AIMS Energy, 8(4): 580–614.
DOI: 10.3934/energy.2020.4.580
Received: 28 March 2020
Accepted: 12 June 2020
Published: 09 July 2020

http://www.aimspress.com/journal/energy

Research article

A DEA model to sustainability improvement of the electricity supply chain in presence dual-role factors and undesirable outputs: A case on the power industry

Mojgan Pouralizadeh*

Department of Applied Mathematics, Lahijan Branch, Islamic Azad University, Lahijan, Iran

* **Correspondence:** Email: pouralizadehmojgan@yahoo.com, pouralizadeh@Liau.ac.ir; Tel: +00989113315783

Appendix: the intermediate measures

In this appendix, the intermediate measures from supplier divisions to manufacturer divisions, from manufacture divisions to the transmitter divisions and from transmitter divisions to distributor divisions and from them to the customer divisions are presented in Tables S1–S6. Tables S7 and S8 indicates inverse intermediate measures exit from manufactures divisions and enter to suppliers divisions, exit from transmitters divisions and enter manufactures divisions. Moreover, the weights of supply chain divisions are defined in Table S9.

Table S1. The material flow (intermediate products desirable outputs) (10^6 Kwa).

DMU						
	$v^{(1,3)}_{l_{(1,3)}\,j}$	$v^{(1,4)}_{l_{(1,4)}}$	$v^{(1,5)}_{l_{(1,5)}}$	$v^{(2,3)}_{l_{(2,3)}}$	$v^{(2,4)}_{l_{(2,4)}}$	$v^{(2,5)}_{l_{(2,5)}}$
1	60.307	0	0	2875.091	220.4	758.293
2	2064.952	203.532	358.519	2336.167	1695.484	258.119
3	2548.744	1724.993	1130.38	129.687	801.96	1462.15
4	2860.549	1507.982	1504.277	932.017	1093.177	724.781
5	503.449	378.483	1765.210	467.063	286.531	1048.213

Continued on next page

DMU	$v^{(1,3)}_{1_{(1,3)}\,j}$	$v^{(1,4)}_{1_{(1,4)}}$	$v^{(1,5)}_{1_{(1,5)}}$	$v^{(2,3)}_{1_{(2,3)}}$	$v^{(2,4)}_{1_{(2,4)}}$	$v^{(2,5)}_{1_{(2,5)}}$
6	1839.757	35.852	0	1886.773	285.119	597.451
7	16.681	2028.841	6074.007	93.521	1421.775	1891.574
8	0	5307.55	419.537	206.169	1116.091	742.636
9	203.507	102.486	111.235	570.477	1230.004	589.926
10	142.515	15401.05	2053.038	1645.455	705.324	120.806

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table S2. The material flow (intermediate products desirable outputs) (10^6 Kwa).

DMU	$v^{(3,6)}_{1_{(2,7)}\,j}$	$v^{(3,7)}_{1_{(3,7)}}$	$v^{(4,6)}_{1_{(4,6)}}$	$v^{(4,7)}_{1_{(4,7)}}$	$v^{(5,6)}_{1_{(5,6)}}$	$v^{(5,7)}_{1_{(5,7)}}$
1	16849.166	0	0	954.941	0	762.931
2	6641.271	2846.259	0	6081.337	0	1066.752
3	0	7144.31	3791.372	0	2015.572	4703.002
4	4923.416	0	1666.995	3889.655	4277.035	0
5	1174.200	503.228	1069.482	0	0	8238.071
6	8439.133	0	0	1214.901	0	2353.958
7	0	259.243	4179.104	1791.044	10644.237	0
8	550.870	0	0	6689.385	11825.766	0
9	0	2796.766	5426.567	0	3625.006	0
10	7291.361	0	2448.571	0	0	1285.702

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table S3. The material flow (intermediate products desirable outputs) (10^6 Kwa).

DMU	$v^{(6,8)}_{1_{(6,8)}}$	$v^{(6,9)}_{1_{(6,9)}}$	$v^{(6,10)}_{1_{(6,10)}}$	$v^{(6,11)}_{1_{(6,11)}}$	$v^{(7,8)}_{1_{(7,8)}}$	$v^{(7,9)}_{1_{(7,9)}}$
1	11438.225	0	0	4902.096	0	499.798
2	4508.493	1932.211	0	0	0	0
3	0	0	3942.347	1689.577	8042.661	3446.851
4	0	7377.474	3161.775	0	2640.531	0
5	652.777	0	0	1523.146	0	2543.194
6	0	8184.271	0	0	356.886	0
7	10062.973	0	0	4312.703	0	1391.858
8	8402.003	0	0	3600.858	0	4399.742
9	0	0	2633.465	6144.751	813.691	1898.613
10	0	6612.050	2833.736	0	827.812	0

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table S4. The material flow (intermediate products desirable outputs) (10^6 Kwa).

DMU	$v_{1_{(7,10)}j}^{(7,10)}$	$v_{1_{(7,11)}}^{(7,11)}$	$v_{1_{(8,12)}}^{(8,12)}$	$v_{1_{(8,13)}}^{(8,13)}$	$v_{1_{(8,14)}}^{(8,14)}$	$v_{1_{(8,15)}}^{(8,15)}$
1	1166.195	0	3888.996	2058.880	1715.834	3774.614
2	2907.756	6784.863	1532.888	811.529	676.274	1487.803
3	0	0	2734.506	1447.680	1206.400	2654.080
4	574.437	377.219	897.781	475.297	396.080	871.375
5	5934.119	0	221.944	117.500	97.917	215.416
6	2498.201	713.772	121.341	64.239	53.533	117.772
7	596.511	0	3421.411	1811.335	1509.446	3320.781
8	1885.604	0	2856.681	1512.361	1260.300	2772.661
9	0	0	276.655	146.464	122.054	268.518
10	0	374.062	296.755	157.106	130.922	288.028

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table S5. The material flow (intermediate products desirable outputs) (10^6 Kwa).

DMU	$v_{1_{(9,12)}j}^{(9,12)}$	$v_{1_{(9,13)}}^{(9,13)}$	$v_{1_{(9,14)}}^{(9,14)}$	$v_{1_{(9,15)}}^{(9,15)}$	$v_{1_{(10,12)}}^{(10,12)}$	$v_{1_{(10,13)}}^{(10,13)}$
1	169.931	89.964	74.970	164.933	396.506	209.915
2	656.952	347.798	289.832	637.630	988.637	523.396
3	1171.931	620.434	517.029	1137.463	1340.398	709.622
4	2508.341	1327.945	1106.621	2434.567	1331.512	704.918
5	864.686	457.775	381.490	839.254	2017.600	1068.141
6	2782.652	1473.169	1227.641	2700.809	849.388	449.376
7	473.232	250.534	208.779	459.311	202.814	107.372
8	1495.912	791.954	659.961	1451.915	641.105	339.409
9	645.528	341.750	284.792	626.542	895.378	474.024
10	2248.097	1190.169	991.808	2181.977	963.470	510.072

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table S6. The material flow (intermediate products desirable outputs) (106 Kwa).

DMU	$v_{1_{(10,14)}j}^{(10,14)}$	$v_{1_{(10,15)}}^{(10,15)}$	$v_{1_{(11,12)}}^{(11,12)}$	$v_{1_{(11,13)}}^{(11,13)}$	$v_{1_{(11,14)}}^{(11,14)}$	$v_{1_{(11,15)}}^{(11,15)}$
1	174.922	384.844	1666.713	882.377	735.314	1617.692
2	436.163	959.559	2306.820	1221.257	1017.714	2238.972
3	591.352	1300.974	574.456	304.124	253.437	557.560
4	587.432	1292.350	128.254	67.899	56.583	124.482
5	890.118	1958.259	517.870	274.166	228.472	502.638

Continued on next page

DMU						
	$v^{(10,14)}_{1_{(10,14)}\,j}$	$v^{(10,15)}_{1_{(10,15)}}$	$v^{(11,12)}_{1_{(11,12)}}$	$v^{(11,13)}_{1_{(11,13)}}$	$v^{(11,14)}_{1_{(11,14)}}$	$v^{(11,15)}_{1_{(11,15)}}$
6	374.830	824.406	242.682	128.479	107.066	235.545
7	89.477	196.849	1466.319	776.276	646.905	1423.192
8	282.841	622.250	1224.292	648.155	540.129	1188.283
9	395.020	869.043	2089.215	1106.055	921.713	2027.768
10	425.060	935.133	127.181	67.331	56.109	123.441

Source: http//amar.tavanir.org.ir//tolid and calculations million kilo watt hour

Table S7. The inverse material flow (intermediate products desirable outputs).

DMU						
	$z^{(3,1)}_{1_{(3,1)}\,j}$	$z^{(3,2)}_{1_{(3,2)}}$	$z^{(4,1)}_{1_{(4,1)}}$	$z^{(4,2)}_{1_{(4,2)}}$	$z^{(5,1)}_{1_{(5,1)}}$	$z^{(5,2)}_{1_{(5,2)}}$
1	0	0	92.568	61.712	212.322	318.483
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	221.442	147.628	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0

Table S8. The inverse material flow (intermediate products desirable outputs).

DMU						
	$z^{(6,3)}_{1_{(6,3)}\,j}$	$z^{(6,4)}_{1_{(6,4)}}$	$z^{(6,5)}_{1_{(6,5)}}$	$z^{(7,3)}_{1_{(7,3)}}$	$z^{(7,4)}_{1_{(7,4)}}$	$z^{(7,5)}_{1_{(7,5)}}$
1	145	0	92.568	61.712	40	55
2	413	0	0	0	96	0
3	0	104	0	0	0	413
4	96	0	0	0	413	0
5	0	88	0	0	0	104
6	154	0	0	0	0	25
7	0	0	112	88	0	0
8	69	0	0	0	0	69
9	0	95	0	25	0	0
10	0	69	0	0	0	69

According to fuzzy—weighted average definition, the fuzzy index has been calculated and the entity weights, division weights and the overall weights of the 15 divisions are presented in Table 26.

Table S9. The weights of the divisions.

Supply chains Entity	Importance Weights	Division	Division Weight	Overall Weight
Suppliers	0.15	S_1	0.45	0.0675
		S_2	0.55	0.0825
Manufacturers	0.20	M_1	0.35	0.07
		M_2	0.30	0.06
		M_3	0.35	0.07
Transmitters	0.20	T1	0.65	0.13
		T2	0.35	0.07
Distributers	0.15	D1	0.25	0.0375
		D2	0.30	0.045
		D3	0.20	0.03
		D4	0.25	0.0375
Customers	0.30	C1	0.27	0.081
		C2	0.24	0.072
		C3	0.20	0.06
		C4	0.29	0.087