseline, Scenarios and Solve for Solutions

Command Prompt - run

```
 2046100   57  2.0  2.0  2.1  2.1  2.1  2.6  2.4  2.9  2.9  2.5  0.0  1.7  7.3
 2047100   57  2.0  2.0  2.1  2.1  2.2  2.6  2.4  2.9  2.9  2.5  0.0  1.7  7.3
 2048100   57  2.1  2.0  2.0  2.2  2.2  2.6  2.4  2.9  2.9  2.5  0.0  1.6  7.3
 2049100   58  2.1  2.1  2.1  2.2  2.2  2.6  2.4  2.9  2.9  2.5  0.0  1.6  7.3
 2050100   58  2.1  2.1  2.0  2.2  2.2  2.6  2.4  3.0  2.9  2.5  0.0  1.6  7.3
 Time taken (minutes): 108.09

e:\Kyoto2021_JapanNZ>e3mer In dRep Asns\Assumptions Scenarios\B_ETS Databank Output\ Rep_ba
 Time taken (minutes):   0.00
E3ME data analysis: please wait until completed.

e:\Kyoto2021_JapanNZ>e3mer In Dan1 Asns\Assumptions Scenarios\B_ETS Databank Output\ Dan_ba
 Time taken (minutes):   0.01
E3ME data analysis: please wait until completed.

e:\Kyoto2021_JapanNZ>e3mer In EnJapanNZ Asns\Assumptions Scenarios\B_ETS Databank Output\ E
E3ME60 SUMMARY SOLUTION FOR EACH YEAR
 Last iteration for 61 region(s) as % change (D) previous year:
 DATE IT  GHG DGDP  DSC  DSV  DSX  DSM DPSH DPCE DPSX DPSM  DAW BTRA PBRA UNRA
 2011 11   54  3.1  2.7  5.0  6.7  7.6  4.2  2.1  4.2  4.7  4.0  0.0  2.6  6.3
 2012  9   55  2.5  2.6  3.9  2.5  2.2  3.9  4.9  2.0  1.7  9.3  0.0  2.3  6.2
 2013 10   55  2.7  2.6  3.4  2.7  2.3  0.5 -0.4 -0.1 -0.3 -3.0  0.0  1.4  6.2
 2014  9   56  2.9  2.8  3.5  3.5  3.3 -0.5 -2.2  1.0 -0.3  0.9  0.0  1.6  6.2
 2015 50   56  2.1  2.4 -0.4  1.2  0.8  1.7 12.2  7.8  7.8 13.1 -0.0  1.7  6.1
 2016 57   56  2.0  2.4  1.7  1.8  1.9 -3.0 -5.3 -4.5 -5.5 -0.5 -0.0  1.8  7.6
 2017 86   56  2.4  2.1  3.0  3.1  3.0  3.4  3.4  4.5  4.8  2.6 -0.0  1.8  7.4
 2018 48   55  4.0  2.9  6.9  3.3  3.1  3.4  3.3  5.5  5.7  3.3 -0.0  1.7  7.2
 2019 42   55  3.2  2.8  4.0  3.7  3.6  2.9  2.7  2.5  2.5  3.3 -0.0  1.7  7.1
 2020 42   55  2.7  2.5  3.1  3.4  3.4  3.0  2.9  2.5  2.5  2.9 -0.0  1.7  6.9
```

- Each scenario takes about 30 mins to run!
- Solution can become unstable/ crash
- Fixes are added and re run again

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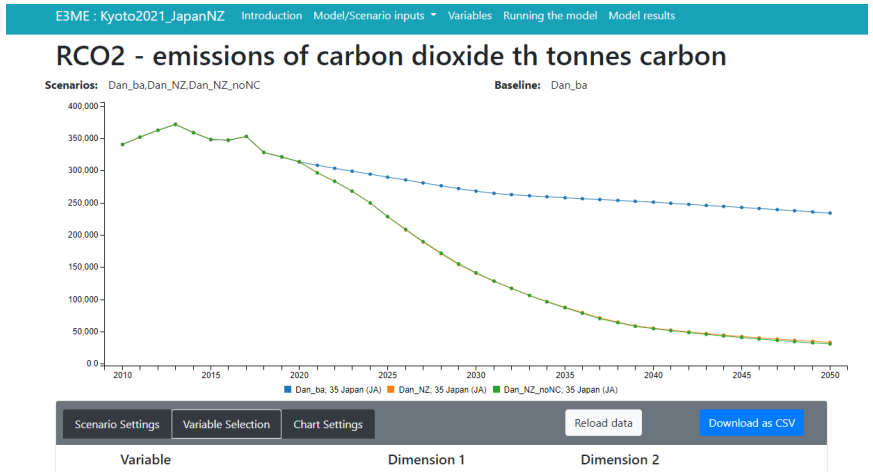
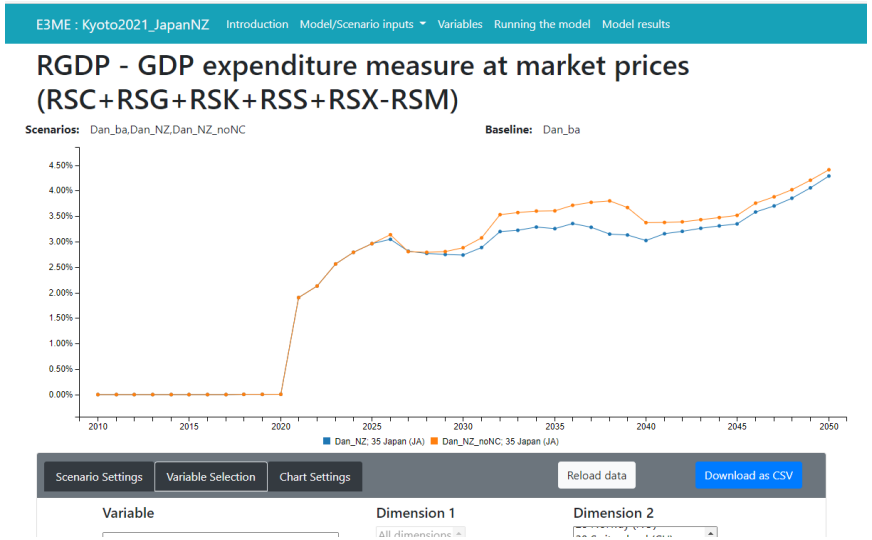
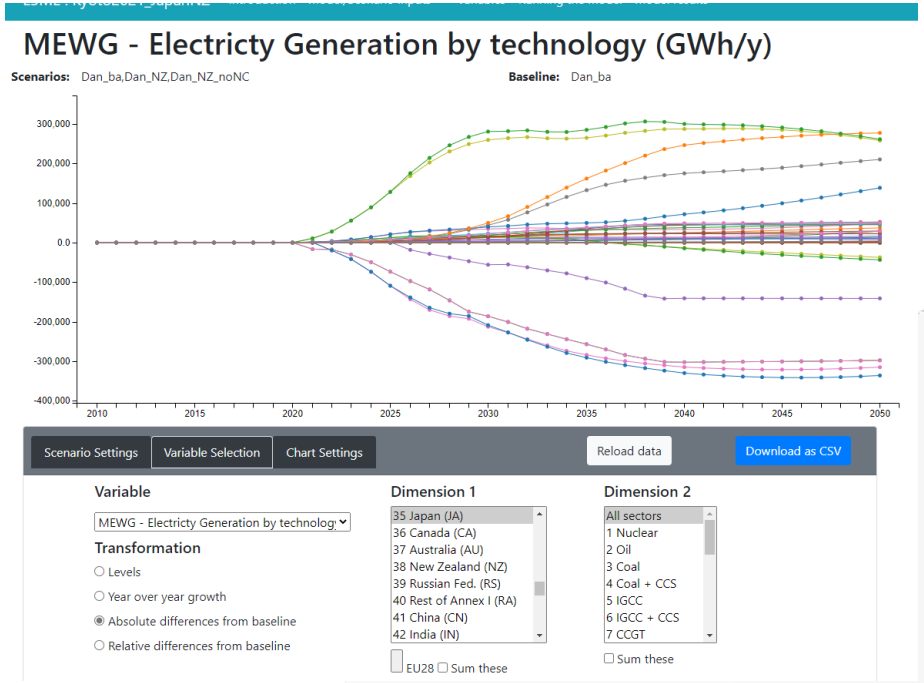
Step 6: Inspect Model Results using E3ME FrontEnd







- E3ME contains many variables across dimensions
- Check inputs and outputs and interactions
- Check for any unstable results

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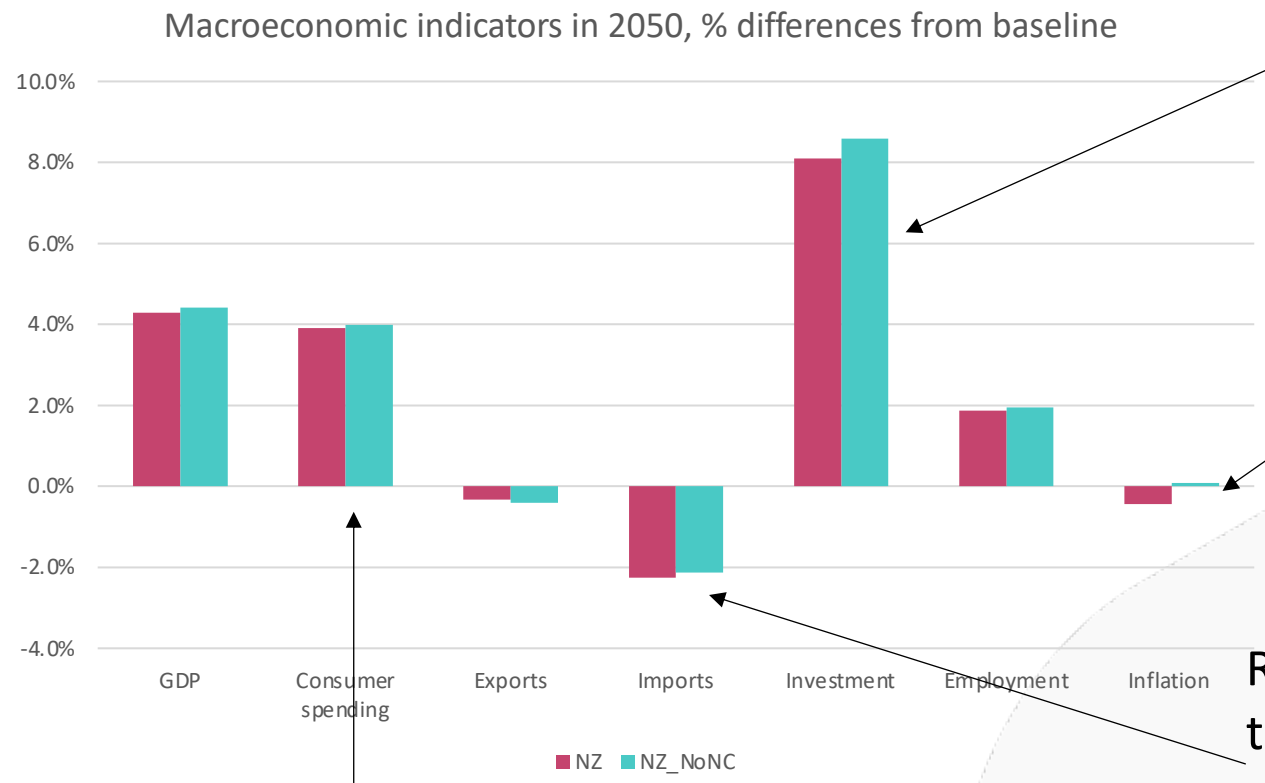
Final Step: Present Key Findings



Additional investment uses resources that would otherwise be idle

Despite higher electricity price, lower inflation from energy savings and moving away from other fuels

Reduce fuel imports mean that imports don't increase when GDP does

Reduced energy bills, additional income from employment

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Kyoto University Seminar

E3ME-FTTs: Modelling of Japan Net Zero

Unnada Chewpreecha
Email: uc@camecon.com

29th March 2021

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clarity from complexity