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An electric energy substitute planning model with economic cost and environmental constraints

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An electric energy substitute planning model with economic cost and environmental constraints

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Abstract. The planning of electric energy substitution is one of the important bases for the decision-making of electric energy substitution propulsion. Nevertheless, there are still some problems in the planning of electric energy substitution, since the planning relies heavily on personal experience and local calculations. In this paper, a comprehensive planning model for electric energy substitute is proposed with considering the air pollution prevention, economic cost and technical feasibility of each region. The proposed planning model could be applied to efficiently and orderly develop the electric energy substitution, and consequently help to realize the energy transformation and the establishment of a green low-carbon society.

1. Introduction

Electric energy substitution is regard as an important arrangement for the implementation of the sixth meeting of the Central Financial and Economic Group, the State Council Action Plan for Air Pollution Prevention and Control, and the National Strategic Action Plan for Energy Development [1]. The important position of electric energy substitution planning is clarified in the paper. The direction and result of electric energy substitution planning will influence the overall operation state of power grid enterprises in a long time, and then influence the business structure and operation state, and influence the efficiency effect of the whole operation. The planning of electric energy substitution is one of the important bases for the decision-making of electric energy substitution propulsion, among which the determination of the construction scale and the choice of the project determine the efficiency and effect of the electric energy substitution planning to a great extent [2].

However, there are still some problems in the planning of electric energy substitution, especially in the determination of investment scale and project planning and construction, such as the lack of mature quantitative operation means and optimization path [3]. Experience-based programmes vary from person to person, are less operational, less coherent and contrary to the concept of precise planning. The existing electric energy substitute planning of the city and above is carried out by the planner on the basis of personal experience and local computation. The lack of extensive and sufficient consideration of internal and external factors, the low importance attached to benefits, the method too dependent on personal experience management means, the lack of regulatory basis, the lack of optimization approach, resulting in extensive planning, the implementation of the direction and path of electrical energy substitution is not clear, and not well connected with the market. The specific development of electrical energy substitution in some regions is limited to the assessment or construction of specific projects, lack of overall vision, does not form a systematic strategic planning.

There are no standards and procedures for the electrical energy substitution in all parts of the country, and there is no rapid and timely formation of a benign cycle of mutual promotion and interconnection.

In the face of the emerging new problems and the increasing scale of substitution, the traditional electrical energy substitution planning methods need to be improved and adapted [4]. This paper proposes a comprehensive planning model for electric energy substitute (CPMEES) considering the air pollution prevention, economic cost and technical feasibility of each region. The planning model contributes to the efficient and orderly development of electric energy substitution, and ultimately to the realization of energy transformation and the building of a green low-carbon society.

2. Electric energy substitution planning model

The CPMEES gives the plan of dividing the technical fields and the total amount of the substitute scale suitable for the national conditions of our country and the local characteristics.

The modeling process is as follows.

$$\begin{aligned} &\min_{E_{ij}} \quad \sum_{i=1}^{N} \alpha_i \sum_{j=1}^{M} \beta_{ij} P_{ij} E_{ij} \\ &s.t. \sum_{i=1}^{N}\sum_{j=1}^{M} E_{ij} \geq \max\left(E^e, E^t\right) \\ &\quad L_{ij} \leq E_{ij} \leq U_{ij} \\ &\quad \sum_{j=1}^{M} E_{ij} \geq E_i^e \end{aligned} \tag{1}$$

N indicates the number of regions covered by the plan;

M indicates the number of electric energy substitution field covered by the plan;

P_{ij} indicates the unit *cost* driving electric energy substitution in j-th technical field of i-th region;

E_{ij} indicates the planned electric energy substitution electricity in j-th technical field of i-th region;

L_{ij} indicates the lower limit of electric energy substitution electricity in j-th technical field of i-th region;

U_{ij} indicates the upper limit of electric energy substitution electricity in j-th technical field of i-th region;

α_i indicates the weight of i-th region which reflects the development situation of electric energy substitute in i-th region;

β_{ij} indicates the weight of j-th technical field in i-th region which reflects the national promotion of electric energy substitution key regions and key fields;

E^e indicates the electric energy substitution planning total electricity under the constraint of atmospheric environmental protection;

$E^e{}_i$ indicates the electric energy substitution planning electricity under the constraint of atmospheric environmental protection in i-th region;

E^t indicates the electric energy substitution total quantity estimated on the basis of electric energy substitution quantity completed last year and the rate of growth of electricity consumption in society as a whole.

3. Electric energy substitution planning example

In this example, the 26 provinces and cities (1-Beijing, 2-Tianjin, 3-Hebei, 4-Shanxi, 5-Inner Mongolia, 6-Shanxi, 7-Liaoning, 8-Jilin, 9-Heilongjiang, 10-Gansu, 11-Xinjiang, 12-Shandong, 13-Qinghai, 14-Henan, 15-Hubei, 16-Hunan, 17-Anhui, 18-Zhejiang, 19-Jibei, 20-Jiangxi, 21-Fujian, 22-Chongqing, 23-Sichuan, 24-Shanghai, 25-Ningxia, 26-Jiangsu) involved in the region of 5 technical fields (1-industry, 2-agriculture, 3-construction, 4-residential life, 5-transportation).

$$\begin{aligned}&\min_{E_{ij}} \quad \sum_{i=1}^{26}\alpha_i\sum_{j=1}^{5}\beta_{ij}P_{ij}E_{ij}\\&s.t. \sum_{i=1}^{26}\sum_{j=1}^{5}E_{ij}\geq\max\left(E^e,E^t\right)\\&L_{ij}\leq E_{ij}\leq U_{ij}\\&\sum_{j=1}^{5}E_{ij}\geq E_i^e\end{aligned} \tag{2}$$

P_{ij} is obtained by dividing the investment in i-th region j-th technical field completed last year by the scale of electrical energy substitution in i-th region j-th technical field completed last year shown in Table 1;

Table 1. Unit cost driving electric energy substitution in 5 technical field by region (yuan/kwh).

Region	unit cost driving electric energy substitution					average cost
	Industry	Construction	Residential Life	Transportation	Agriculture	
Beijing	0	2.881419	86.40852	11.50284	0	3.614861
Tianjin	0.717716	5.438676	9.039732	1.198481	5.645906	1.351497
Hebei	0.279828	2.440205	0	15.91565	1.090768	1.978301
Jibei	0.351458	2.20604	12.41472	15.73354	0.461409	1.737175
Shanxi	0.425786	3.25166	0	1.616471	0	0.678837
Shandong	0.468669	6.22598	1.603204	9.440976	0.098435	2.056023
Shanghai	0.103041	1.202685	2.633107	0.314915	6.168118	0.482203
Jiangsu	0.609961	1.432702	1.82177	71.08893	1.246056	3.925734
Zhejiang	0.29947	1.161392	3.101102	8.168797	1.585365	1.684306
Anhui	0.178651	20.71504	0.52671	2.480017	6.520653	1.339582
Fujian	0.168739	0.278485	0	2.537061	2.237095	0.318394
Hubei	0.31031	7.959584	2.27861	7.195966	2.626436	3.009177
Hunan	0.589891	5.121956	0	0.69301	4.220581	1.32518
Henan	0.499927	0.906628	0.637439	1.312534	1.384747	0.686804
Jiangxi	0.559057	1.599858	0.929999	1.24686	4.400188	0.954618
Liaoning	0.032504	3.90514	0	1.846381	0	0.682034
Jilin	0.168449	3.869323	0	0.83772	5.177299	0.9607
Heilongjiang	0.427922	2.602967	0.089033	0.569107	0.415542	0.899871
East Inner Mongolia	0.282326	4.168034	2.495445	7.434587	1.095092	1.313197
Shaanxi	0.443944	1.180272	5.06833	0.882674	2.851079	0.812906
Gangsu	0.183324	4.303837	0.314994	1.943859	0.726077	0.746571
Qinghai	0.505013	8.878621	0	0.125885	0	0.549756
Ningxia	0.521298	29.26809	0	104.1575	13.35291	1.01
Xinjiang	0.4895	14.018	725.5769	3.587428	1.503286	1.088144
Sichuang	0.636449	7.236462	18.67132	24.01208	2.850273	3.032695
Chongqing	0.454548	4.355831	31.29495	0.098348	51.13589	1.345067

L_{ij} is obtained by economic potential of electric energy substitution based on energy price comparison shown in Table 2;

Table 2. Economic potential of electric energy substitution based on energy price comparison by region (10^8kwh).

Region	Potential	Region	Potential	Region	Potential
Beijing	5.74	Shandong	13.36	Chongqing	4.19
Tianjin	4.31	Qinghai	0.96	Sichuan	13.02
Hebei	8.23	Henan	10.76	Guizhou	5.05
Shanxi	4.39	Hubei	11.11	Yunnan	5.79
Inner Mongolia	5.27	Hunan	8.39	Tibet	0.0
Shaanxi	4.62	Guangdong	19.83	Shanghai	8.88
Liaoning	12.61	Guangxi	5.51	Jiangsu	14.22
Jilin	3.36	Hainan	1.48	Zhejiang	12.14
Heilongjiang	5.80	Jiangxi	5.29	Anhui	7.46
Gansu	3.10	Fujian	6.86	Ningxia	0.90
Xinjiang	5.39			**Total**	**218.03**

U_{ij} is obtained by the electric energy substitution theoretical potential based on re-electrification target in j-th field of i-th region [5] shown in Table 3;

Table 3. Electrification levels and theoretical potential for electrical energy substitution in 5 technical fields.

Technical field	Electrification level (2020)	Potential (10^8kwh, 2020)	Electrification level (2030)	Potential (10^8kwh, 2030)
1-Industry	25%	2608	35%	17281
2-Agriculture	18%	242	25%	803
3-Construction	2%	340	10%	4494
4-Residential Life	34%	605	40%	2794
5-Transportation	4%	333	15%	4347

Table 4. Potential of electric energy substitution for environmental protection by region 2017-2030 (10^8kwh).

Region	Potential	Region	Potential	Region	Potential
Beijing	181.4	Shandong	5035.9	Chongqing	63.7
Tianjin	242.5	Qinghai	0.00	Sichuan	1571.9
Hebei	4528.7	Henan	2351.3	Guizhou	955.4
Shanxi	77.2	Hubei	960.2	Yunnan	0.00
Inner Mongolia	0.00	Hunan	1070.4	Tibet	111.0
Shaanxi	0.00	Guangdong	0.00	Shanghai	0.00
Liaoning	159.5	Guangxi	0.00	Jiangsu	1995.3
Jilin	0.00	Hainan	0.00	Zhejiang	0.00
Heilongjiang	0.00	Jiangxi	188.4	Anhui	1429.3
Gansu	0.00	Fujian	0.00	Ningxia	0.00
Xinjiang	427.7			**Total**	**21349.5**

α_i is obtained by the development strategy of electric energy substitution in different regions [6], 26 regions were divided into four levels according to the cluster analysis of regional electric energy substitution situation. α_i=1 in the areas with the best electric energy substitution situation (Beijing, Hebei, Tianjin, Shandong and so on), α_i=1.25 in the areas with good electric energy substitute situation (Shanxi, Anhui, Hubei and so on), α_i=1.5 in the areas with difficult electric energy substitution popularization (Hainan, Fujian, Heilongjiang and so on), α_i=2 in the most difficult areas to promote electric energy substitution (Xinjiang, Shanxi, Sichuan);

β_{ij} is valued based on the annual priorities of the national government and the state grid corporation. For example, promoting clean heating in the north and electric power construction of ports along the yangtze river basin are the key work of the state grid in 2018. Therefore, Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Shaanxi, Gansu, Ningxia, Xinjiang, Qinghai and other 14 provinces (autonomous regions and municipalities) as well as parts of Henan Province as designated by the Northern Region Clean Heating Plan (2017-2021) are key work regions for substituting electricity for coal β_{i3}=1, while the rest β_{i3}=1.5. Similarly, 8 provinces (Hubei, Hunan, Anhui, Jiangxi, Chongqing, Sichuan, Shanghai, Jiangsu) in the yangtze river basin are key work regions for substituting electricity for diesel oil β_{i5}=1, while the rest β_{i5}=1.5.

E^e and E^e_i are obtained by the potential model of electric energy substitution for environmental protection based on emission reduction targets [7] shown in Table 4;

E^t = 1236.25×10^8kwh. State Grid Corporation achieves 115 billion kilowatt-hours of electricity substitution in 2017, with full-year sales up 7.5 per cent.

In this example, according to CPMEES, the planned electric energy substitution electricity in j-th technical field of i-th region E_{ij} are shown in Table 5.

Table 5. Unit cost driving electric energy substitution in 5 technical field by region (10^4kwh).

Region	Electric energy substitution					Total
	Industry	Construction	Residential Life	Transportation	Agriculture	
Beijing	2648.094	170749.2	416.6256	13561.87	1843.115	189218.9028
Tianjin	220142.8	30154.4	1991.209	43388.26	1771.195	297447.8642
Hebei	450276.8	91795.56	2805.856	54914.5	42172.14	641964.856
Jibei	409721.6	38077.28	2899.784	38262.22	13003.65	501964.53
Shanxi	540177.4	24602.82	9689.478	97743.76	17201.3	689414.758
Shandong	810807	173466.7	47405.06	116937.1	142225.8	1290841.58
Shanghai	155278.54	96450.88	759.559	95263.7	648.496	348401.175
Jiangsu	590201.6	145180.2	3293.5	34885.88	6420.256	779981.436
Zhejiang	360636.8	56828.38	5159.456	80550.42	5046.156	508221.212
Anhui	425410.6	20757.86	15188.62	50806.1	8894.814	521057.99
Fujian	568926.6	71817.16	25288.18	40204	3576.066	709812.006
Hubei	244916.4	87441.76	3510.912	55586.7	5330.418	396786.19
Hunan	379731.4	80438.02	558.6872	92350.76	11372.84	564451.7092
Henan	736106.8	156624.3	15687.78	82283.56	75103.96	1065806.422
Jiangxi	125210.94	31252.78	8602.16	36892.68	5454.312	207412.872
Liaoning	430720	47629.54	5303.342	115902.4	7453.026	607008.288
Jilin	189968.14	48070.42	165.9476	31036.64	3476.716	272717.8636
Heilongjiang	98148.82	52248.06	22463.56	31628.48	28877.98	233366.9
East Inner Mongolia	92092.06	5758.11	6411.682	12105.58	14610.64	130978.076
Shaanxi	171192.7	50835.74	4340.68	106494.6	9119.354	341983.074
Gangsu	229102.4	9294.032	19047.96	87454.9	24790.76	369690.05
Qinghai	221776.6	2252.602	1438.938	15887.54	2388.624	243744.306
Ningxia	176482.6	2255.016	185.4109	76.80674	1198.241	180198.0742
Xinjiang	273748.8	6991.012	66.15426	6690.03	21286.7	308782.6963
Sichuang	559353.8	27085.06	3749.066	55721.96	6315.184	652225.07
Chongqing	131999.14	23876.04	1917.242	40671.92	782.2294	199246.5716
Total	8594778.4	1551933	208346.8	1437302	460364	**12252724.47**

4. Summary

Based on the goal of minimizing the total economic cost of electrical energy substitution, this paper constructs a planning model of electrical energy substitution based on the constraints of completing national environmental protection requirements and policy requirements and meeting the actual development of electric energy substitution in various regions. Firstly, according to the investment cost and substitute electricity quantity in the development of electric energy substitution in China, the unit economic cost of electric energy substitution in each region is calculated. Second, according to the environmental capacity of various regions in China and the emission of major pollutants in the exhaust gases calculate substitute electricity quantity in various regions under the constraints of environmental protection. Third, determine the upper and lower limits of substitute electricity quantity in each region according to economic potential of electric energy substitution based on energy price comparison and electric energy substitution theoretical potential based on re-electrification target. Fourth, estimate the electric energy substitution total quantity according to electric energy substitution quantity completed last year and the rate of growth of electricity consumption in society as a whole. Through the above steps, the programming model is established, and the optimal solution method can be used to solve the programming model.

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