Electronic Supplementary Material

Optimization of biofuel supply chain integrated with petroleum refineries under carbon trade policy

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In the following, sets, parameters and variables are defined:

Sets:

I: the set of production biomass supply location i

J: the set of potential pretreatment plant locations j

K: the set of biodiesel refinery locations k

O: the set of biodiesel demand point location o

M: the set of petrochemical refinery locations m

Parameters:

d_{ij}: the distance from i to j

d_{jk}: the distance from j to k

d_{ko}: the distance from k to o

d_{jm}: the distance from j to m

d_{km}: the distance from k to m

d_{mo}: the distance from m to o

X_i: the supply of biomass at location i

D_o: the demand for biodiesel at o

C_j: the processing capacity of the pretreatment plant j

C_k: the processing capacity of biodiesel refinery k

C_m: the processing capacity of a petroleum refinery m

CJU: unit processing charges of pretreatment plant

CKU: unit processing charges for biodiesel refinery

CMU: unit processing charges for petrochemical refinery

c_{ij}: the distance transportation cost from i to j

c_{jk}: the distance transportation cost from j to k

c_{ko}: the distance transportation cost from k to o

c_{jm}: the distance transportation cost from j to m

c_{km}: the distance transportation cost from k to m

c_{mo}: the distance transportation cost from m to o

f_j: construction fee of j

f_k: construction fee of j

EIU: carbon emissions per unit of biomass in collection process

EJU: carbon emissions per unit of biomass in preprocessing

EKU: carbon emissions per unit of feedstock processed in a biodiesel refinery

EMU: carbon emissions per unit of feedstock processed in a petroleum refinery

e_{ij}: carbon emissions per kilometer of road transport from i to j

e_{jk}: carbon emissions per kilometer of road transport from j to k

e_{ko}: carbon emissions per kilometer of road transport from k to o

e_{jm}: carbon emissions per kilometer of road transport from j to m

e_{km}: carbon emissions per kilometer of road transport from k to m

e_{mo}: carbon emissions per kilometer of road transport from m to o

α: conversion rate in j

β: conversion rate in k

γ: conversion rate in m

Variables:

e: carbon cap

P: trading price of carbon emission rights in the carbon trading market

q_{ij}: the amounts of shipments from i to j

q_{jk}: the amounts of shipments from j to k

q_{ko}: the amounts of shipments from k to o

q_{jm}: the amounts of shipments from j to m

q_{km}: the amounts of shipments from k to m

q_{mo}: the amounts of shipments from m to o

Y_j: 1 if pretreatment plant j is installed, 0 otherwise

Y_k: 1 if biorefinery k is installed, 0 otherwise

A_i: collection capacity of biomass location i

A_j: processing capacity of pretreatment plant j

A_k: processing capacity of biodiesel refinery j

A_m: processing capacity of petrochemical refinery m

Model data:

Illinois county location information:

County	Latitude	Longitude
Jo Daviess	42.34251	-90.14167
Lake	42.3689363	-87.827153
Stephenson	42.314489	-89.625165
Winnebago	42.3121109	-89.1706
Boone	42.3484976	-88.826301
McHenry	42.32428942	-88.45242
Carroll	42.0385843	-89.96268
Ogle	41.9969811	-89.322695
DeKalb	41.8329981	-88.710896
Kane	41.93865289	-88.428661
DuPage	41.8243831	-88.090076
Cook	41.7376587	-87.697554
Whiteside	41.7605503	-89.850501
Lee	41.6789842	-89.322695
Kendall	41.5507043	-88.440388
Will	41.5054724	-88.090076
Rock Island	41.3998209	-90.563609
Henry	41.361088	-90.074677
Bureau	41.3599156	-89.474218
Wayne	38.3899815	-88.401604
Edwards	38.4267827	-88.050979
Wabash	38.4226484	-87.815672
Monroe	38.2742526	-90.186964
Randolph	38.0629321	-89.775534
Perry	38.0612022	-89.322695
Franklin	38.0157197	-88.90306
Hamilton	38.0543187	-88.556531
White	38.0501137	-88.246118
Montgomery	39.2363688	-89.474218
Bond	38.902985	-89.474218
St. Clair	38.400812	-89.925323
Clinton	38.5684442	-89.625165
Marion	38.7313284	-88.864698
Clay	38.7279431	-88.556531
Richland	38.7212791	-88.090076
Lawrence	38.7157534	-87.776333
Washington	38.3988869	-89.322695
Jefferson	38.2267348	-88.864698
LaSalle	41.4363987	-88.941387
Grundy	41.3500531	-88.401604
Putnam	41.238474	-89.284725
Kankakee	41.1790977	-87.776333
Mercer	41.1985037	-90.677305
Stark	41.0795661	-89.813036
Marshall	40.9972934	-89.36063
Livingston	40.8688604	-88.556531
Iroquois	40.7740275	-87.697554
Henderson	40.8335548	-90.943847
Warren	40.8758777	-90.677305
Knox	40.8776411	-90.224466
Peoria	40.7156396	-89.775534
Woodford	40.7128889	-89.1706
McLean	40.5478429	-88.864698
Ford	40.4988592	-88.20716
Vermilion	40.122469	-87.697554
Hancock	40.3849365	-91.135302
McDonough	40.3885122	-90.677305
Fulton	40.5531823	-90.224466
Tazewell	40.5522078	-89.474218
Schuyler	40.1844543	-90.63937
Mason	40.2271003	-89.925323
Logan	40.061338	-89.322695
De Witt	40.1810363	-88.90306
Champaign	40.2138865	-88.246118
Edgar	39.7131223	-87.776333
Adams	40.0577692	-91.135302
Brown	39.9379573	-90.715275
Cass	39.9398601	-90.262004
Menard	40.0221361	-89.813036
Macon	39.8949055	-89.017933
Piatt	40.0543526	-88.556531
Douglas	39.7617631	-88.20716
Moultrie	39.6020543	-88.595175
Clark	39.3824189	-87.776333
Cumberland	39.2653533	-88.20716
Coles	39.5560011	-88.246118
Shelby	39.3980704	-88.864698
Christian	39.5672183	-89.322695
Sangamon	39.7337353	-89.625165
Morgan	39.7341219	-90.224466
County	Latitude	Longitude

Pike	39.5662363	-90.8294	Williamson	37.7183241	-88.864698
Scott	39.6094934	-90.487992	Saline	37.7149675	-88.556531
Calhoun	39.1733216	-90.658333	Gallatin	37.7107751	-88.246118
Jersey	39.0704754	-90.374835	Union	37.5086525	-89.284725
Greene	39.4029862	-90.374835	Johnson	37.4203764	-88.90306
Macoupin	39.2375268	-89.925323	Pope	37.417132	-88.595175
Fayette	39.0669568	-89.017933	Hardin	37.4995097	-88.362785
Effingham	39.0621773	-88.556531	Alexander	37.1670164	-89.36063
Jasper	39.0554965	-88.090076	Pulaski	37.2512419	-89.132487
Crawfor	39.0499568	-87.776333	Massac	37.2478298	-88.7494
Jackson	37.7218304	-89.322695	Madison	38.9041402	-89.925323

Geographic location and corresponding output of ten suppliers:

	Soybean yield (bu.)	Latitude	Longitude
1	56546000	38.6467172	-89.83726
2	39206000	41.81461306	-88.24922
3	42719000	38.71823452	-88.20268
4	78091000	40.95090874	-89.27156
5	35173000	37.64904208	-88.86835
6	85071000	40.00854447	-88.04565
7	29734000	39.88389577	-90.58874
8	35456000	41.01423836	-90.48367
9	74496000	39.67638198	-89.19566
10	36460000	42.06345854	-89.628

Potential pretreatment plant location:

	Latitude	Longitude
1	41.60966	-89.04959413
2	40.92469	-88.52214426
3	41.34287	-89.79440871
4	39.46772	-88.48132937
5	40.19151	-90.08935695
6	39.40233	-89.87388923
7	38.67259	-89.02598849

The proposed biorefinery information:

Name	Latitude	Longitude	Maximum processing capacity (gal.)
Lena	42.37946	-89.8223	4000000
Gilman	40.7667	-87.9923	62000000

Danville	40.12448	-87.63	50000000
Seneca	41.31114	-88.6098	76000000

Illinois petroleum refinery information:

Name	Latitude	Longitude	Maximum processing capacity (gal.)
Joliet	41.52503	-88.0817	358463035
Robinson	39.00532	-87.7392	340132538.9
Lemont	41.67364	-88.0017	395775778.2
Wood River	38.86116	-90.0976	245628647.9

Illinois demand information:

Name	Latitude	Longitude	Demand(t)
1	39.46772	-88.4813	4200000
2	40.44906	-90.5362	2500000
3	41.60966	-89.0495	1800000
4	38.14787	-89.3528	5500000

Other parameters:

Name	Parameter value
Preprocess conversion rates	0.2
Biodiesel conversion rate in biorefinery	0.8
Biodiesel conversion rate in petroleum refinery	0.75
Preprocess unit costs	9370 $/t
Process unit costs in biodiesel refinery and petroleum refinery	0.69 M$/t
Carbon price	9 $/t
Pretreatment plant carbon emissions	48kg/t
Biorefinery carbon emissions	5500kg/t
Petroleum refinery carbon emissions	6500kg/t
Transport emissions	4.6kg/t