Table S1. The major parameters used in sub-sector for TOS in the LEAP-Hebei model.

Terminal Sectors	2015	2016–2020	2021–2030	2031–2040	2041–2050
Primary sector [a]	Raw coal and diesel account for 51.79%, natural gas and electricity account for 28.67% [1]	Raw coal and diesel account for 49.20%, natural gas and electricity replace 5% of raw coal and diesel [2,3]	Raw coal and diesel account for 44.02%, natural gas and electricity replace 15% of raw coal and diesel [2,3]	Raw coal and diesel account for 36.25%, natural gas and electricity replace 30% of raw coal and diesel [2–4]	Raw coal and diesel account for 31.07%, natural gas and electricity replace 40% of raw coal and diesel [2–4]
Industrial sector [b]	Raw coal and coke account for 59.97%, natural gas and electricity account for 15.64% [1]	Raw coal and coke account for 53.97%, natural gas and electricity replace 10% of raw coal and coke [2,3]	Raw coal and coke account for 44.97%, natural gas and electricity replace 25% of raw coal and coke [2,3]	Raw coal and coke account for 35.98%, natural gas and electricity replace 40% of raw coal and coke [2–4]	Raw coal and coke account for 29.99%, natural gas and electricity replace 50% of raw coal and coke [2–4]
Construct sector [c]	Raw coal and diesel account for 26.93%, natural gas and electricity account for 18.36% [1]	Raw coal and diesel account for 24.24%, natural gas and electricity replace 10% of gasoline and diesel [2,3]	Raw coal and diesel account for 21.54%, natural gas and electricity replace 20% of gasoline and diesel [2,3]	Raw coal and diesel account for 18.83%, natural gas and electricity replace 30% of gasoline and diesel [2–4]	Raw coal and diesel account for 16.16%, natural gas and electricity replace 40% of gasoline and diesel [2–4]
Transport sector [d]	gasoline and diesel account for 72.72%, electricity account for 11.60% [1]	gasoline and diesel account for 65.45%, renewable energy replace 10% of gasoline and diesel [2,3]	gasoline and diesel account for 58.17%, renewable energy replace 20% of gasoline and diesel [2,3]	gasoline and diesel account for 50.90%, renewable energy replace 30% of gasoline and diesel [2–4]	gasoline and diesel account for 43.63%, renewable energy replace 40% of gasoline and diesel [2–4]
Commercial sector [e]	Raw coal and diesel account for 19.50%, natural gas and electricity account for 52.73% [1]	Raw coal and diesel account for 16.57%, natural gas and electricity replace 15% of raw coal and diesel [2,3]	Raw coal and diesel account for 13.65%, natural gas and electricity replace 30% of raw coal and diesel [2,3]	Raw coal and diesel account for 11.70%, natural gas and electricity replace 40% of raw coal and diesel [2–4]	Raw coal and diesel account for 9.75%, natural gas and electricity replace 50% of raw coal and diesel [2–4]
Service sector [f]	Raw coal, gasoline and diesel account for 41.25%, natural gas and electricity account for 38.10% [1]	Raw coal, gasoline and diesel account for 35.06%, natural gas and electricity replace 15% of raw coal	Raw coal, gasoline and diesel account for 28.88%, natural gas and electricity replace 30% of raw coal	Raw coal, gasoline and diesel account for 20.63%, natural gas and electricity replace 50% of raw coal	Raw coal, gasoline and diesel account for 12.38%, natural gas and electricity replace 70% of raw coal

		and diesel [2,3]	and diesel [2,3]	and diesel [2–4]	and diesel [2–4]
Thermal generation sector [g]	Raw coal account for 81.49%, natural gas account for 0.04% [1]	Raw coal account for 78.23%, natural gas replaces 4% of raw coal, transmission and distribution losses remain stable [2,3]	Raw coal account for 73.34%, natural gas replaces 10% of raw coal, transmission and distribution losses remain stable [2,3]	Raw coal account for 69.26%, natural gas replaces 15% of raw coal, transmission and distribution losses remain stable [2–4]	Raw coal account for 65.19%, natural gas replaces 20% of raw coal, transmission and distribution losses remain stable [2–4]
Heating sector [h]	Raw coal account for 77.74%, natural gas account for 1.18% [1]	Raw coal account for 72.30%, natural gas replaces 7% of raw coal [2,3]	Raw coal account for 67.63%, natural gas replaces 13% of raw coal [2,3]	Raw coal account for 64.52%, natural gas replaces 17% of raw coal [2–4]	Raw coal account for 60.63%, natural gas replaces 22% of raw coal [2–4]
Household sector [i]	In the urban sector, raw coal and gasoline account for 35.75%, natural gas and electricity account for 27.51%; in the rural sector, raw coal and gasoline account for 64.57%, natural gas and electricity account for 18.91% [1]	In the urban sector, raw coal and gasoline account for 28.60%, natural gas and electricity replace 20% of raw coal; in the rural sector, raw coal and gasoline account for 58.11%, natural gas and electricity replace 10% of raw coal [2,3]	In the urban sector, raw coal and gasoline account for 21.45%, natural gas and electricity replace 40% of raw coal; in the rural sector, raw coal and gasoline account for 51.65%, natural gas and electricity replace 20% of raw coal [2,3]	In the urban sector, raw coal and gasoline account for 14.30%, natural gas and electricity replace 60% of raw coal; in the rural sector, raw coal and gasoline account for 38.74%, natural gas and electricity replace 40% of raw coal [2–4]	In the urban sector, raw coal and gasoline account for 7.15%, natural gas and electricity replace 80% of raw coal; in the rural sector, raw coal and gasoline account for 25.82%, natural gas and electricity replace 60% of raw coal [2–4]

Note: a-i The parameters are statistic from the Hebei economic yearbook 2016 [1], the upgrading energy structure in Hebei Province [2,3] and 2050 China Energy and Carbon Report [4].

Table S2. The major parameters used in sub-sector for LCD in the LEAP-Hebei model.

Terminal Sectors	**2015**	**2016–2020**	**2021–2030**	**2031–2040**	**2041–2050**

Primary sector [a]	Effective energy intensity: 1.32×10^{-5} (tce/yuan) [1]	The effective energy intensity of the primary industry decreased by 2.5% annually [5]	The effective energy intensity of the primary industry decreased by 4.0% annually [4]	The effective energy intensity of the primary industry decreased by 2.5% annually [4]	The effective energy intensity of the primary industry decreased by 2.0% annually [4]
Industrial sector [b]	Effective energy intensity: 1.57×10^{-4} (tce/yuan) [1]	The effective energy intensity of the industrial sector decreased by 4% annually [5]	The effective energy intensity of the industrial sector decreased by 4.5% annually [4]	The effective energy intensity of the industrial sector decreased by 3.5% annually [4]	The effective energy intensity of the industrial sector decreased by 3.0% annually [4]
Construct sector [c]	Effective energy intensity: 1.69×10^{-5} (tce/yuan) [1]	The effective energy intensity of the construct sector decreased by 3.5% annually [5]	The effective energy intensity of the construct sector decreased by 3.0% annually [4]	The effective energy intensity of the construct sector decreased by 2.5% annually [4]	The effective energy intensity of the construct sector decreased by 2.0% annually [4]
Transport sector [d]	Effective energy intensity: 3.41×10^{-5} (tce/yuan) [1]	The effective energy intensity of the transport sector decreased by 2.5% annually [5]	The effective energy intensity of the transport sector decreased by 3.5% annually [4]	The effective energy intensity of the transport sector decreased by 3.0% annually [4]	The effective energy intensity of the transport sector decreased by 2.5% annually [4]
Commercial sector [e]	Effective energy intensity: 1.67×10^{-5} (tce/yuan) [1]	The effective energy intensity of the commercial sector decreased by 2.5% annually [5]	The effective energy intensity of the commercial sector decreased by 3.5% annually [4]	The effective energy intensity of the commercial sector decreased by 3.0% annually [4]	The effective energy intensity of the commercial sector decreased by 2.5% annually [4]
Service sector [f]	Effective energy intensity: $1.32E\times10^{-5}$ (tce/yuan) [1]	The effective energy intensity of the service sector decreased by 2.5% annually [5]	The effective energy intensity of the service sector decreased by 3.5% annually [4]	The effective energy intensity of the service sector decreased by 3.0% annually [4]	The effective energy intensity of the service sector decreased by 2.5% annually [4]
Thermal generation sector [g]		The thermal power generation efficiency grows to 10% and loss of transmission and distribution decrease by	The thermal power generation efficiency grows to 20% and loss of transmission and distribution decrease by	The thermal power generation efficiency grows to 25% and loss of transmission and distribution decrease by	The thermal power generation efficiency grows to 30% and loss of transmission and distribution decrease by

		1.03% annually [5]	0.75% annually [4]	0.81% annually [4]	1.12% annually [4]
Household sector [h]	Effective energy intensity of urban sector: 0.31 (tce/person); Effective energy intensity of rural sector: 0.42 (tce/person) [1]	The per capita energy intensity of urban sector and rural sector decrease by 0.5% annually [5]	The per capita energy intensity of urban sector and decrease by 1% annually and rural sector decrease by 0.7%annually [4]	The per capita energy intensity of urban sector and decrease by 1.2% annually and rural sector decrease by 0.9% annually [4]	The per capita energy intensity of urban sector and decrease by 1% annually and rural sector decrease by 0.75% annually [4]

Note: a-h The parameters are statistic from the Hebei economic yearbook 2016 [1], 2050 China Energy and Carbon Report [4] and the "13th Five-Year Plan" Energy Development Plan of Hebei [5].

Table S3. The related power production structure of REF, ISO, TOS and LCD used in the LEAP-Hebei model.

Power Structure [a] **(%)**	**REF**	**ISO**	**TOS**					**REF**				
	2015–2050	2015–2050	2015	2016–2020	2021–2030	2031–2040	2041–2050	2015	2016–2020	2021–2030	2031–2040	2041–2050
Thermal power	91.94	91.94	91.94	81.94	72.12	61.45	50.78	91.94	61.02	56.12	45.34	34.34
Wind power	7.45	7.45	7.45	11.5	16.5	20.62	26.06	7.45	19.08	21.32	24.56	28.92
Hydroelectric	0.43	0.43	0.43	2.35	2.23	2.56	2.24	0.43	2.32	1.87	1.39	1.25
Solar power	0.17	0.17	0.17	4.03	9.06	15.27	20.78	0.17	17.47	20.28	28.65	35.42
Biomass power	0.01	0.01	0.01	0.18	0.09	0.1	0.14	0.01	0.11	0.05	0.06	0.07

Note: a The parameters are statistic from the China power yearbook 2016 [6], the research on Hebei electric power consumption forecast [7], the "13th Five-Year Plan" Energy Development Plan of Hebei [5] and 2050 China Energy and Carbon Report [4].

Table S4. The adjusted energy flow balance sheet in Hebei Province (Unit: 10,000 tons standard coal) [1].

Total Primary Energy Supply	**Raw Coal**	**Cleaned Coal**	**Other Washed Coal**	**Other coal Products**	**Coke**	**Other coking Products**
1.Indigenous Production	5,312.28					
2.Import	16,103.96	777.00			2,507.05	35.59
3.Export(-)		-23.95	-960.81		-319.79	-258.48
4.Stock Change	113.09	-64.97	19.78	-41.50	-2.56	2.05
Input(-) & Output(+) of	**-15,787.88**	**-160.76**	**556.34**	**224.61**	**5,320.79**	**3,303.12**

Transformation						
1.Thermal Power	-6,145.29		-19.68	-38.62		-1,089.98
2.Heating Supply	-1,228.47		-12.68	-13.50		-292.97
3.Coal Washing	-7,933.62	6,176.24	588.70	55.00		
4.Coking	-256.63	-6,337.00			5,320.79	1,229.95
5.Petroleum Refineries						
6.Natural Gas Liquefaction						
7.Briquettes	-223.88		221.72			
8.Recovery of Energy						3,456.12
Loss						
Total Final Consumption	**5,741.45**	**527.32**	**16.92**	**183.11**	**7,505.47**	**3,082.29**
1.Agriculture, Forestry, Animal Husbandry and Fishery	94.00					
2.Industry	4,320.89	527.32	16.92	80.94	7,503.47	2,993.60
Non-Energy Use	182.98	29.53	0.13	0.31	27.66	111.14
3.Construction	9.16					
4.Transport, Storage and Post	21.56					
5.Wholesale, Retail Trade and Hotel, Restaurants	72.34			2.64		20.21
6.Others services	130.65					
7.Household Consumption	1,092.83			99.53		68.48
Urban	220.68			17.95		39.34
Rural	872.15			81.59		29.14
Statistical Difference						
Total Energy Consumption	**21,529.33**	**6,864.32**	**49.28**	**235.23**	**7,505.47**	**4,465.24**

Note: Table *S4* is the simplification of energy flow balance sheet of Hebei Province in 《*Hebei economic yearbook 2016*》 [1].

Continued-1

Total Primary Energy Supply	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	LPG	Other Petroleum Products
1.Indigenous Production	828.73						
2.Import	276.28	222.87		434.80	628.56		5.82
3.Export(-)	-113.00	-150.41	-52.50	-44.24	-751.47	-330.14	-240.30
4.Stock Change	-4.11	-9.95	-0.34	-24.26	-19.70	-1.25	-4.07
Input(-) & Output(+) of Transformation	**-2,339.56**	**636.87**	**64.96**	**722.90**	**172.20**	**197.85**	**485.96**
1.Thermal Power				-2.20	-0.03		-3.50
2.Heating Supply				-0.23	-1.11		-7.52
3.Coal Washing							
4.Coking							
5.Petroleum Refineries	-2,339.56	636.87	64.96	725.33	175.73	197.85	679.36
6.Natural Gas Liquefaction							
7.Briquettes							
8.Recovery of Energy							
Loss	**19.29**						
Total Final Consumption	**22.37**	**699.39**	**12.12**	**1,089.20**	**70.37**	**154.15**	**283.50**
1.Agriculture, Forestry, Animal Husbandry and Fishery		76.59	1.18	143.93	1.94	1.08	
2.Industry	22.37	45.27	0.90	94.93	37.49	1.90	139.28
Non-Energy Use	5.36	0.01	5.35			0.03	32.73
3.Construction		32.71	0.54	48.38	6.51	1.95	
4.Transport, Storage and Post		107.19	7.24	567.57	22.40	0.79	
5.Wholesale, Retail Trade and Hotel, Restaurants		15.41	0.69	22.00	0.71	22.10	
6.Others services		103.19	1.57	77.04	1.31	10.82	
7. Household Consumption		319.03		135.35		115.51	
Urban		202.86		51.63		58.13	
Rural		116.17		83.72		57.38	
Statistical Difference							
Total Energy Consumption	**2,381.22**	**699.39**	**12.12**	**1,091.63**	**73.90**	**154.15**	**476.90**

Continued-2

Total Primary Energy Supply	Natural Gas	LNG	Heat	Electricity	Other Energy
1.Indigenous Production	138.72			252.72	
2.Import	823.00	9.39		837.35	
3.Export(-)					
4.Stock Change	-0.67	-0.40			
Input(-) & Output(+) of Transformation	**-38.17**	**15.67**	**1,289.53**	**2,812.81**	**62.08**
1.Thermal Power	-3.06		-151.79	2,812.81	-86.73
2.Heating Supply	-18.62		1,150.72		-5.13
3.Coal Washing					
4.Coking					
5.Petroleum Refineries					
6.Natural Gas Liquefaction	-16.49	15.67			
7.Briquettes					
8.Recovery of Energy			290.59		153.94
Loss				**239.02**	
Total Final Consumption	**922.89**	**24.66**	**1,289.53**	**3,663.87**	**62.08**
1.Agriculture, Forestry, Animal Husbandry and Fishery	9.18		3.23	121.07	
2.Industry	495.16	1.88	782.38	2,587.89	62.08
Non-Energy Use	22.74	0.23			
3.Construction	15.56		2.33	39.72	
4.Transport, Storage and Post	51.87	22.78	18.83	107.60	
5.Wholesale, Retail Trade and Hotel, Restaurants	103.61		72.58	151.56	
6.Others services	87.91		141.95	199.18	
7. Household Consumption	159.60		268.23	456.84	
Urban	146.30		268.23	179.78	
Rural	13.30			277.07	
Statistical Difference					
Total Energy Consumption	**944.70**	**24.66**	**1,441.32**	**3,902.89**	**153.94**

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