

Supplementary Materials

Coupling compliance and voluntary carbon markets: a system dynamics assessment in China

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Supplementary Table 1. Variables and parameter settings

Category	Variable Name	Setting and Unit
Policy Parameters	CCER Offset Rate	Exogenous, calibrated based on the current policy document <i>Administrative measures for carbon emissions trading (Trial Implementation)</i> and the actual scenario settings for the pilot operation, 5%, Dmnl
	Carbon Trading Price	Exogenous, calibrated against historical carbon market observations, 100 CNY/ton

	Auction Price	Exogenous, Carbon Trading Price
	Free Allocation Rate	Exogenous, calibrated based on the experiences from the pilot carbon trading markets operation and the policy target, 95%, Dmnl
	CCER Price	Exogenous, calibrated against historical carbon market observations, 80 CNY/ton
	CCER Coefficient	Exogenous, 0.5366 ton CO ₂ /thousand kWh
	CCER Certification Rate	Exogenous, set based on the literature review and referring to Zhang and Lin (2024), 30%, Dmnl
	Carbon Intensity Reduction Rate - Power Generation	Exogenous, source: policy documents, linear interpolation, Dmnl
	Carbon Intensity Reduction Rate - Steel	Exogenous, source: policy documents, linear interpolation, Dmnl
	Carbon Intensity Reduction Rate - Cement	Exogenous, source: policy documents, linear interpolation, Dmnl
	Carbon Intensity Reduction Rate - Electrolytic Aluminum	Exogenous, source: policy target, linear interpolation, Dmnl
	Base Carbon Intensity - Power Generation	Exogenous, 3.31 MtCO ₂ /Billion CNY
	Base Carbon Intensity - Steel	Exogenous, 0.92 MtCO ₂ /Billion CNY
	Base Carbon Intensity - Cement	Exogenous, 1.19 MtCO ₂ /Billion CNY
	Base Carbon Intensity - Electrolytic Aluminum	Exogenous, 0.33 MtCO ₂ /Billion CNY

	GDP Inflator	Exogenous, source: historical data, Dmnl
	Power Generation Capacity	Exogenous, source: historical data and policy target
	Coal/ Oil/ Natural Gas Proportion - Power Generation/ Steel/ Cement/ Electrolytic Aluminum	Exogenous, source: historical data and policy target, Dmnl
	Self-owned Electricity Proportion - Steel/ Cement/ Electrolytic Aluminum	Exogenous, source: historical data and policy target, Dmnl
	Energy Intensity - Power Generation/ Steel/ Cement/ Electrolytic Aluminum	Exogenous, source: historical data and policy target
	Natural Gas Emission Coefficient	Exogenous, 1.63 MtCO2/Mtce
	Coal Emission Coefficient	Exogenous, 2.60 MtCO2/Mtce
	Oil Emission Coefficient	Exogenous, 2.11 MtCO2/Mtce
	Electricity Emission Coefficient	Exogenous, 4.40 MtCO2/Mtce
	Growth Rate - Power Generation/ Steel/ Cement/ Electrolytic Aluminum/ Other Industries	Exogenous, source: historical data and policy target, Dmnl
Industry Variables <i>(Power Generation Example)</i>	CO2 Emissions - Power Generation	Calculated, MtCO2
	Energy Consumption - Power Generation	Calculated, Mtce
	Real Output - Power Generation	Calculated, Billion CNY
	Value Added - Power Generation	Calculated, Billion CNY
	CCER Trading Volume - Power Generation	Calculated, MtCO2
	Primary Market Difference - Power Generation	Calculated, MtCO2
	Secondary Market Trading Volume - Power Generation	Calculated, MtCO2
	Free Quotas - Power Generation	Calculated, MtCO2

	Initial Carbon Quotas - Power Generation	Calculated, MtCO ₂
	Carbon Intensity - Power Generation	Calculated, MtCO ₂ /Billion CNY
	Carbon Intensity Target - Power Generation	Calculated, MtCO ₂ /Billion CNY
	Auction Quotas - Power Generation	Calculated, MtCO ₂
	Natural Gas Consumption - Power Generation	Calculated, Mtce
	Coal Consumption - Power Generation	Calculated, Mtce
	Oil Consumption - Power Generation	Calculated, Mtce
	Cost - Power Generation	Calculated, Billion CNY
	Real Cost - Power Generation	Calculated, Billion CNY
	CCER Trading Costs - Power Generation	Calculated, Billion CNY
	Coefficient φ	Calculated, calibrated using a weighted average based on the sector-specific energy structure in the model, drawing on the simulated effects of carbon market transaction costs on different types of energy consumption reported by Lin and Jia (2019), Mtce per billion CNY
Macroeconomic Variables	Carbon Trading Costs - Power Generation	Calculated, Billion CNY
	Nominal GDP	Calculated, Billion CNY
	Total Costs	Calculated, Billion CNY
	Total CO ₂ Emissions	Calculated, MtCO ₂
	Value Added - Other Industries	Calculated, Billion CNY

	Real Output - Other Industries	Calculated, Billion CNY
CCER Market Variables	CCER Trading Volume	Calculated, MtCO ₂
	CCER Supply	Calculated, MtCO ₂
	CCER Stock	Calculated, MtCO ₂
	CCER Current Increment	Calculated, MtCO ₂
	CCER Carried Forward Volume	Calculated, MtCO ₂
	CCER Demand	Calculated, MtCO ₂
	Total CCER Trading Costs	Calculated, Billion CNY
	Delayed CCER Costs Adjustment	Calculated, Billion CNY
	Proportion of CCER Projects in Electricity	Calculated, Dmnl

Note: Dmnl indicates no unit. ETS: Emissions Trading System; CCER: China Certified Emission Reduction.

Supplementary Model Equations

(001) auction price= carbon trading price

Units: RMB/ton

(002) auction quotas of cement= IF THEN ELSE(carbon trading price>=auction price, initial carbon quotas of cement -free quotas of cement, 0)

Units: Mt CO₂

(003) auction quotas of electrolytic aluminum= IF THEN ELSE(carbon trading price>=auction price, initial carbon quotas of electrolytic aluminum -free quotas of electrolytic aluminum, 0)

Units: Mt CO₂

(004) auction quotas of power generation= IF THEN ELSE(carbon trading price>=auction price, initial carbon quotas of power generation -free quotas of power generation , 0)

Units: Mt CO₂

(005) auction quotas of steel= IF THEN ELSE(carbon trading price>=auction price, initial carbon quotas of steel -free quotas of steel, 0)

Units: Mt CO₂

(006) base carbon intensity of cement= 1.18851

Units: Mt CO₂/Billion RMB

(007) base carbon intensity of electrolytic aluminum= 0.330124

Units: Mt CO2/Billion RMB

(008) base carbon intensity of power generation= 3.31339

Units: Mt CO2/Billion RMB

(009) base carbon intensity of steel= 0.919859

Units: Mt CO2/Billion RMB

(010) carbon intensity of cement= CO2 emissions of cement/real output of cement

Units: Mt CO2/Billion RMB

(011) carbon intensity of electrolytic aluminum= CO2 emissions of electrolytic aluminum/real output of electrolytic aluminum

Units: Mt CO2/Billion RMB

(012) carbon intensity of power generation= CO2 emissions of power generation/real output of power generation

Units: Mt CO2/Billion RMB

(013) carbon intensity of steel= CO2 emissions of steel/real output of steel

Units: Mt CO2/Billion RMB

(014) carbon intensity reduction rate of cement = WITH LOOKUP (Time, ([(2005, 0) - (2030,1)], (2005,0),(2020,0.484), (2025,0.5768), (2030,0.65)))

Units: Dmnl

(015) carbon intensity reduction rate of electrolytic aluminum = WITH LOOKUP (Time, ([(2005, 0) - (2030,1)], (2005,0),(2020,0.484), (2025,0.5768), (2030,0.65)))

Units: Dmnl

(016) carbon intensity reduction rate of power generation = WITH LOOKUP (Time, ([(2005, 0) - (2030,1)], (2005,0),(2020,0.484), (2025,0.5768), (2030,0.65)))

Units: Dmnl

(017) carbon intensity reduction rate of steel = WITH LOOKUP (Time, ([(2005, 0) - (2030,1)], (2005,0),(2020,0.484), (2025,0.5768), (2030,0.65)))

Units: Dmnl

(018) carbon intensity target of cement= base carbon intensity of cement*(1-carbon intensity reduction rate of cement)

Units: Mt CO2/Billion RMB

(019) carbon intensity target of electrolytic aluminum= base carbon intensity of electrolytic aluminum*(1-carbon intensity reduction rate of electrolytic aluminum)

Units: Mt CO2/Billion RMB

(020) carbon intensity target of power generation= base carbon intensity of power generation*(1-carbon intensity reduction rate of power generation)

Units: Mt CO2/Billion RMB

(021) carbon intensity target of steel= base carbon intensity of steel*(1-carbon intensity reduction rate of steel)

Units: Mt CO2/Billion RMB

(022) carbon trading costs of cement= (auction price *auction quotas of cement + carbon trading price*secondary market trading volume of cement)/1000

Units: Billion RMB

(023) carbon trading costs of electrolytic aluminum= (auction price*auction quotas of electrolytic aluminum + secondary market trading volume of electrolytic aluminum *carbon trading price)/1000

Units: Billion RMB

(024) carbon trading costs of power generation= (carbon trading price*secondary market trading volume of power generation +auction price*auction quotas of power generation)/1000

Units: Billion RMB

(025) carbon trading costs of steel= (secondary market trading volume of steel*carbon trading price + auction price *auction quotas of steel)/1000

Units: Billion RMB

(026) carbon trading price= IF THEN ELSE(Time>=2020, 100, 0)

Units: RMB/ton

(027) CCER carried forward volume= DELAY FIXED((CCER supply-CCER trading volume), 1 , 0)

Units: Mt CO2

(028) CCER certification rate= 0.3

Units: Dmnl

(029) CCER coefficient= 0.5366

Units: ton CO2/thousand kWh

(030) CCER current increment= IF THEN ELSE(Time>=2020, power generation capacity*Proportion of CCER projects in electricity *CCER coefficient*CCER certification rate , 0)

Units: Mt CO₂

(031) CCER demand= IF THEN ELSE(primary market difference of power generation>0, primary market difference of power generation ,0)+IF THEN ELSE(primary market difference of cement>0, primary market difference of cement ,0)+IF THEN ELSE(primary market difference of electrolytic aluminum>0,primary market difference of electrolytic aluminum , 0)+IF THEN ELSE(primary market difference of steel>0, primary market difference of steel , 0)

Units: Mt CO₂

(032) CCER maximum offset= total CO₂ emissions*CCER offset rate

Units: Mt CO₂

(033) CCER offset rate= IF THEN ELSE(Time >=2020, 0.05, 0)

Units: Dmnl

(034) CCER price= IF THEN ELSE(Time >=2020, 80, 0)

Units: RMB/ton

(035) CCER stock= CCER carried forward volume + CCER current increment

Units: Mt CO₂

(036) CCER supply= CCER stock

Units: Mt CO₂

(037) CCER trading costs of cement= CCER price*CCER trading volume of cement/1000

Units: Billion RMB

(038) CCER trading costs of electrolytic aluminum= CCER price*CCER trading volume of electrolytic aluminum/1000

Units: Billion RMB

(039) CCER trading costs of power generation= CCER trading volume of power generation*CCER price/1000

Units: Billion RMB

(040) CCER trading costs of steel= CCER trading volume of steel*CCER price/1000

Units: Billion RMB

(041) CCER trading volume= MIN(CCER supply, MIN(CCER offset rate*total CO₂ emissions, CCER demand))

Units: Mt CO₂

(042) CCER trading volume of cement= IF THEN ELSE(primary market difference of cement>0, MIN(CCER trading volume *primary market difference of cement/CCER demand, primary market difference of cement) , 0)

Units: Mt CO2

(043) CCER trading volume of electrolytic aluminum= IF THEN ELSE(primary market difference of electrolytic aluminum>0, MIN(CCER trading volume *primary market difference of electrolytic aluminum/CCER demand , primary market difference of electrolytic aluminum) , 0)

Units: Mt CO2

(044) CCER trading volume of power generation= IF THEN ELSE(primary market difference of power generation>0, MIN(CCER trading volume *primary market difference of power generation/CCER demand , primary market difference of power generation), 0)

Units: Mt CO2

(045) CCER trading volume of steel= IF THEN ELSE(primary market difference of steel>0, MIN(CCER trading volume *primary market difference of steel/CCER demand, primary market difference of steel), 0)

Units: Mt CO2

(046) CO2 emissions of cement= coal consumption of cement*coal emission coefficient + oil consumption of cement *oil emission coefficient + natural gas consumption of cement*natural gas emission coefficient+ self-owned electricity consumption of cement *electricity emission coefficient

Units: Mt CO2

(047) CO2 emissions of electrolytic aluminum= coal emission coefficient*coal consumption of electrolytic aluminum+ oil emission coefficient *oil consumption of electrolytic aluminum+ natural gas emission coefficient *natural gas consumption of electrolytic aluminum+ electricity emission coefficient *"self-owned electricity consumption of electrolytic aluminum"

Units: Mt CO2

(048) CO2 emissions of power generation= natural gas consumption of power generation*natural gas emission coefficient +coal consumption of power

generation*coal emission coefficient+ oil consumption of power generation *oil emission coefficient

Units: Mt CO2

(049) CO2 emissions of steel= natural gas emission coefficient*natural gas consumption of steel+coal emission coefficient *coal consumption of steel+ oil emission coefficient*oil consumption of steel+ electricity emission coefficient *"self-owned electricity consumption of steel"

Units: Mt CO2

(050) coal consumption of cement= coal proportion of cement*energy consumption of cement

Units: Mtce

(051) coal consumption of electrolytic aluminum= coal proportion of electrolytic aluminum*energy consumption of electrolytic aluminum

Units: Mtce

(052) coal consumption of power generation= coal proportion of power generation*energy consumption of power generation

Units: Mtce

(053) coal consumption of steel= coal proportion of steel*energy consumption of steel

Units: Mtce

(054) coal emission coefficient= 2.60138

Units: Mt CO2/Mtce

(055) coal proportion of cement = WITH LOOKUP (Time,([(2005,0)-(2030,1)], (2005,0.78),(2006,0.75),(2007,0.73),(2008 ,0.79),(2009,0.79),(2010,0.72),(2011,0.72) ,(2012,0.71),(2013,0.75),(2014,0.74),(2015,0.74),(2016,0.73),(2017,0.7),(2018,0.65), (2019,0.61),(2020,0.61),(2021,0.56),(2030,0.48)))

Units: Dmnl

(056) coal proportion of electrolytic aluminum = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.34),(2006,0.31),(2007,0.27),(2008 ,0.32),(2009,0.34),(2010,0.25),(2011,0.24),(2012,0.21),(2013,0.26),(2014,0.25),(2015,0.21),(2016,0.2),(2017,0.2),(2018,0.19),(2019,0.2),(2020,0.18),(2021 ,0.17),(2022,0.17),(2023,0.16),(2024,0.15),(2030,0.15)))

Units: Dmnl

(057) coal proportion of power generation = WITH LOOKUP (Time, ([(2005,0)-(2030,1)],(2005,0.898169),(2006,0.93),(2007,0.93),(2008 ,0.94),(2009,0.93),(2010,0.92),(2011,0.92),(2012,0.91),(2013,0.91),(2014,0.9),(2015,0.91),(2016,0.9),(2017,0.9),(2018,0.9),(2019,0.9),(2020,0.89),(2021 ,0.89),(2025,0.88),(2030,0.85)))

Units: Dmnl

(058) coal proportion of steel = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.84),(2006,0.84),(2007,0.83),(2008,0.85),(2009,0.86),(2010,0.83),(2011,0.83),(2012,0.83),(2013,0.83),(2014,0.84),(2015,0.85),(2016,0.85),(2017,0.84),(2018,0.82),(2019,0.82),(2020,0.82),(2021 ,0.81),(2030,0.69)))

Units: Dmnl

(059) Cost of the cement= CCER trading costs of cement + carbon trading costs of cement

Units: Billion RMB

(060) Cost of the electrolytic aluminum= CCER trading costs of electrolytic aluminum + carbon trading costs of electrolytic aluminum

Units: Billion RMB

(061) Cost of the power generation= CCER trading costs of power generation + carbon trading costs of power generation

Units: Billion RMB

(062) Cost of the steel= CCER trading costs of steel + carbon trading costs of steel

Units: Billion RMB

(063) delayed CCER costs adjustment= DELAY FIXED(total CCER trading costs , 1 , 0)

Units: Billion RMB

(064) electricity emission coefficient= 4.39836

Units: Mt CO2/Mtce

(065) energy consumption of cement= IF THEN ELSE(Time>2020, real output of cement*energy intensity of cement- 2.16*real cost of cement , real output of cement*energy intensity of cement)

Units: Mtce

(066) energy consumption of electrolytic aluminum= IF THEN ELSE(Time>2020, real output of electrolytic aluminum*energy intensity of electrolytic aluminum - 1.06*real cost of electrolytic aluminum , real output of electrolytic aluminum

*energy intensity of electrolytic aluminum)

Units: Mtce

(067) energy consumption of power generation= IF THEN ELSE(Time>2020, real output of power generation*energy intensity of power generation -real cost of power generation*3.2, real output of power generation*energy intensity of power generation)

Units: Mtce

(068) energy consumption of steel= IF THEN ELSE(Time>2020, real output of steel*energy intensity of steel-2.81 *real cost of steel , real output of steel*energy intensity of steel)

Units: Mtce

(069) energy intensity of cement = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.51809),(2006,0.411186),(2007 ,0.320969),(2008,0.384958),(2009,0.365701),(2010,0.331934),(2011,0.324133) ,(2012,0.288255),(2013,0.346424),(2014,0.317948),(2015,0.283773),(2016,0.249994),(2017,0.231972),(2018,0.192452),(2019,0.191026),(2020,0.209586),(2021,0.203927),(2022,0.203723),(2023,0.202704),(2024,0.195002),(2025,0.189346),(2030,0.163438)))

Units: Mtce/Billion RMB

(070) energy intensity of electrolytic aluminum = WITH LOOKUP (Time,([(2005,0)-(2030,0.5)],(2005,0.17865),(2006,0.171609),(2007 ,0.167619),(2008,0.171084),(2009 ,0.157429),(2010,0.152054),(2011,0.148119) ,(2012,0.141562),(2013,0.157763),(2014,0.158753),(2015,0.178916),(2016,0.178006),(2017,0.181678),(2018,0.193674),(2019,0.177847),(2020,0.176386),(2021,0.171624),(2022,0.171452),(2023,0.170595),(2024,0.164112),(2025,0.159353),(2030,0.137549)))

Units: Mtce/Billion RMB

(071) energy intensity of power generation = WITH LOOKUP (Time, ([(2005,0)-(2030,2)],(2005,1.36562),(2006,1.40958),(2007,1.44378),(2008,1.36006),(2009,1.35736),(2010,1.37991),(2011,1.48382),(2012,1.43004),(2013,1.47566),(2014,1.37637),(2015,1.31685),(2016,1.29925),(2017,1.28569),(2018,1.25003),(2019,1.20806),(2020,1.21212),(2021,1.25124),(2022,1.24999),(2023,1.24374),(2024,1.19648),(2025,1.16178),(2026,1.12809),(2027,1.09538),(2028,1.06361),(2029,1.03277),(2030,1.00282)))

Units: Mtce/Billion RMB

(072) energy intensity of steel = WITH LOOKUP (Time, ([(2005,0)-(2030,1)],(2005,0.393097),(2006,0.419129),(2007 ,0.425584),(2008,0.431484),(2009,0.445319),(2010,0.417495),(2011,0.429688) ,(2012,0.412111),(2013,0.513457),(2014 ,0.499421),(2015,0.457172),(2016,0.441377),(2017,0.428785),(2018,0.387994),(2019,0.408398),(2020,0.445544),(2021,0.433514),(2022,0.43308),(2023,0.430915),(2024,0.41454),(2025,0.402519),(2030,0.347442)))

Units: Mtce/Billion RMB

(073) FINAL TIME = 2030

Units: Year

(074) free allocation rate= 0.95

Units: Dmnl

(075) free quotas of cement= initial carbon quotas of cement*free allocation rate

Units: Mt CO2

(076) free quotas of electrolytic aluminum= initial carbon quotas of electrolytic aluminum*free allocation rate

Units: Mt CO2

(077) free quotas of power generation= initial carbon quotas of power generation*free allocation rate

Units: Mt CO2

(078) free quotas of steel= free allocation rate*initial carbon quotas of steel

Units: Mt CO2

(079) GDP inflator= IF THEN ELSE(Time=2005, 1 , IF THEN ELSE(Time=2006, 1.01979 ,IF THEN ELSE (Time=2007, 1.09429 , IF THEN ELSE(Time=2008, 1.175 , IF THEN ELSE(Time=2009, 1.1818 ,IF THEN ELSE(Time=2010, 1.2664 , IF THEN ELSE(Time=2011, 1.37564 , IF THEN ELSE(Time=2012, 1.39782 , IF THEN ELSE(Time=2013, 1.43646 ,IF THEN ELSE(Time=2014 , 1.43764 , IF THEN ELSE(Time=2015, 1.44632 , IF THEN ELSE(Time=2016, 1.46695 , IF THEN ELSE(Time=2017, 1.52345 , IF THEN ELSE (Time=2018,1.58165 , IF THEN ELSE(Time=2019,1.59946,IF THEN ELSE(Time=2020,1.61577 , 0.0399047*(Time-2004)+1.00821))))))))))))))

Units: Dmnl

(080) growth rate of cement = WITH LOOKUP (Time, ([(2005,-1)-(2030,1)],(2005,0.313612),(2006,0.37898),(2007,0.181983),(2008,0.120494),(2009,0.197688),(2010,0.199),(2011,0.117612),(2012,0.102026),(2013,0.0863691),(2014,0.0714017),(2015,0.0845565),(2016,0.115799),(2017,0.24324),(2018,0.0285908),(2019,-0.0170747),(2020,0.08),
(2021,-0.015),(2022,-0.005),(2023,-0.014),(2024,0.05),(2025,0.05),(2026,0.05),(2027,0.05),
(2028,0.05),(2029,0.05),(2030,0.05)))

Units: Dmnl

(081) growth rate of electrolytic aluminum = WITH LOOKUP (Time,([(2005,-1)-(2030,1)],(2005,0.232418),(2006,0.307651),(2007 ,0.181983),(2008,0.133131),(2009,0.204112),(2010,0.205237),(2011,0.123252) ,(2012,0.0642443),(2013,0.0478752),(2014,0.0321184),(2015,0.0433559),(2016 ,0.0718219),(2017,0.0856786),(2018,0.0976665),(2019,0.0503806),(2020,0.098),(2021,0.052),(2022,0.073),(2023,0.089),(2024,0.05),(2025,0.05),(2026,0.05),(2027,0.05),(2028,0.05),(2029,0.05),(2030,0.05)))

Units: Dmnl

(082) growth rate of other industries = WITH LOOKUP (Time,([(2005,-1)-(2030,1)],(2005,0.156835),(2006,0.232252),(2007,0.183378),(2008,0.0934912),(2009 ,0.184159),(2010,0.185645),(2011,0.105334) ,(2012,0.10351),(2013,0.0878271),(2014,0.0728349),(2015,0.0860027),(2016,0.117282),(2017,0.0964991),(2018,0.0762969) ,(2019,0.0304373),(2020,0.139873),(2021,0.0506404),(2022,0.0466142),(2023,0.0510492),(2024,0.05),(2025,0.05),(2026,0.05),(2027,0.05),(2028,0.05),(2029,0.05),(2030,0.05)))

Units: Dmnl

(083) growth rate of power generation = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.0943949),(2006,0.162108),(2007,0.141697),(2008,0.0531727),(2009,0.139239),(2010,0.139027),(2011,0.0602228),(2012,0.0844335),(2013,0.0687785) ,(2014,0.0538015),(2015,0.0664771),(2016,0.0969198),(2017,0.158907),(2018,0.076555),(2019,0.030683),(2020,0.114),(2021,0.05) ,(2022,0.043),(2023,0.052),(2024,0.05),(2025,0.05),(2026,0.05),(2027,0.05) ,(2028,0.05),(2029,0.05),(2030,0.05)))

Units: Dmnl

(084) growth rate of steel = WITH LOOKUP (Time,([(2005,-1)-(2030,1)],

(2005,0.0981144),(2006,0.16651),(2007,0.182007),(2008,0.0509657),(2009,0.159591),(2010,0.160595),(2011,0.0815448),(2012,0.0609678),(2013,0.0444078),(2014,0.0284378),(2015,0.0393343),(2016,0.0673425),(2017,0.230188),(2018,0.00560993),(2019,-0.0415709),(2020,0.012),(2021,0.012),(2022,0.071),(2023,0.04),(2024,0.05),(2025,0.05),(2026,0.05),(2027,0.05) ,(2028,0.05),(2029,0.05),(2030,0.05)))

Units: Dmnl

(085) increment of cement= Value added of cement*growth rate of cement-Cost of the cement

Units: Billion RMB

(086) increment of electrolytic aluminum = Value added of electrolytic aluminum*growth rate of electrolytic aluminum -Cost of the electrolytic aluminum

Units: Billion RMB

(087) increment of other industries= Value added of other industries*growth rate of other industries

Units: Billion RMB

(088) increment of power generation= Value added of power generation*growth rate of power generation-Cost of the power generation

Units: Billion RMB

(089) increment of steel= growth rate of steel*Value added of steel-Cost of the steel

Units: Billion RMB

(090) initial carbon quotas of cement= real output of cement*carbon intensity target of cement

Units: Mt CO2

(091) initial carbon quotas of electrolytic aluminum= real output of electrolytic aluminum*carbon intensity target of electrolytic aluminum

Units: Mt CO2

(092) initial carbon quotas of power generation= real output of power generation*carbon intensity target of power generation

Units: Mt CO2

(093) initial carbon quotas of steel= real output of steel*carbon intensity target of steel

Units: Mt CO2

(094) INITIAL TIME = 2005

Units: Year

(095) natural gas consumption of cement= natural gas proportion of cement*energy consumption of cement

Units: Mtce

(096) natural gas consumption of electrolytic aluminum= natural gas proportion of electrolytic aluminum*energy consumption of electrolytic aluminum

Units: Mtce

(097) natural gas consumption of power generation= natural gas proportion of power generation*energy consumption of power generation

Units: Mtce

(098) natural gas consumption of steel= natural gas proportion of steel*energy consumption of steel

Units: Mtce

(099) natural gas emission coefficient= 1.62771

Units: Mt CO2/Mtce

(100) natural gas proportion of cement = WITH LOOKUP (Time, ([(2005,0)-(2030,1)],(2005,0.02),(2006,0.02),(2007,0.03),(2008 ,0.03),(2009,0.03),(2010,0.02),(2011,0.03),(2012,0.04),(2013,0.03),(2014,0.04),(2015,0.04),(2016,0.04),(2017,0.05),(2018,0.06),(2019,0.08),(2020,0.1),(2021,0.12),(2022,0.1),(2023,0.1),(2024,0.11),(2025,0.11),(2026,0.12),(2027 ,0.12),(2028,0.13),(2029,0.13),(2030,0.14)))

Units: Dmnl

(101) natural gas proportion of electrolytic aluminum = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.02),(2006,0.02),(2007,0.01),(2008, 0.01),(2009,0.01),(2010,0.02),(2011,0.03),(2012,0.05),(2013,0.05),(2014,0.06),(2015,0.05),(2016,0.05),(2017,0.06),(2018,0.06),(2019,0.06),(2020,0.05),(2021,0.06),(2030,0.1)))

Units: Dmnl

(102) natural gas proportion of power generation = WITH LOOKUP (Time,([(2005,0)-(2030,0.2)],(2005,0.00881646),(2006,0.01),(2008,0.01),(2009 ,0.02),(2013,0.02),(2014,0.03),(2015,0.03),(2016,0.04),(2021,0.04),(2025,0.04),(2030,0.04)))

Units: Dmnl

(103) natural gas proportion of steel = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0),(2006,0),(2007,0.01),(2008,0.01),(2009,0.01),(2010,0.01),(2011,0.01),(2012,0.01),(2013,0.01),(2014,0.01),(2015,0.01),(2016,0.01),(2017,0.02),(2018,0.03),(2019,0.03),(2020,0.04),(2021,0.04),(2030,0.07)))

Units: Dmnl

(104) nominal GDP= Value added of other industries + Value added of power generation + Value added of cement + Value added of electrolytic aluminum + Value added of steel

Units: Billion RMB

(105) oil consumption of cement= oil proportion of cement*energy consumption of cement

Units: Mtce

(106) oil consumption of electrolytic aluminum= oil proportion of electrolytic aluminum*energy consumption of electrolytic aluminum

Units: Mtce

(107) oil consumption of power generation= oil proportion of power generation*energy consumption of power generation

Units: Mtce

(108) oil consumption of steel= oil proportion of steel*energy consumption of steel

Units: Mtce

(109) oil emission coefficient= 2.11461

Units: Mt CO2/Mtce

(110) oil proportion of cement = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.09),(2006,0.09),(2007,0.09),(2008,0.07),(2009,0.06),(2010,0.12),(2011,0.1),(2012,0.1),(2013,0.08),(2014,0.08),(2015,0.09),(2016,0.08),(2017,0.1),(2018,0.13),(2019,0.13),(2020,0.12),(2021,0.14),(2022,0.17),(2023,0.16),(2024,0.14),(2025,0.13),(2026,0.12),(2027,0.11),(2028,0.1),(2029,0.09),(2030,0.08)))

Units: Dmnl

(111) oil proportion of electrolytic aluminum = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.09),(2006,0.08),(2007,0.08),(2008,0.08),(2009,0.07),(2010,0.09),(2011,0.07),(2012,0.06),(2013,0.05),(2014,0.04),(2015,0.04),(2016,0.03),(2017,0.03),(2018,0.03),(2019,0.03),(2020,0.03),(2021,0.03),(2030,0.03)))

Units: Dmnl

(112) oil proportion of power generation = WITH LOOKUP (Time,([(2005,0)-(2030,0.2)],(2005,0.0356785),(2006,0.03),(2007,0.02),(2008,0.02),(2009,0.01),(2030,0.01)))

Units: Dmnl

(113) oil proportion of steel = WITH LOOKUP (Time,([(2005,0)-(2030,1)],(2005,0.02),(2006,0.02),(2007,0.01),(2008,0.01),(2009,0.01),(2010,0.01),(2011,0.01),(2012,0.01),(2013,0),(2014,0),(2015,0),(2016,0),(2017,0),(2018,0),(2019,0),(2020,0),(2021,0),(2030,0)))

Units: Dmnl

(114) power generation capacity = WITH LOOKUP (Time, ([(2005,0)-(2030,160000)],(2005,24940.8),(2006,28657.3),(2007,32815.5),(2008,34668.8),(2009,37032.7),(2010,42071.6),(2011,47130.2),(2012,49875.5),(2013,54316.4),(2014,56495.8),(2015,58145.7),(2016,61424.9),(2017,64951.4),(2018,71661.3),(2019,75034.3),(2020,77790.6),(2021,85342.5),(2022,88487.1),(2023,94564),(2024,94181),(2025,104000),(2026,109160),(2027,114320),(2028,119480),(2029,124640),(2030,129800)))

Units: Billion thousand kWh

(115) primary market difference of cement= CO2 emissions of cement-free quotas of cement-auction quotas of cement

Units: Mt CO2

(116) primary market difference of electrolytic aluminum= CO2 emissions of electrolytic aluminum-free quotas of electrolytic aluminum -auction quotas of electrolytic aluminum

Units: Mt CO2

(117) primary market difference of power generation= CO2 emissions of power generation-auction quotas of power generation-free quotas of power generation

Units: Mt CO2

(118) primary market difference of steel= CO2 emissions of steel-free quotas of steel-auction quotas of steel

Units: Mt CO2

(119) Proportion of CCER projects in electricity= 0.0048+3.98*delayed CCER costs adjustment*0.0001

Units: Dmnl

(120) real cost of cement= DELAY FIXED(Cost of the cement/GDP inflator, 1, 0)

Units: Billion RMB

(121) real cost of electrolytic aluminum= DELAY FIXED(Cost of the electrolytic aluminum/GDP inflator, 1, 0)

Units: Billion RMB

(122) real cost of power generation= DELAY FIXED(Cost of the power generation/GDP inflator, 1, 0)

Units: Billion RMB

(123) real cost of steel= DELAY FIXED(Cost of the steel/GDP inflator, 1, 0)

Units: Billion RMB

(124) real output of cement= Value added of cement/GDP inflator

Units: Billion RMB

(125) real output of electrolytic aluminum= Value added of electrolytic aluminum/GDP inflator

Units: Billion RMB

(126) real output of other industries= Value added of other industries/GDP inflator

Units: Billion RMB

(127) real output of power generation= Value added of power generation/GDP inflator

Units: Billion RMB

(128) real output of steel= Value added of steel/GDP inflator

Units: Billion RMB

(129) SAVEPER = TIME STEP

Units: Year

(130) secondary market trading volume of cement= IF THEN ELSE(primary market difference of cement-CCER trading volume of cement >0, primary market difference of cement-CCER trading volume of cement, primary market difference of cement)

Units: Mt CO2

(131) secondary market trading volume of electrolytic aluminum= IF THEN ELSE(primary market difference of electrolytic aluminum-CCER trading volume of electrolytic aluminum >0, primary market difference of electrolytic aluminum-CCER trading volume of electrolytic aluminum, primary market difference of electrolytic aluminum)

Units: Mt CO2

(132) secondary market trading volume of power generation= IF THEN
 ELSE(primary market difference of power generation-CCER trading volume of
 power generation >0, primary market difference of power generation-CCER trading
 volume of power generation , primary market difference of power generation)

Units: Mt CO2

(133) secondary market trading volume of steel= IF THEN ELSE(primary market
 difference of steel-CCER trading volume of steel >0, primary market difference of
 steel-CCER trading volume of steel , primary market difference of steel)

Units: Mt CO2

(134) "self-owned electricity consumption of cement"= energy consumption of
 cement*"self-owned electricity proportion of cement"

Units: Mtce

(135) "self-owned electricity consumption of electrolytic aluminum"= energy
 consumption of electrolytic aluminum*"self-owned electricity proportion of
 electrolytic aluminum"

Units: Mtce

(136) "self-owned electricity consumption of steel"= energy consumption of
 steel*"self-owned electricity proportion of steel"

Units: Mtce

(137) "self-owned electricity proportion of cement" = WITH LOOKUP

(Time,([(2005,0)-
 (2030,1)],(2005,0.011078),(2006,0.0128074),(2007,0.0158107),(2008,0.0124546),(2
 009,0.0139288),(2010,0.0171291),(2011,0.0203957),(2012 ,0.0225962),(2013,0.0199
 516),(2014,0.0224674),(2015,0.0233793),(2016,0.028309),(2017,0.0309098),(2018,0
 .0361516),(2019,0.0384041),(2020,0.03759),(2021, 0.0425503),(2030,0.09)))

Units: Dmnl

(138) "self-owned electricity proportion of electrolytic aluminum" = WITH LOOKUP
 (Time,([(2005,0)-(2030,1)],(2005,0.17),(2006,0.19),(2007,0.22),(2008 ,0.21),
 (2009,0.22),(2010,0.26),(2011,0.3),(2012,0.34),(2013,0.34),(2014,0.38),(2015,0.44),(
 2016,0.48),(2017,0.45),(2018,0.44),(2019,0.42),(2020,0.44),(2021,0.42),(2022,0.42),(
 2023,0.41),(2024,0.4),(2025,0.39),(2026,0.38),(2027 ,0.37),(2028,0.36),(2029,0.34),(
 2030,0.33)))

Units: Dmnl

(139) "self-owned electricity proportion of steel" = WITH LOOKUP
 (Time,([(2005,0)-
 (2030,1)],(2005,0.0236431),(2006,0.0274162),(2007,0.0331581),(2008,0.0326163),(
 2009,0.0353864),(2010,0.0440108),(2011,0.0478492),(2012 ,0.0504742),(2013,0.046
 1419),(2014,0.0494458),(2015,0.0518861),(2016,0.0557214),(2017,0.059146),(2018,
 0.0669397),(2019,0.0669747),(2020,0.0663373),(2021 ,0.0714332),(2030,0.0714332)
))

Units: Dmnl

(140) TIME STEP = 1

Units: Year

(141) total CCER trading costs= CCER trading costs of power generation + CCER
 trading costs of steel + CCER trading costs of cement +CCER trading costs of
 electrolytic aluminum

Units: Billion RMB

(142) total CO2 emissions= CO2 emissions of power generation+CO2 emissions of
 steel+CO2 emissions of cement +CO2 emissions of electrolytic aluminum

Units: Mt CO2

(143) total costs= Cost of the power generation + Cost of the cement +Cost of the
 electrolytic aluminum +Cost of the steel

Units: Billion RMB

(144) Value added of cement= INTEG (increment of cement, 303.241)

Units: Billion RMB

(145) Value added of electrolytic aluminum= INTEG (increment of electrolytic
 aluminium, 208.392)

Units: Billion RMB

(146) Value added of other industries= INTEG (increment of other industries,
 17011.9)

Units: Billion RMB

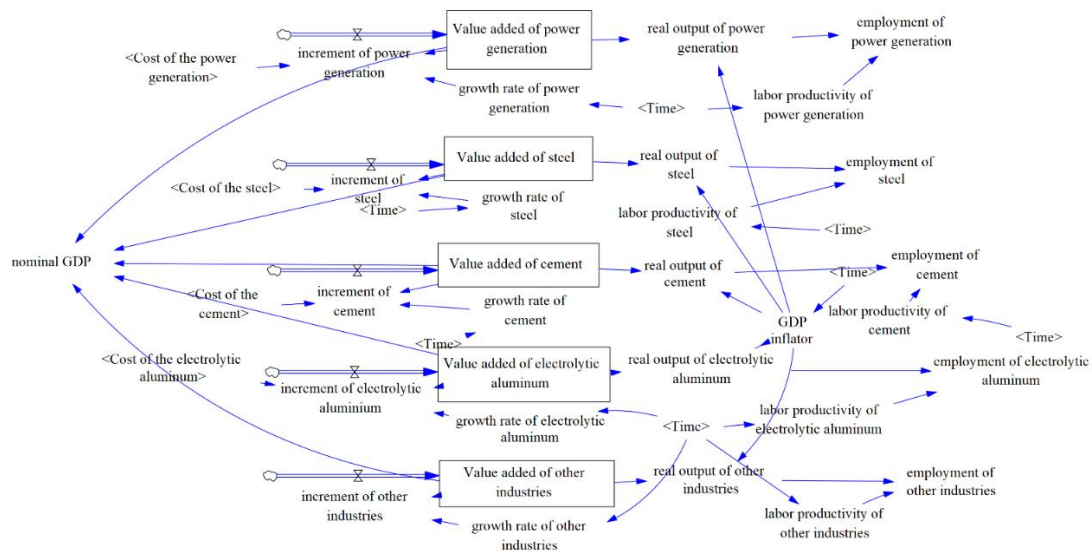
(147) Value added of power generation= INTEG (increment of power generation,
 660.492)

Units: Billion RMB

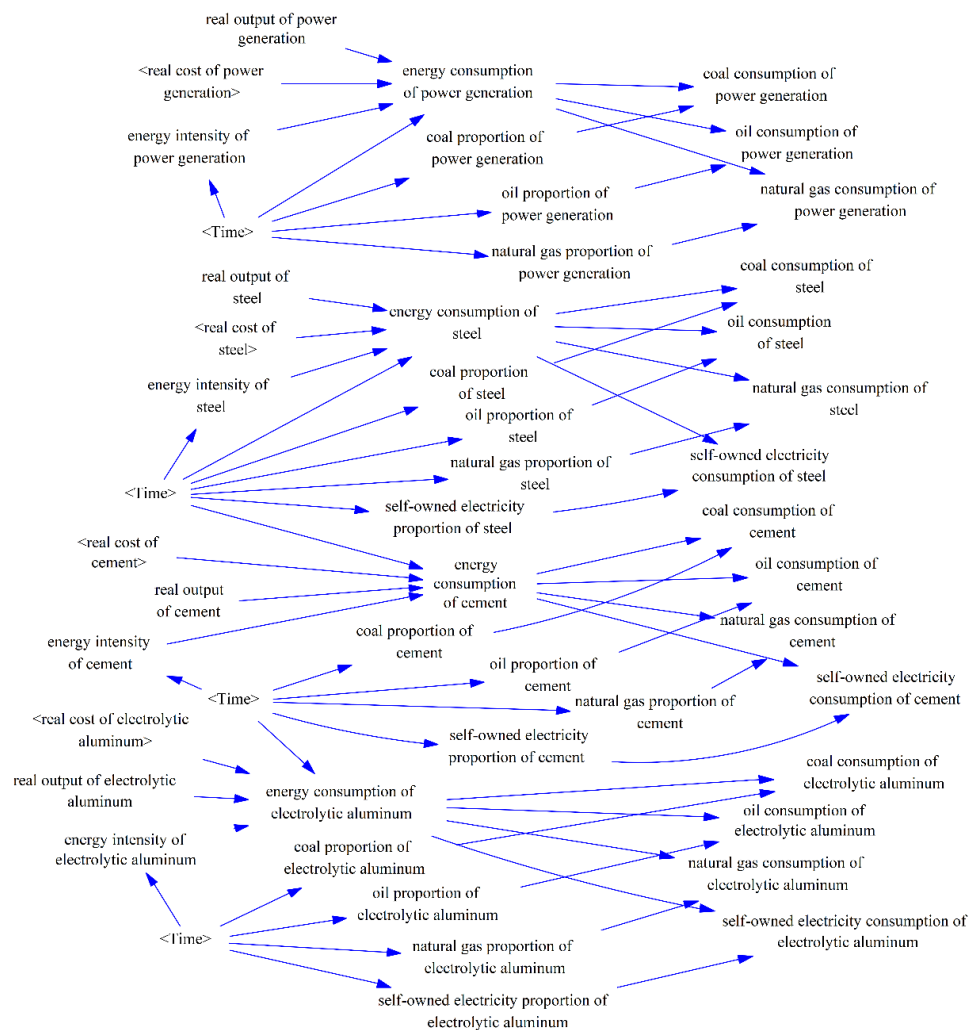
(148) Value added of steel= INTEG (increment of steel, 806.752)

Units: Billion RMB

Stock and Flow Diagram

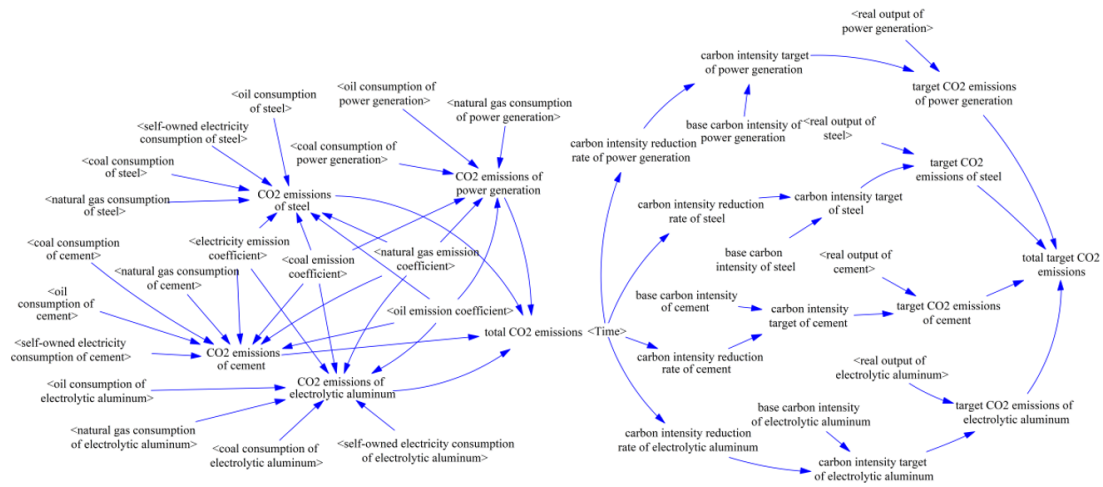


Supplementary Figure 1. Stock flow diagram of the macro-economic subsystem.

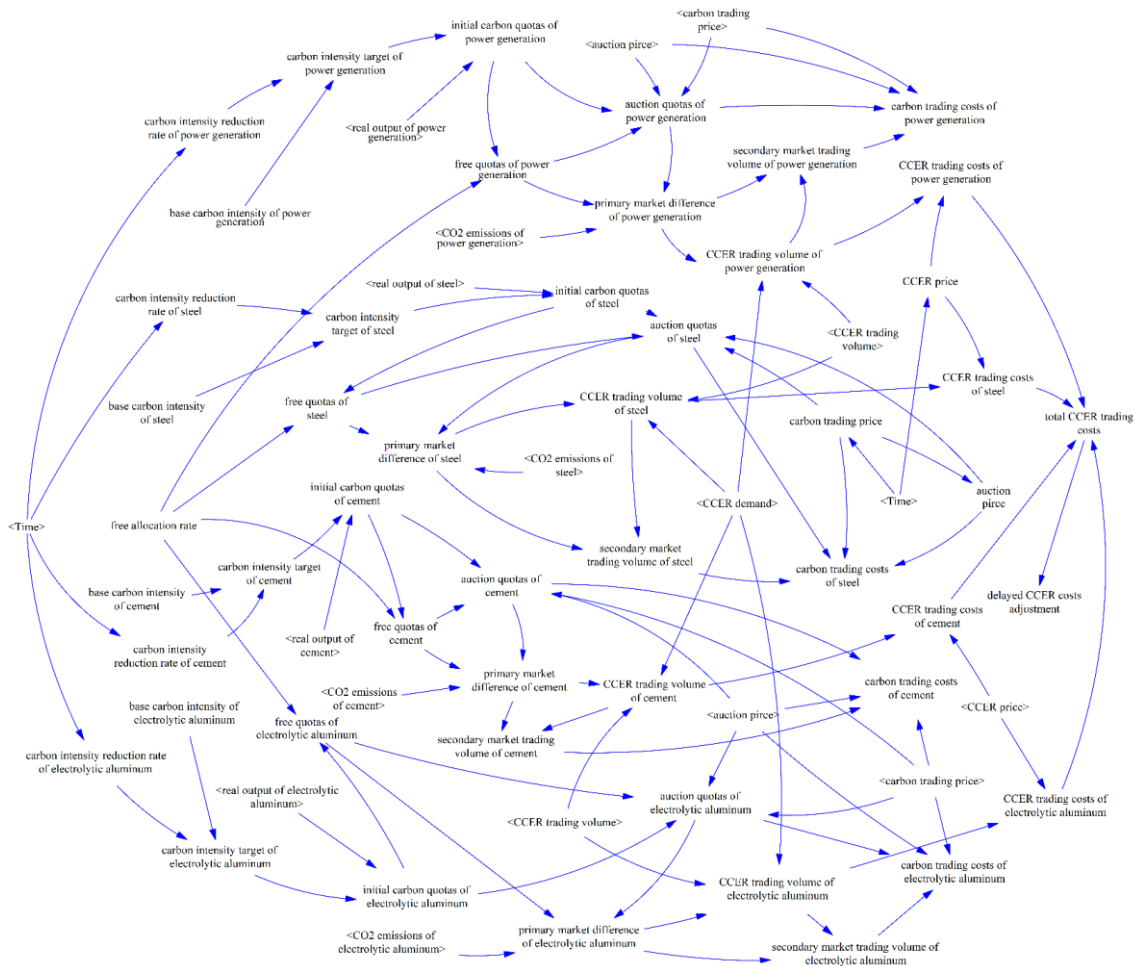


Supplementary Figure 2. Stock flow diagram of the energy subsystem. <Time>

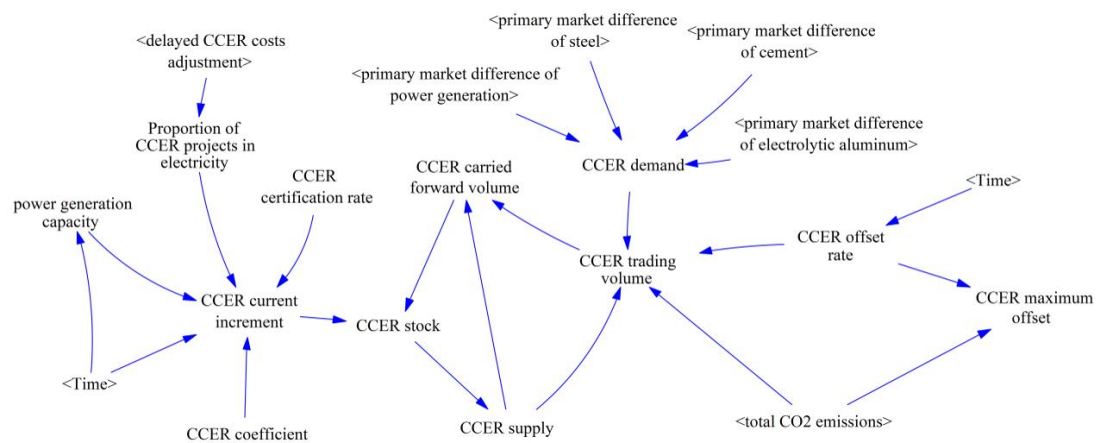
denotes simulated time, and <real cost > variables represent inflation-adjusted costs expressed in constant 2005 CNY.



Supplementary Figure 3. Stock flow diagram of the environmental subsystem.



Supplementary Figure 4. Stock flow diagram of the allowance trading module.



Supplementary Figure 5. Stock flow diagram of the emission reductions trading module.

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