Supplementary material

Identifying optimal energy-related air pollution control strategy using a multistage factorial environment-oriented input-output model: A case study of Fujian province

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Detailed steps of Entropy-based TOPSIS method

Entropy-TOPSIS method is an objective method in calculating index weights and it is particularly suitable for evaluating emerging new objects. The initial matrix of evaluation indicators is X $=\{x_{ij}\}_{m\times n}$ ($0 \le i \le$ m, $0 \le j \le$ n), in which m is the number of analyzed scenarios, n is the number of environmental emission indicators. The weights of environmental emission indicator could be calculated through entropy method, as shown in Equations (S1) to (S4):

$$p_{ij} = \frac{x_{ij}}{\max x_j - \min x_j} \quad \text{(S1)}$$

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij}\ln(p_{ij}) \quad \text{(S2)}$$

$$h_j = 1 - e_j \quad \text{(S3)}$$

$$\omega_j = \frac{h_j}{\sum_{j=1}^{n} h_j} \quad \text{(S4)}$$

The dimensionless processing is performed on normalize the influence of environmental emission indicator matrix. The dimensionless data matrix could be obtained through Equation (S5):

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \qquad \text{(S5)}$$

The weighted normalized matrix could be calculated through Equation (S6):

$$y_{ij} = x_{ij}^{*} \times \omega_{j} \qquad \text{(S6)}$$

Determine the positive ideal solution Y^{+} and negative ideal solution Y^{-}, where Y^{+}= min {y_1, y_2......y_n} and Y^{-} = max {y_1, y_2......y_n}, the Euclidean Distance of scenario *i* to positive solution and negative positive could be calculated as follows:

$$D_{i}^{+} = \sqrt{\sum_{j=1}^{n} (y_{j}^{+} - y_{ij})^{2}} \qquad \text{(S7)}$$

$$D_{i}^{-} = \sqrt{\sum_{j=1}^{n} (y_{j}^{-} - y_{ij})^{2}} \qquad \text{(S8)}$$

The closeness degree of each analyzed scenario *i* to ideal solution could be defined as Equation (S9). According to the performance value of closeness degree, the evaluation value is arranged and ranked in the descending order. Optimized mitigation scheme could be obtained based on the simulated results.

$$f = \frac{D_{i}^{+}}{D_{i}^{+} + D_{i}^{-}} \qquad \text{(S9)}$$

In this study, system robustness, NO_x emissions, SO_2 emissions, PM emissions and VOCs emissions are selected as the evaluation indicators. The standard values of original values of these indicators are shown in Table S7. According to these values, the weights of these indicators calculated by the entropy method are 0.717, 0.025, 0.021, 0.063 and 0.175, respectively. After forcing these values into the TOPSIS, the final closeness degree is obtained (as shown in Table S7), which shows that S1, S5, S9, S13, S17 and S21 possess high satisfactory scores. Therefore, these scenarios were selected for scheme analysis to find the optimal pollution mitigation strategy.

Table S1. Taguchi experiment orthogonal array

	ELE_coal	NON_coal	CHE_coal	MET_coal	TRA_gasoline	TRA_diesel	TRA_kerosene	TRA_fuel	EQU_a	TEX_a	SER_a	CON_a	WHO_a	NO_x	SO_2	PM	VOCs
S1	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
S2	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H
S3	L	L	L	L	L	L	L	H	H	H	H	H	H	H	H	L	L
S4	L	L	L	L	L	L	L	H	H	H	H	H	H	H	H	H	H
S5	L	L	L	H	H	H	H	L	L	L	L	H	H	H	H	L	L
S6	L	L	L	H	H	H	H	L	L	L	L	H	H	H	H	H	H
S7	L	L	L	H	H	H	H	H	H	H	H	L	L	L	L	L	L
S8	L	L	L	H	H	H	H	H	H	H	H	L	L	L	L	H	H
S9	L	H	H	L	L	H	H	L	L	H	H	L	L	H	H	L	L
S10	L	H	H	L	L	H	H	L	L	H	H	L	L	H	H	H	H
S11	L	H	H	L	L	H	H	H	H	L	L	H	H	L	L	L	L
S12	L	H	H	L	L	H	H	H	H	L	L	H	H	L	L	H	H
S13	L	H	H	H	H	L	L	L	L	H	H	H	H	L	L	L	L
S14	L	H	H	H	H	L	L	L	L	H	H	H	H	L	L	H	H
S15	L	H	H	H	H	L	L	H	H	L	L	L	L	H	H	L	L
S16	L	H	H	H	H	L	L	H	H	L	L	L	L	H	H	H	H
S17	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
S18	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	H	L
S19	H	L	H	L	H	L	H	H	L	H	L	H	L	H	L	L	H
S20	H	L	H	L	H	L	H	H	L	H	L	H	L	H	L	H	L
S21	H	L	H	H	L	H	L	L	H	L	H	H	L	H	L	L	H
S22	H	L	H	H	L	H	L	L	H	L	H	H	L	H	L	H	L
S23	H	L	H	H	L	H	L	H	L	H	L	L	H	L	H	L	H
S24	H	L	H	H	L	H	L	H	L	H	L	L	H	L	H	H	L
S25	H	H	L	L	H	H	L	L	H	H	L	L	H	H	L	L	H
S26	H	H	L	L	H	H	L	L	H	H	L	L	H	H	L	H	L
S27	H	H	L	L	H	H	L	H	L	L	H	H	L	L	H	L	H
S28	H	H	L	L	H	H	L	H	L	L	H	H	L	L	H	H	L
S29	H	H	L	H	L	L	H	L	H	H	L	H	L	L	H	L	H
S30	H	H	L	H	L	L	H	L	H	H	L	H	L	L	H	H	L
S31	H	H	L	H	L	L	H	H	L	L	H	L	H	H	L	L	H
S32	H	H	L	H	L	L	H	H	L	L	H	L	H	H	L	H	L

Note: H means high level, L means low level.

Table S2. Full factorial experiment orthogonal array

	ELE_coal	NON_coal	CHE_coal	EQU_a	NO_x	SO_2		ELE_coal	NON_coal	CHE_coal	EQU_a	NO_x	SO_2		ELE_coal	NON_coal	CHE_coal	EQU_a	NO_x	SO_2
S1	L	L	L	L	L	L	S23	L	H	L	H	H	L	S45	H	L	H	H	L	L
S2	L	L	L	L	L	H	S24	L	H	L	H	H	H	S46	H	L	H	H	L	H
S3	L	L	L	L	H	L	S25	L	H	H	L	L	L	S47	H	L	H	H	H	L
S4	L	L	L	L	H	H	S26	L	H	H	L	L	H	S48	H	L	H	H	H	H
S5	L	L	L	H	L	L	S27	L	H	H	L	H	L	S49	H	H	L	L	L	L
S6	L	L	L	H	L	H	S28	L	H	H	L	H	H	S50	H	H	L	L	L	H
S7	L	L	L	H	H	L	S29	L	H	H	H	L	L	S51	H	H	L	L	H	L
S8	L	L	L	H	H	H	S30	L	H	H	H	L	H	S52	H	H	L	L	H	H
S9	L	L	H	L	L	L	S31	L	H	H	H	H	L	S53	H	H	L	H	L	L
S10	L	L	H	L	L	H	S32	L	H	H	H	H	H	S54	H	H	L	H	L	H
S11	L	L	H	L	H	L	S33	H	L	L	L	L	L	S55	H	H	L	H	H	L
S12	L	L	H	L	H	H	S34	H	L	L	L	L	H	S56	H	H	L	H	H	H
S13	L	L	H	H	L	L	S35	H	L	L	L	H	L	S57	H	H	H	L	L	L
S14	L	L	H	H	L	H	S36	H	L	L	L	H	H	S58	H	H	H	L	L	H
S15	L	L	H	H	H	L	S37	H	L	L	H	L	L	S59	H	H	H	L	H	L
S16	L	L	H	H	H	H	S38	H	L	L	H	L	H	S60	H	H	H	L	H	H
S17	L	H	L	L	L	L	S39	H	L	L	H	H	L	S61	H	H	H	H	L	L
S18	L	H	L	L	L	H	S40	H	L	L	H	H	H	S62	H	H	H	H	L	H
S19	L	H	L	L	H	L	S41	H	L	H	L	L	L	S63	H	H	H	H	H	L
S20	L	H	L	L	H	H	S42	H	L	H	L	L	H	S64	H	H	H	H	H	H
S21	L	H	L	H	L	L	S43	H	L	H	L	H	L							
S22	L	H	L	H	L	H	S44	H	L	H	L	H	H							

Note: H means high level, L means low level

Table S3. P-value test results for design factors (Taguchi analysis, response is APEE)

Designed factors	P value	Designed factors	P value
ELE_coal	<0.001	TEX_a	0.384
NON_coal	<0.001	SER_a	0.551
CHE_coal	<0.001	CON_a	0.366
MET_coal	<0.001	WHO_a	0.196
TRA_gasoline	<0.001	NO_x	<0.001
TRA_diesel	<0.001	SO_2	<0.001
TRA_kerosene	<0.001	PM	<0.001
TRA_fuel oil	<0.001	VOCs	<0.001
EQU_a	0.952		

Table S4. P-value test results for design factors (Taguchi analysis, response is robustness)

Designed factors	P value	Designed factors	P value
ELE_coal	<0.001	TEX_a	<0.001
NON_coal	<0.001	SER_a	<0.001
CHE_coal	<0.001	CON_a	<0.001
MET_coal	<0.001	WHO_a	<0.001
TRA_gasoline	0.396	NO_x	<0.001
TRA_diesel	<0.001	SO_2	<0.001
TRA_kerosene	<0.001	PM	0.038
TRA_fuel oil	<0.001	VOCs	0.028
EQU_a	<0.001		

Table S5. P-value test results for design factors (full factorial analysis, response is APEE)

Designed factors	P value	Designed factors	P value
ELE_coal	<0.001	TEX_a	<0.001
NON_coal	<0.001	NO_x	<0.001
CHE_coal	<0.001	SO_2	<0.001

Table S6. P-value test results for design factors (full factorial analysis, response is robustness)

Designed factors	P value	Designed factors	P value
ELE_coal	<0.001	TEX_a	<0.001
NON_coal	<0.001	NO_x	<0.001
CHE_coal	<0.001	SO_2	<0.001

Table S7. Standardization of indicators and evaluation results of scenarios

Scenario	R	NO_x	SO_2	PM	VOCs	F	Scenario	R	NO_x	SO_2	PM	VOCs	F	Scenario	R	NO_x	SO_2	PM	VOCs	F
S1	**1.000**	**0.000**	**0.000**	**0.000**	**0.000**	**1.000**	S23	0.023	0.707	0.091	0.197	0.214	0.543	S45	0.104	0.235	0.306	0.803	0.786	0.572
S2	0.896	0.000	0.505	0.000	0.000	0.857	S24	0.012	0.707	0.618	0.197	0.214	0.496	S46	0.091	0.235	0.887	0.803	0.786	0.516
S3	0.828	0.620	0.000	0.000	0.000	0.627	S25	0.826	0.118	0.154	0.334	0.363	0.803	S47	0.050	0.913	0.306	0.803	0.786	0.260
S4	0.766	0.620	0.505	0.000	0.000	0.593	S26	0.744	0.118	0.697	0.334	0.363	0.722	S48	0.041	0.913	0.887	0.803	0.786	0.146
S5	**0.112**	**0.000**	**0.000**	**0.000**	**0.000**	**0.997**	S27	0.685	0.767	0.154	0.334	0.363	0.475	S49	0.809	0.256	0.333	0.862	0.851	0.544
S6	0.097	0.000	0.505	0.000	0.000	0.857	S28	0.647	0.767	0.697	0.334	0.363	0.419	S50	0.718	0.256	0.921	0.862	0.851	0.490
S7	0.054	0.620	0.000	0.000	0.000	0.627	S29	0.070	0.118	0.154	0.334	0.363	0.803	S51	0.658	0.939	0.333	0.862	0.851	0.233
S8	0.042	0.620	0.505	0.000	0.000	0.593	S30	0.055	0.118	0.697	0.334	0.363	0.722	S52	0.600	0.939	0.921	0.862	0.851	0.103
S9	**0.978**	**0.049**	**0.063**	**0.138**	**0.149**	**0.919**	S31	0.011	0.767	0.154	0.334	0.363	0.475	S53	0.088	0.256	0.333	0.862	0.851	0.544
S10	0.884	0.049	0.584	0.138	0.149	0.813	S32	0.000	0.767	0.697	0.334	0.363	0.419	S54	0.074	0.256	0.921	0.862	0.851	0.490
S11	0.820	0.681	0.063	0.138	0.149	0.570	S33	0.969	0.186	0.242	0.666	0.637	0.641	S55	0.033	0.939	0.333	0.862	0.851	0.233
S12	0.772	0.681	0.584	0.138	0.149	0.527	S34	0.865	0.186	0.808	0.666	0.637	0.582	S56	0.023	0.939	0.921	0.862	0.851	0.103
S13	**0.099**	**0.049**	**0.063**	**0.138**	**0.149**	**0.919**	S35	0.799	0.852	0.242	0.666	0.637	0.331	S57	0.800	0.304	0.396	1.000	1.000	0.484
S14	0.084	0.049	0.584	0.138	0.149	0.813	S36	0.731	0.852	0.808	0.666	0.637	0.244	S58	0.717	0.304	1.000	1.000	1.000	0.436
S15	0.041	0.681	0.063	0.138	0.149	0.570	S37	0.115	0.186	0.242	0.666	0.637	0.641	S59	0.659	1.000	0.396	1.000	1.000	0.188
S16	0.030	0.681	0.584	0.138	0.149	0.527	S38	0.101	0.186	0.808	0.666	0.637	0.582	S60	0.611	1.000	1.000	1.000	1.000	0.002
S17	**0.839**	**0.070**	**0.091**	**0.197**	**0.214**	**0.884**	S39	0.061	0.852	0.242	0.666	0.637	0.331	S61	0.078	0.304	0.396	1.000	1.000	0.484
S18	0.748	0.070	0.618	0.197	0.214	0.788	S40	0.051	0.852	0.808	0.666	0.637	0.244	S62	0.064	0.304	1.000	1.000	1.000	0.436
S19	0.684	0.707	0.091	0.197	0.214	0.543	S41	0.951	0.235	0.306	0.803	0.786	0.572	S63	0.023	1.000	0.396	1.000	1.000	0.188
S20	0.633	0.707	0.618	0.197	0.214	0.496	S42	0.855	0.235	0.887	0.803	0.786	0.516	S64	0.014	1.000	1.000	1.000	1.000	0.000
S21	**0.082**	**0.070**	**0.091**	**0.197**	**0.214**	**0.884**	S43	0.793	0.913	0.306	0.803	0.786	0.260							
S22	0.067	0.070	0.618	0.197	0.214	0.788	S44	0.735	0.913	0.887	0.803	0.786	0.146							