Design and optimization of a coal substitution path based on cost–benefit analysis: evidence from coal resource-based cities in China

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Supplementary Information Contents

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Part 1. Accounting basis for coal substitution costs

1. Accounting for the incremental costs of coal substitution

Tables S1 and S2 describe the calculation basis. To facilitate the calculation, the electricity price of civil sources was set to 0.23 CNY/kWh. It was obtained from the average distributed electric heating price and centralized electric heating flat load price. The electricity price of industrial boiler sources was set to 0.36 CNY/kWh according to the 35–110 kV flat load price of the Xinjiang power grid.

Table S1. Electricity and natural gas prices of civil sources in the study area.

Electric heating price (CNY/kWh)		Conversion factor from electricity to coal equivalent (10^4 tce/10^8 kWh)	Natural gas price (CNY/m^3)	Conversion factors from natural gas to coal equivalent (10^4 tce/10^8 m^3)	
Distributed	Centralized (Flat load)			Final consumption	Heating
0.22	0.24	3.03	1.34	12.02	12.19

Table S2. Electricity and gas prices of industrial boiler sources in the study area.

Electricity price (CNY/kWh)	Conversion factor from electricity to coal equivalent (10^4 tce/10^8 kWh)	Natural gas price (CNY/m^3)	Conversion factor from natural gas to coal equivalent (10^4 tce/10^8 m^3)
0.36	3.03	1.32	12.19

2. Accounting for the savings of coal substitution

Table S3 shows the calculation basis.

Table S3. Sales price of coal in the study area.

Sales price (CNY/t)	Conversion factors from raw coal to coal equivalent (tce/t)	
	Final consumption	Heating
350	0.69	0.65

Part 2. Estimation of the emission reduction potential of air pollutants

Table S4. Emission reduction potential under the optimal coal substitution path.

Emission situation of Air pollutants (t)				Civil Sources		Industrial boiler sources		Total	Emission reductions as a percentage of 2019 emission
				Civil combustion	Civil boiler	Industrial boiler	Industrial boilers with capacities under 65 t/h		
Air pollutant Emissions	**2019**	**SO_2**		3912.62	2053.09	5009.42	3540.61	10975.13	/
		NOx		962.29	893.48	6105.27	2918.05	7961.04	
		CO		152274.82	3350.55	26484.59	10942.69	182109.95	
		VOCs		634.48	482.48	3813.78	1575.75	4930.74	
		Particulate matter	**PM_{10}**	9326.83	307.37	260.35	128.56	9894.55	
			$PM_{2.5}$	7254.20	107.58	91.12	45.00	7452.91	
Cumulative emission reductions of air pollutant	**2025**	**SO_2**		**3912.62**	**2053.09**	**3540.61**	**3540.61**	**9506.32**	**86.62%**
		NOx	Emission reductions from coal reduction	962.29	893.48	2918.05	2918.05	/	/
			Emission increments from increased gas consumption	59.12	11.62	357.78	87.28	/	/
			Total emission reductions	**903.17**	**881.85**	**2560.27**	**2830.77**	**4345.30**	**54.58%**
		CO	Emission reductions from coal reduction	152274.82	3350.55	10942.69	10942.69	/	/

			Emission increments from increased gas consumption	78.96	15.53	333.81	81.43	/	/
			Total emission reductions	**152195.86**	**3335.02**	**10608.88**	**10861.26**	**166139.76**	**91.23%**
		VOCs	Emission reductions from coal reduction	634.48	482.48	1575.75	1575.75	/	/
			Emission increments from increased gas consumption	0.00	0.00	30.81	7.52	/	/
			Total emission reductions	**634.48**	**482.48**	**1544.93**	**1568.23**	**2661.89**	**53.99%**
		Particulate matter	**PM_{10}**	**9326.83**	**307.37**	**128.56**	**128.56**	**9762.77**	**98.67%**
			$PM_{2.5}$	**7254.20**	**107.58**	**45.00**	**45.00**	**7406.78**	**99.38%**
	2030	**SO_2**		**3912.62**	**2053.09**	**3540.61**	**3540.61**	**9506.32**	**86.62%**
		NOx	Emission reductions from coal reduction	962.29	893.48	2918.05	2918.05	/	/
			Emission increments from increased gas consumption	59.12	11.62	1380.21	115.22	/	/
			Total emission reductions	**903.17**	**881.85**	**1537.84**	**2802.84**	**3322.87**	**41.74%**
		CO	Emission reductions from coal reduction	152274.82	3350.55	10942.69	10942.69	/	/
			Emission increments from	78.96	15.53	1287.75	107.50	/	/

			increased gas consumption						
			Total emission reductions	**152195.86**	**3335.02**	**9654.94**	**10835.19**	**165185.81**	**90.71%**
		VOCs	Emission reductions from coal reduction	634.48	482.48	1575.75	1575.75	/	/
			Emission increments from increased gas consumption	0.00	0.00	118.87	9.92	/	/
			Total emission reductions	**634.48**	**482.48**	**1456.88**	**1565.82**	**2573.84**	**52.20%**
		Particulate matter	**PM_{10}**	9326.83	307.37	128.56	128.56	9762.77	98.67%
			$PM_{2.5}$	7254.20	107.58	45.00	45.00	7406.78	99.38%

Table S5. Emission reduction potential of civil sources under the optimal coal substitution path.

District	Emission sources	Emission base						Emission reductions						Emission reduction ratio					
		SO_2	NOx	CO	VOCs	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	VOCs	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	VOCs	PM_{10}	$PM_{2.5}$
Changeji City	Civil Combustion	959.90	236.08	37358.21	155.66	2288.19	1779.70	959.90	221.58	37338.84	155.66	2288.19	1779.70	/	/	/	/	/	/
	Civil boiler	181.40	65.09	244.10	35.15	9.50	3.32	181.40	64.25	242.97	35.15	9.50	3.32	/	/	/	/	/	/
Fukang	Civil Combustion	549.85	135.23	21399.55	89.16	1310.72	1019.45	549.85	126.93	21388.46	89.16	1310.72	1019.45	/	/	/	/	/	/
	Civil boiler	565.40	282.41	1059.02	152.50	137.95	48.28	565.40	278.73	1054.12	152.50	137.95	48.28	/	/	/	/	/	/
Hutubi	Civil Combustion	375.83	92.43	14626.94	60.95	895.40	696.81	375.83	86.76	14619.36	60.95	895.90	696.81	/	/	/	/	/	/
	Civil boiler	405.85	159.16	596.84	85.94	47.75	16.71	405.85	157.09	594.07	85.94	47.75	16.71	/	/	/	/	/	/
Jimsar	Civil Combustion	522.62	128.54	20339.71	84.75	1245.81	968.96	522.62	120.64	20329.17	84.75	1245.81	968.96	/	/	/	/	/	/
	Civil boiler	170.19	99.23	372.12	53.58	18.64	6.52	170.19	97.94	370.39	53.58	18.64	6.52	/	/	/	/	/	/
Manasi	Civil Combustion	424.64	104.44	16526.59	68.86	1012.25	787.31	424.64	98.02	16518.02	68.86	1012.25	787.31	/	/	/	/	/	/
	Civil boiler	208.56	122.68	460.07	66.25	40.12	14.04	208.56	121.09	457.93	66.25	40.12	14.04	/	/	/	/	/	/
Mulei	Civil Combustion	328.15	80.71	12771.07	53.21	782.23	608.40	328.15	75.75	12764.45	53.21	782.23	608.40	/	/	/	/	/	/
	Civil boiler	65.00	30.59	114.71	16.52	2.16	0.76	65.00	30.19	114.17	16.52	2.16	0.76	/	/	/	/	/	/
Qitai	Civil Combustion	751.63	184.86	29252.74	121.89	1791.73	1393.57	751.63	173.50	29237.57	121.89	1791.73	1393.57	/	/	/	/	/	/
	Civil boiler	456.69	134.32	503.70	72.53	51.26	17.94	456.69	132.57	501.37	72.53	51.26	17.94	/	/	/	/	/	/

District	Emission sources	Emission base						Emission reductions						Emission reduction ratio					
		SO_2	NOx	CO	VOCs	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	VOCs	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	VOCs	PM_{10}	$PM_{2.5}$
Total	Civil Combustion	3912.62	962.29	152274.82	634.48	9326.83	7254.20	3912.62	903.17	152195.86	634.48	9326.83	7254.20	100.00	93.86	99.95	100.00	100.00	100.00
	Civil boiler	2053.09	893.48	3350.55	482.48	307.37	107.58	2053.09	881.85	3335.02	482.48	307.37	107.58	100.00	98.70	99.54	100.00	100.00	100.00