Supplementary Material

Impact assessment of energy transition policy on air quality over a typical district of the Pearl River Delta region, China

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Section S1. The performance evaluation of air quality model.

The hourly meteorological observations of temperature, wind speed, and relative humidity for January, April, July, and October in 2019 from the Sugang and Ronggui national monitor sites of Shunde District were used to evaluate the performance of the WRF model and the evaluation results were listed in Table S5. For temperature and relative humidity, the Pearson correlation coefficients (R) performed well, ranging from 0.75 to 0.94 and 0.72 to 0.91, and the Normalized Mean Bias (NMB) ranged from −3.25% to 7.79% and -22.62% to 7.78%, respectively. The R and NMB of wind speed ranged from 0.50 to 0.77 and -18.55% to 24.10%. Overall, the above results were within the acceptable ranges of meteorological modeling research (Wang et al., 2016; Yin et al., 2017).

The CMAQ model performance was evaluated by comparing hourly model concentrations of SO_2, NO_2, CO, PM_{10}, $PM_{2.5}$ and O_3 with the observations from Sugang and Ronggui sites (Table S6). The NMB of SO_2, NO_2, CO, PM_{10}, $PM_{2.5}$ and O_3 ranged from -38.70% to 24.94%, -29.62% to 41.59%, -30.55% to 13.48%, -11.50% to 16.29%, -27.54% to 22.73% and -14.61% to 25.48%, respectively. The R of O_3 was high than that of other pollutants, which ranged from 0.71 to 0.86. In general, the above statistical values were acceptable as reported by the previous research (Emery et al., 2017; Yu et al., 2019).

Section S2. Calculation method of Comprehensive Air Quality Index (CAQI).

Referring to the Technical Regulation on Ambient Air Quality Index, the CAQI could be calculated by using Eq. (1) and Eq. (2).

$$SI_i = \frac{C_i}{S_i} \tag{1}$$

$$CAQI = \sum_i SI_i \tag{2}$$

Where i is the air pollutant type (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, O_3), SI_i is the single index of pollutant i, C_i is the annual concentration of pollutant i, S_i is the national Grade II annual standard of pollutant i (if i is CO, S_i is the national Grade II daily standard for CO and if i is O_3, S_i is the national Grade II maximum daily 8-hr averaged standard for O_3). The national Grade II standard of each pollutant limit was shown in Table S7.

Fig. S1. Proportions of air pollutant emissions from various anthropogenic emission sources.

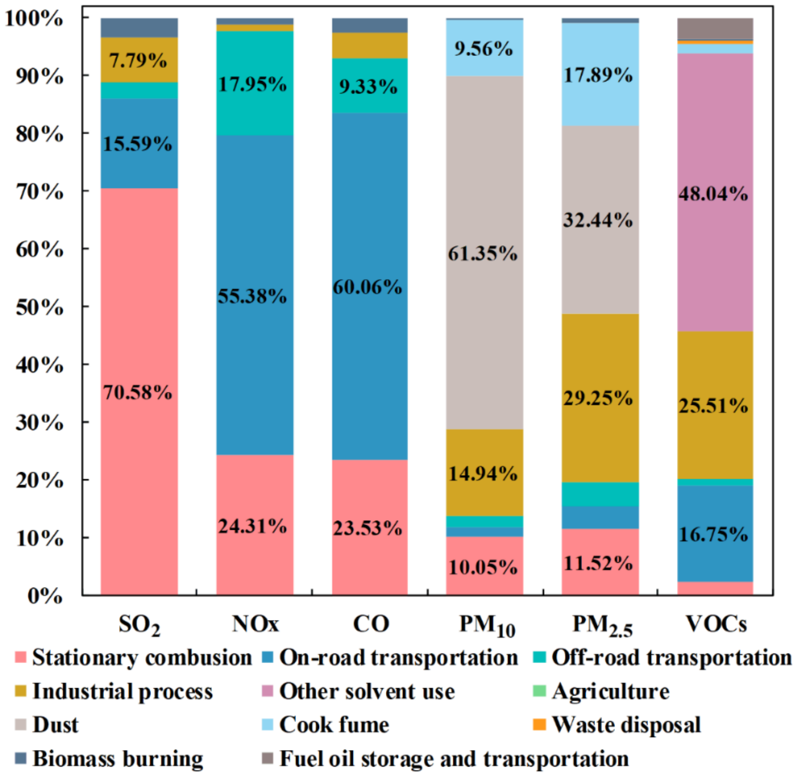

Table S1. Classification for CO_2 emission sectors in this research.

First-level sector category	Subsector category
Power	Power generation Heat production
Transportation	Light passenger vehicles Road freight Road public passenger transport Mechanical facilities Water transport
Industry	Icon and steel Chemical and Petrochemical Non-Ferrous Metals Non-Metallic Minerals Transport Equipment Machinery Food and Tobacco Paper Pulp and Print Wood and Wood Products Textiles and Leather Other industries
Building	Residential building Commercial building
Others*	/

Note: * Others includes construction and agriculture sectors.

Table S2. Correspondence between air pollution sources and CO_2 emission sectors.

Source Category	Air pollutant emission source Category		CO_2 emission sectors
	Primary sector	**Subsector**	
Energy-related emission source	Stationary combustion	Power generation	Power
		Industrial boiler	Industry
		Non-industrial boiler	Building
		Civil combustion	Building
	On-road transportation	/	Transportation
	Off-road transportation	/	
Non-energy emission source	Industrial process	/	/
	Solvent use	/	/
	Agriculture	/	/
	Dust	/	/
	Fuel oil storage and transportation	/	/
	Waste treatment	/	/
	Biomass burning	/	
	Catering	/	/.

Table S3. Main energy transition measures of the scenarios in LEAP model.

Sectors	Measures	BAU scenario	ET scenario	EET scenario
Economy, Population and Industry structure		The GDP reaches 670 billion Yuan and population reaches 3.4 million in 2030; Proportion of three industries is 1.2%, 51.8% and 47% in 2030, respectively		
Power	Reduce coal power plants	Installed capacity of coal keeps 648MW during the period	Installed capacity of coal reduces to 600 MW by 2025	Same as the ET scenario;
	Construct natural gas cogeneration plant	Installed capacity of natural gas cogeneration keeps 1197MW during the period	Installed capacity of natural gas cogeneration increases to 1474MW by 2025	Same as the ET scenario
	Develop renewable energy power	Installed capacity of renewable energy keeps 180MW during the period	Installed capacity of renewable energy increases to 260 MW by 2030	Installed capacity of renewable energy increases to 340 MW by 2030
Transportation	Clean energy replacement	Proportion of electric cars for buses increases to 100% in 2025; Proportion of electric cars for cabs and private cars increases to 100% and 20% in 2030, respectively; The proportion of natural gas and hydrogen-energy vehicles for trucks increases to 10% and 2% in 2030	Proportion of electric cars for bus and cabs increases to 100% in 2025; Proportion of electric cars for private car stock increases to 30% in 2030; The proportion of natural gas and hydrogen-energy vehicles for trucks increases to 15% and 6% in 2030	Proportion of electric cars for bus and cabs increases to 100% in 2025; Proportion of electric cars for private car stock increases to 35% in 2030; The proportion of natural gas and hydrogen-energy vehicles for trucks increases to 18% and 8% in 2030
	Efficiency improvement	Energy intensity of public road transportation and waterway cargo transport keeps same as 2019 during the period	Energy intensity of public road transportation and waterway cargo transport decreases 10% and 5% by 2030, respectively.	Energy intensity of public road transportation and waterway cargo transport decreases 15% and 10% by 2030, respectively.
Industry	Energy consumption structure adjustment	Proportion of coal decreases to 20% while electricity increases to 55% in 2030	Proportion of coal decreases to 15% while electricity increases to 57% in 2030	Proportion of coal decreases to 10% while electricity increases to 59% in 2030
	Efficiency improvement	Energy intensity decrease 20% during the period	Energy intensity decrease 25% during the period	Energy intensity decrease 30% during the period
Building	Efficiency improvement	Energy intensity of residential buildings and commercial buildings decreases 7% and 10% during the period	Same as the BAU scenario	Same as the BAU scenario

Table S4. Available measures for air pollution control.

Sectors	Measures
Stationnary combustion	(1) Retrofit of flue gas denitrification in coal-fired unit and gas-fired unit (2) Upgrading of low nitrogen burner in gas-fired unit (3) Replace high-emission boilers with new environmentally boilers
Transportation	(1) Implement higher stage emission standards and oil use standards for new vehicles (2) Promote the installation of diesel particulate filters (DPF) on medium and heavy diesel vehicles (3) Control the growth of private car ownership (4) Eliminate unregistered or smoky construction machinery (5) Rectify ships that couldn’t meet environmental standards
Industrial process	(1) Adopt more stringent end-of-pipe treatment technology for VOCs (2) Strengthen the collection of exhaust gases from production plants involving VOCs (3) Limit the pollutant emission from steel, cement and other industries
Solvent use	(1) Promote the use of raw or auxiliary materials with low volatile organic compounds (VOCs) contents (2) Promote water-based paints, water-based adhesives, water-based inks, water-based cleaning agents
Dust	(1) Strengthen dust prevention and control for road transportation and construction sites (2) Strengthen on-line monitoring and control of dust emissions from construction
Fuel oil storage and transportation	(1) Promote the collection and management of VOC emissions from oil stations, oil storage depots and tanker trucks
Biomass burning	(1) Strengthen the control of rural biomass fuel combustion
Catering	(1) Strengthen on-line monitoring and control for oil fume

Table S5. Validation of temperature, wind speed, and relative humidity at monitor sites in 2019.

Site	Month	Temperature (℃)		Wind speed ($m\ s^{-1}$)		Relative humidity (%)	
		NMB (%)	R	NMB (%)	R	NMB (%)	R
SG	JAN	6.64	0.94	24.10	0.77	-8.62	0.88
	APR	7.79	0.86	10.10	0.50	-13.69	0.76
	JUL	7.38	0.75	14.21	0.70	-22.62	0.72
	OCT	-2.93	0.91	-17.67	0.59	-14.03	0.83
RG	JAN	-3.25	0.90	-18.55	0.67	0.99	0.88
	APR	7.77	0.85	-5.14	0.77	7.78	0.78
	JUL	7.60	0.80	-12.74	0.70	-1.70	0.83
	OCT	2.62	0.89	22.10	0.58	-6.46	0.91

Note: SG: Sugang, RG: Ronggui. JAN-January, APR-April, JUL-July, OCT-October. NMB: Normalized Mean Bias, R: Correlation coefficient.

NMB: normalized mean bias and R: correlation coefficient, defined as:

$$NMB=\frac{\sum_{i=1}^{N}(M_i-O_i)}{\sum_{i=1}^{N}O_i}$$

$$R=\frac{\sum_{i=1}^{N}(M_i-\bar{M})(O_i-\bar{O})}{\sqrt{\sum_{i=1}^{N}(M_i-\bar{M})^2\sum_{i=1}^{N}(O_i-\bar{O})^2}}$$

where N is the number of samples; M_i is the model value of sample i; O_i is the observed value of sample i; $\bar{M}$ is the mean value of all model values; $\bar{O}$ is the mean value of all observed values.

Table S6. Statistical comparisons of simulated and observed SO_2, NO_2, CO, $PM_{2.5}$, PM_{10}, and O_3 in 2019.

Month	Site	SO_2		NO_2		CO		PM_{10}		$PM_{2.5}$		O_3	
		NMB (%)	R	NMB (%)	R	NMB (%)	R	NMB (%)	R	NMB (%)	R	NMB (%)	R
JAN	SG	-9.21	0.49	-12.57	0.49	-30.55	0.47	5.64	0.45	-7.62	0.52	24.54	0.71
	RG	27.94	0.54	5.28	0.56	-28.55	0.44	-4.33	0.45	-7.18	0.51	3.28	0.83
APR	SG	-22.36	0.42	-29.62	0.46	-13.48	0.49	2.37	0.49	-22.03	0.48	17.65	0.81
	RG	-24.78	0.52	-13.31	0.55	-21.96	0.45	-11.50	0.50	-27.54	0.52	25.48	0.85
JUL	SG	-15.07	0.48	1.04	0.48	-20.80	0.41	16.29	0.59	-19.41	0.54	7.50	0.76
	RG	-30.67	0.53	13.73	0.57	-12.55	0.41	16.02	0.65	-16.95	0.49	19.00	0.83
OCT	SG	-38.70	0.43	28.58	0.62	-11.80	0.52	-0.61	0.52	20.03	0.55	-7.58	0.86
	RG	-21.99	0.50	41.59	0.70	-11.11	0.57	-3.14	0.54	22.73	0.53	-14.61	0.85

Note: SG: Sugang, RG: Ronggui. JAN-January, APR-April, JUL-July, OCT-October. NMB: Normalized Mean Bias, R: Correlation coefficient.

Table S7. The air pollutants concentration limits.

Pollutant	Averaging time	Grade II standard	Unit
SO_2	Annual 24-hours (or daily) Hourly	60 150 500	μg m^{-3}
NO_2	Annual 24-hours Hourly	40 80 200	μg m^{-3}
PM_{10}	Annual 24-hours	70 150	μg m^{-3}
$PM_{2.5}$	Annual 24-hours	35 75	μg m^{-3}
O_3	Daily, 8-hour maximum Hourly	160 200	μg m^{-3}
CO	24-hours Hourly	4 10	mg m^{-3}

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