Supplementary material

- Detailed calculation process involved in the study

1. Particle swarm optimization

PSO is inspired by animal social behavior, such as birds flocking and of fish schooling. Each bird or fish is called a particle. PSO can be applied to a multivariable problem with many local optima. Particles will roam in the search space and move together to find the optimal solution with instant information sharing. Each particle in the *d*-dimensional space is represented by its velocity and position vectors, as $x_i = [x_{i1}, x_{i2}, ..., x_{id}]$ and $v_i = [v_{i1}, v_{il}, ..., v_{id}]$, respectively, where i=1, …, n_p and n_p is the number of particles. The particle behaves according to three simple formulae to update its velocity and position vectors. 1) to refer to its current velocity; 2) to follow its own best position achieved by itself, p_{best}; 3) to follow the best performing particle in the entire population, g_{best}. Thus, in each iteration, the updating velocity and position of each particle can be given as:

$$v_i^{k+1} = w \times v_i^k + c_1 \times rand_1 \times (p_{besti}{}^k - x_i^k) + c_2 \times rand_2 \times (g_{best}{}^k - x_i^k) \quad \text{(S. Eq. 1)}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad \text{(S. Eq. 2)}$$

By this process, but not guaranteed, all particles will eventually swarm to a global optimal solution. Here *k* is the iteration counter, v_i^{k+1} and x_i^{k+1} are the updating velocity and position of the i_{th} particle at iteration *k+1*; v_i^k and x_i^k are the current velocity and position of the i_{th} particle at iteration *k*; $rand_1$ and $rand_2$ are random numbers in the range of 0 to 1; c_1 and c_2 are the cognitive and social acceleration coefficients, respectively; $p_{besti}{}^k$ is the best position of the i_{th} particle at iteration *k* achieved by its own experience; $g_{best}{}^k$ is the global best particle position at iteration *k* achieved by overall swarm experience; *w* is the inertial weight and allowed to decrease linearly as follows:

$$w = w_{min} + (w_{max} - w_{min}) \times (k_{max} - k) / k_{max} \quad \text{(S. Eq. 3)}$$

Where w_{min} and w_{max} are the minimum and maximum value of the inertial weight, respectively; and k_{max} is the maximum number of iterations. A large inertial weight tends global exploitation whereas a small inertial weight facilitates local exploitation. The linear decrease of *w* could allow a wide space search at the beginning and a local search in the end. Here, w_{max}=0.9, w_{min}=0.4, and acceleration constants c_1=2, c_2=2.

In the manuscript, the Equation (7) in Economic Emission Dispatch and Equation (11) in Economic Emission Dispatch with Varied Weights are calculated using PSO methods by coding to find the optimal values, i.e.,

Minimize

$$F = S_C \sum_{i=1}^{n} f_{C_i}(P_i) + I + O + \sum_{i=1}^{n} (S_S f_{S_i}(P_i) + S_N f_{N_i}(P_i) + S_D f_{D_i}(P_i)) \quad \text{(S. Eq. 4)}$$

Minimize

$$F=\sum_{i=1}^{n}A_C\frac{f_{C_i}(P_i)-C_{i0}(P_i)}{(\Delta C)_i}+\sum_{i=1}^{n}A_S\frac{f_{S_i}(P_i)-(SO_2)_{i0}}{(\Delta SO_2)_i}+\sum_{i=1}^{n}A_N\frac{f_{N_i}(P_i)-(NO_x)_{i0}}{(\Delta NO_x)_i}+\sum_{i=1}^{n}A_D\frac{f_{D_i}(P_i)-(D)_{i0}}{(\Delta D)_i}$$

(S. Eq. 5)

The coal consumption and pollutant emission curves are fitted by a quadratic function:

Coal:

$$f_{C_i}(P_i)=a_i(P_i)^2+b_i(P_i)+c_i \quad \text{(S. Eq. 6)}$$

SO_2:

$$f_{S_i}(P_i)=d_i(P_i)^2+e_i(P_i)+f_i \quad \text{(S. Eq. 7)}$$

NO_x:

$$f_{N_i}(P_i)=g_i(P_i)^2+h_i(P_i)+i_i \quad \text{(S. Eq. 8)}$$

Dust:

$$f_{D_i}(P_i)=p_i(P_i)^2+q_i(P_i)+r_i \quad \text{(S. Eq. 9)}$$

The coefficients of the quadratic functions above are shown in Table 1 in the original manuscript.

The results of economic emission dispatch scheme and economic emission dispatch scheme with varied weights are shown in Table 8 and Table 9 in the original manuscript.

2. Pairwise comparison in AHP

In AHP, pairwise comparisons of each criterion are conducted firstly, and the comparison matrix is obtained according to the experts' opinions.

The pairwise comparisons of basic pollutants are shown in Table S1.

Table S1. Pairwise comparisons of basic pollutants

	SO_2	NO_x	Dust
SO_2	1	1	3
NO_x	1	1	3
Dust	1/3	1/3	1

The comparisons are then converted into weights as follows.

(1) Table S1 is a matrix as:

$$\begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 3 \\ 1/3 & 1/3 & 1 \end{bmatrix}$$

The eigenvalues of the matrix is λ_1=3, λ_2=0 and λ_3=0, the corresponding eigenvectors are [0.6882, 0.6882, 0.2294]^T, [-0.2374, -0.8951, 0.3775]^T and [0.6529, -0.7566, 0.0346]^T. λ_{max} is 3, and the corresponding eigenvector of λ_{max} is [0.6882, 0.6882, 0.2294]^T.

(2) The consistency index *CI*, $CI=\frac{\lambda_{\max}-n}{n-1}=\frac{3-3}{3-1}=0$, *RI* is 0.58 indexed from Table S2 as *n*=3.

Table S2. Random index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The consistency ratio $CR = \frac{CI}{RI} = \frac{0}{0.58} = 0$. *CR*<0.1 is considered acceptable, so here the *CR* of this comparison matrix is acceptable.

(3) The eigenvector of λ_{max} is adopted and normalized into relative weights, 0~1:

$$[0.6882, 0.6882, 0.2294]^T \Rightarrow \left[\frac{0.6882}{0.6882+0.6882+0.2294}, \frac{0.6882}{0.6882+0.6882+0.2294}, \frac{0.2294}{0.6882+0.6882+0.2294}\right]^T$$

= $[0.428, 0.428, 0.144]^T$.

So the weights of SO_2, NO_x and dust are 0.428, 0.428 and 0.144, respectively.

For the specific ancillary power consumption in FGD, the pairwise comparisons are shown in Table S3.

Table S3. Pairwise comparisons of specific ancillary power consumption in FGD

	Blower	Pump	Seal blower	Oxidization blower
Blower	1	2	4	3
Pump	1/2	1	2	3/2
Seal blower	1/4	1/2	1	3/4
Oxidization blower	1/3	2/3	4/3	1

Using the same calculation method above, the weights of blower, pump, seal blower and oxidization blower are 0.463, 0.262, 0.103 and 0.172, respectively. The *CR* is 0, which is acceptable.

Table S4. Pairwise comparisons of FGD unit

	Specific power consumption	Desulfurization efficiency
Specific power consumption	1	1/2
Desulfurization efficiency	2	1

For FGD unit, as shown in Table S4, the weights of specific power consumption and desulfurization efficiency are 0.417 and 0.583, respectively. The *CR* is 0, which is acceptable.

Table S5. Pairwise comparison of specific ancillary power consumption in SCR

	Blower	Heating
Blower	1	1/7
Heating	7	1

For specific ancillary power consumption in SCR, as shown in Table S5, the weights of blower and heating are 0.125 and 0.875, respectively. The *CR* is 0, which is acceptable.

Table S6. Pairwise comparison of SCR unit

	Specific power consumption	Denitration efficiency
Specific power consumption	1	1/2
Denitration efficiency	2	1

For SCR unit, as shown in Table S6, the weights of specific power consumption and denitration efficiency are 0.417 and 0.583, respectively. The *CR* is 0, which is acceptable.

Table S7. Pairwise comparison of environment benefit

	Pollutant emission	FGD unit	SCR unit
Pollutant emission	1	10	10
FGD unit	1/10	1	1
SCR unit	1/10	1	1

For environment benefit, as shown in Table S7, the weights of pollutant emission, FGD unit and SCR unit are 0.831, 0.087 and 0.082, respectively. The *CR* is 0, which is acceptable.

Table S8. Pairwise comparison of material consumption

	Coal consumption	Auxiliary power	Desulfurizer	Denitration agent
Coal consumption	1	2	6	7
Auxiliary power	1/2	1	3	7/2
Desulfurizer	1/6	1/3	1	7/6
Denitration agent	1/7	2/7	6/7	1

For material consumption, as shown in Table S8, the weights of coal consumption, auxiliary power, desulfurizer and denitration agent are 0.561, 0.261, 0.099 and 0.079, respectively. The *CR* is 0, which is acceptable.

Table S9. Pairwise comparison between unit performances

	Material consumption	Electrical efficiency	Exergy efficiency	Environment benefit
Material consumption	1	1/2	3	2
Electrical efficiency	2	1	5	4
Exergy efficiency	1/3	1/5	1	1/2
Environment benefit	1/2	1/4	2	1

For unit performance, as shown in Table S9, the weights of material consumption, electrical efficiency, exergy efficiency and environment benefit are 0.264, 0.506, 0.087 and 0.143, respectively. The *CR* is 7.86×10^{-3}, which is acceptable.

Through the pairwise comparison, the weights of different of criterion are obtained. The weights are combined with the grey relational coefficients later to get the final score of each criterion.

3. Conversion to grey relational coefficients

In this section, the actual data of different criteria in the power plants are normalized to a grey relational coefficient from 0 to 1. The grey relational coefficient is then multiplied by the weight of each criterion obtained from section 2, and the score of each criterion can be obtained.

The procedure of the conversion is shown as follows.

For a system expressed as the matrix:

$$F=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{n2} & \cdots & x_{mn} \end{bmatrix} \quad \text{(S. Eq. 10)}$$

The factors could be transformed into values in a range of 0-1 to allow a comparison, as follows:

$$r_{ij}=\frac{x_{ij}-\min(x_i)}{\max(x_i)-\min(x_i)} \quad \text{(S. Eq. 11)}$$

$$r_{ij}=\frac{\max(x_i)-x_{ij}}{\max(x_i)-\min(x_i)} \quad \text{(S. Eq. 12)}$$

The multi-layer grey relational coefficient is expressed as:

$$\xi_{ij} = \frac{\min_i \min_j \left| r_{i0} - r_{ij} \right| + \rho \max_i \max_j \left| r_{i0} - r_{ij} \right|}{\left| r_{i0} - r_{ij} \right| + \rho \max_i \max_j \left| r_{i0} - r_{ij} \right|} \quad \text{(S. Eq. 13)}$$

ρ is the distinguishing coefficient, 0.5 (usually $\rho \in [0,1]$).

Then the matrix F is then transformed into the multilayer grey relational matrix U:

$$U = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{m1} & \xi_{n2} & \cdots & \xi_{mn} \end{bmatrix} \quad \text{(S. Eq. 14)}$$

As normalized metrics of various scheme indicators with diverse units and forms, the multilayer grey relational matrix U can then be processed and compared in AHP.

Table S10 (Table 18 in the original manuscript) shows the environment benefit of units using different dispatch schemes. In each criterion, the data in Table S10 are converted to grey relational coefficients, by multiplying its respective weight obtained in Table S1-Table S7, the final score of each criterion can be obtained.

Table S10. Environment benefit of units at different dispatch schemes

			Scheme I	Scheme II	Scheme III	Scheme IV
Pollutant emission	SO_2 (mg/kWh)		51.87	52.24	50.87	49.85
	NO_x (mg/kWh)		112.27	114.47	115.65	111.86
	Dust (mg/kWh)		13.56	12.05	12.84	12.31
FGD unit	Ancillary specific power consumption ($\times 10^{-3}$)	Blower	4.54	3.29	2.86	2.88
		Pump	3.25	2.47	1.38	1.66
		Seal blower	3.38	2.69	1.24	1.79
		Oxidization blower	0.44	0.27	0.19	0.21
	Desulfurization efficiency (%)		92.7	93.2	96.5	94.1
SCR unit	Ancillary specific power consumption ($\times 10^{-3}$)	Blower	0.52	0.36	0.20	0.24
		Heating	11.42	7.20	5.82	7.65
	Denitration efficiency (%)		78.2	78.4	79.4	73.9

For the criterion of pollution emission, the pollution emissions are converted into grey relational coefficients, shown in Table S11.

Table S11. Grey relational coefficient of pollution emissions

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Specific SO_2 emission	0.5567	0.5454	0.8641	0.8398
Specific NO_x	0.8498	0.7856	0.8546	0.8276
Specific dust emission	0.4072	1.0000	0.7559	0.7923

By multiplying its respective weight, SO_2 0.428, NO_x 0.428 and dust emission 0.144, the scores of pollution emission of each scheme are obtained, as shown in Table S12.

Table S12. Scores of pollution emission of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
Pollutant emission	0.6606	0.7137	0.8445	0.8277

The specific ancillary power consumption in FGD is shown in Table S10, and it is converted into grey relational coefficient, as shown in Table S13.

Table S13. Grey relational coefficients of specific ancillary power consumption in FGD

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Blower	1.0000	1.0000	1.0000	1.0000
Pump	0.4155	0.3966	1.0000	0.6249
Seal blower	0.3568	0.3333	1.0000	0.4729
Oxidization blower	0.4241	0.5522	1.0000	0.7532

By multiplying its respective weight, blower 0.463, pump 0.262, seal blower 0.103, oxidization blower 0.172, the final scores of each scheme in the subcriteria of specific power consumption is shown in Table S14.

Table S14. Scores of specific ancillary power consumption in FGD of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
Specific power consumption	0.6817	0.6962	1.0000	0.8050

For FGD unit, it includes two subcriteria, i.e., specific power consumption and desulfurization efficiency, the specific power consumption, which have been obtained in Table S14, and the desulfurization efficiency are converted into grey relational coefficient, as shown in Table S15. Because the desulfurization efficiency of each scheme has already met the requirement of EPA, so they are all normalized to 1.

Table S15. FGD unit performance

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Specific power consumption	0.3333	0.3437	1.0000	0.4705
Desulfurization efficiency	1.0000	1.0000	1.0000	1.0000

By multiplying its respective weight, specific power consumption 0.417, and desulfurization efficiency 0.583, the final score of FDG unit of each scheme is shown in Table S16.

Table S16. Score of FGD unit of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
FGD unit	0.7222	0.7265	1.0000	0.7794

For SCR unit, the specific ancillary power consumption includes two subcriteria, i.e., blower and heating, as shown in Table S10. They are converted into grey relational coefficients, as shown in Table S17.

Table S17. Grey relational coefficient of specific ancillary power consumption in SCR

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Blower	1.0000	1.0000	1.0000	0.6706
Heating	0.3986	0.3333	1.0000	1.0000

By multiplying its respective weight, blower 0.125 and heating 0.875, the score of specific power consumption is obtained as shown in Table S18.

Table S18. Score of specific power consumption of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
Specific power consumption	0.4738	0.4166	1.0000	0.9588

The SCR unit performance includes two subcriteria, i.e., specific power consumption which is shown in Table S18, and the denitration efficiency, they are converted into grey relational coefficients. Because the denitration efficiency of each scheme has already met the requirement of EPA, so they are all normalized to 1.

Table S19. Grey relational coefficients of SCR unit performance

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Specific power consumption	0.3671	0.3333	1.0000	0.9318
Denitration efficiency	1.0000	1.0000	1.0000	1.0000

By multiplying its respective weight, specific power consumption 0.417 and denitration efficiency 0.583, the final score of SCR unit is shown in Table S20.

Table S20. Score of SCR unit of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
SCR unit	0.7363	0.7222	1.0000	0.9716

Table S21. Grey relational coefficients of environment benefit

Subcriteria	Grey rational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Pollutant emission	0.7353	0.6823	0.8569	0.9608
FGD unit	0.7222	0.7265	1.0000	0.7794
SCR unit	0.7363	0.7222	1.0000	0.9716

By multiplying its respective weight, pollution emission 0.831, FGD unit 0.087 and SCR unit 0.082, the final score of environment benefit is shown in Table S22.

Table S22. Score of environment benefit of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
Environment benefit	0.7326	0.7013	0.9117	0.9255

The material consumption of different dispatch schemes are shown in Table S23. The data are converted into grey relational coefficients as shown in Table S24.

Table S23. Material consumption using different dispatch schemes

			Scheme			
			I	II	III	IV
Material consumption	Specific coal consumption	g/kWh	330.94	330.38	320.71	322.77
	Auxiliary power rate	%	5.17	5.01	4.56	4.88
	Desulphurization agent	g/kWh	5.47	5.12	3.82	4.22
	Denitration agent	g/kWh	1.91	1.57	1.20	1.31

Table S24. Weights of material consumption

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Coal consumption	0.3333	0.4304	1.0000	0.9147
Auxiliary power	0.3961	0.5213	1.0000	0.7624
Desulfurizer	0.7037	1.0000	1.0000	1.0000
Denitration agent	1.0000	0.9074	1.0000	0.7343

By multiplying its respective weight, coal consumption 0.561, auxiliary power 0.261, desulfurizer 0.099, and denitration agent 0.079. The score of material consumption of each scheme is shown in Table S25.

Table S25. Score of material consumption of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
Material consumption	0.4390	0.5482	1.0000	0.8691

The four primary criteria, material consumption, electrical efficiency, exergy efficiency and environment benefit are converted to grey relational coefficient, as shown in Table S26.

Table S26. Comparison of different schemes

Subcriteria	Grey relational coefficient			
	Scheme I	Scheme II	Scheme III	Scheme IV
Material consumption	0.7606	0.7572	1.0000	0.8500
Electrical efficiency	0.6798	0.6798	0.7705	0.7544
Exergy efficiency	0.6391	0.5747	1.0000	0.8982
Environment benefit	0.9797	0.9420	0.9853	0.9938

By multiplying its respective weight, material consumption 0.264, electrical efficiency 0.506, exergy efficiency 0.087 and environment benefit 0.143, the final score of each scheme is shown in Table S27.

Table S27. Score of unit performance of each scheme

	Scheme I	Scheme II	Scheme III	Scheme IV
Unit performance	0.7405	0.7286	0.8817	0.8265