Electronic Supplementary Material (ESI) for Green Chemistry.

Electronic supplementary information -- Optimal Design of a Biofuel Supply Chain Using an Augmented Multi-Objective and TOPSIS Method

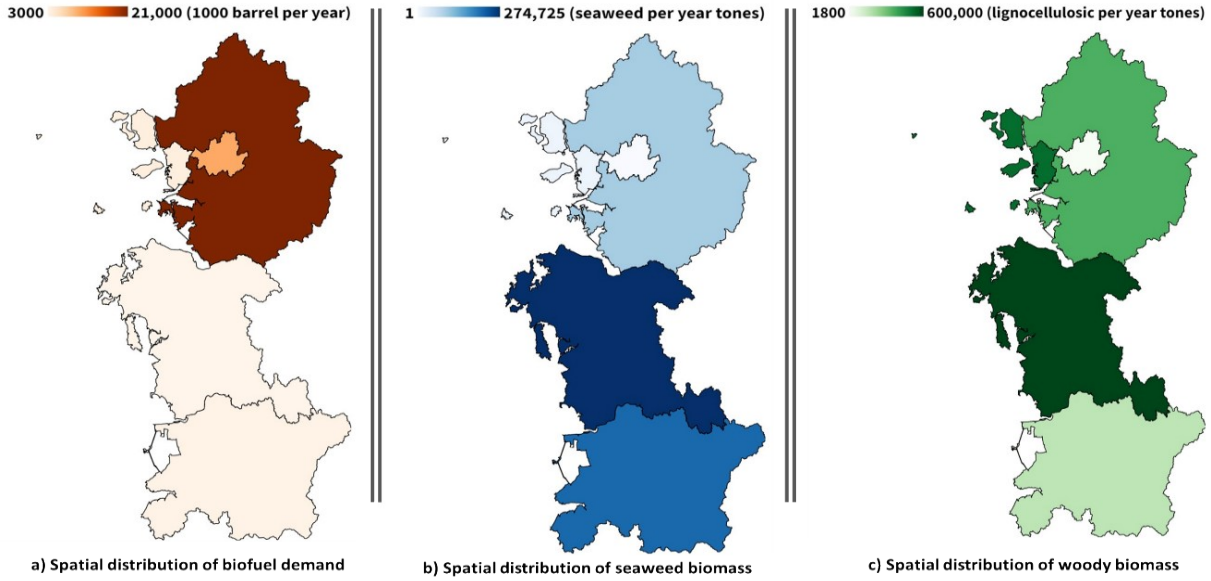

Figure I. Spatial distribution of biomass resources and biofuel demand in Korea.

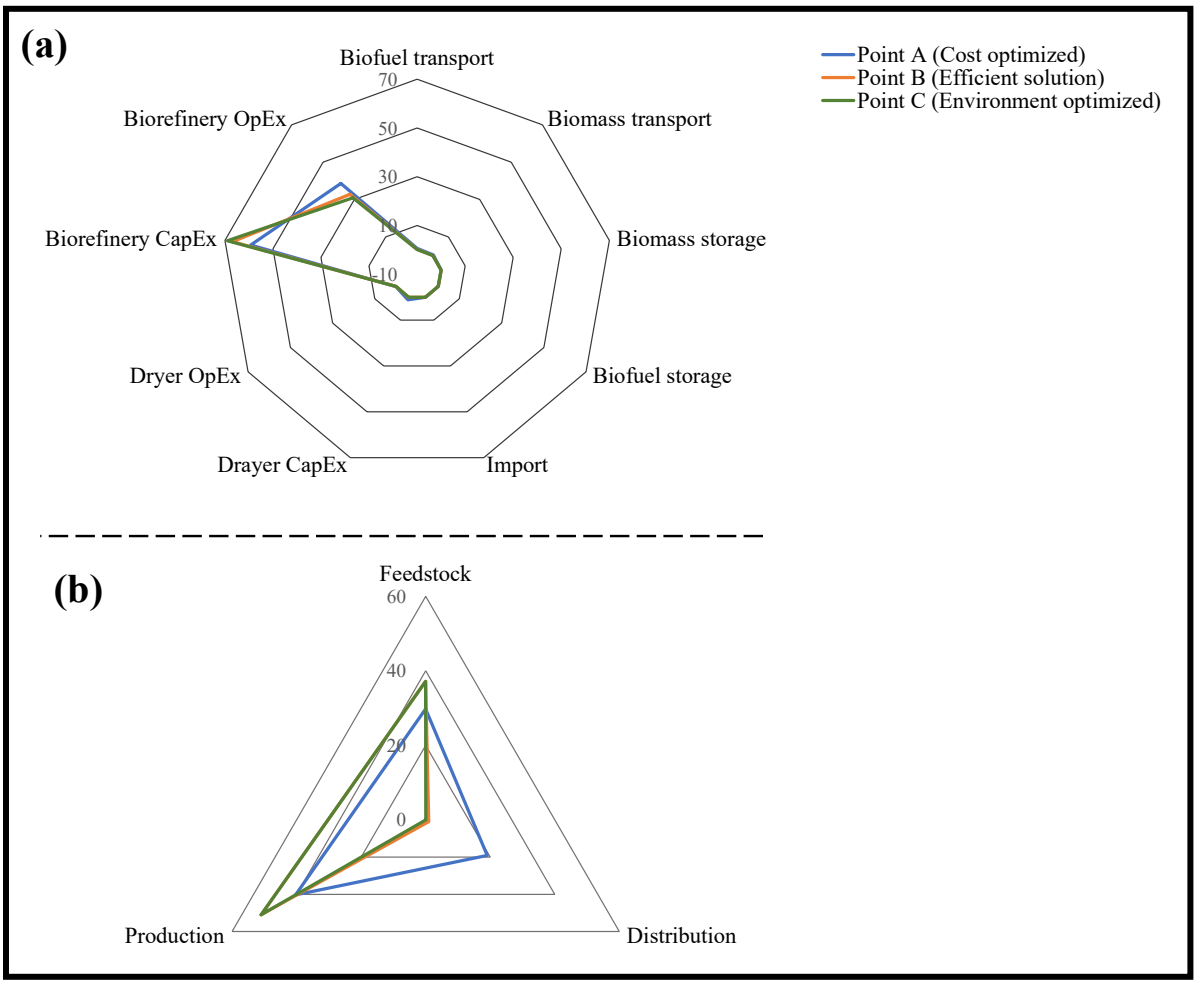

Figure II. Radar diagram of the pay-off table (values based on percentage).

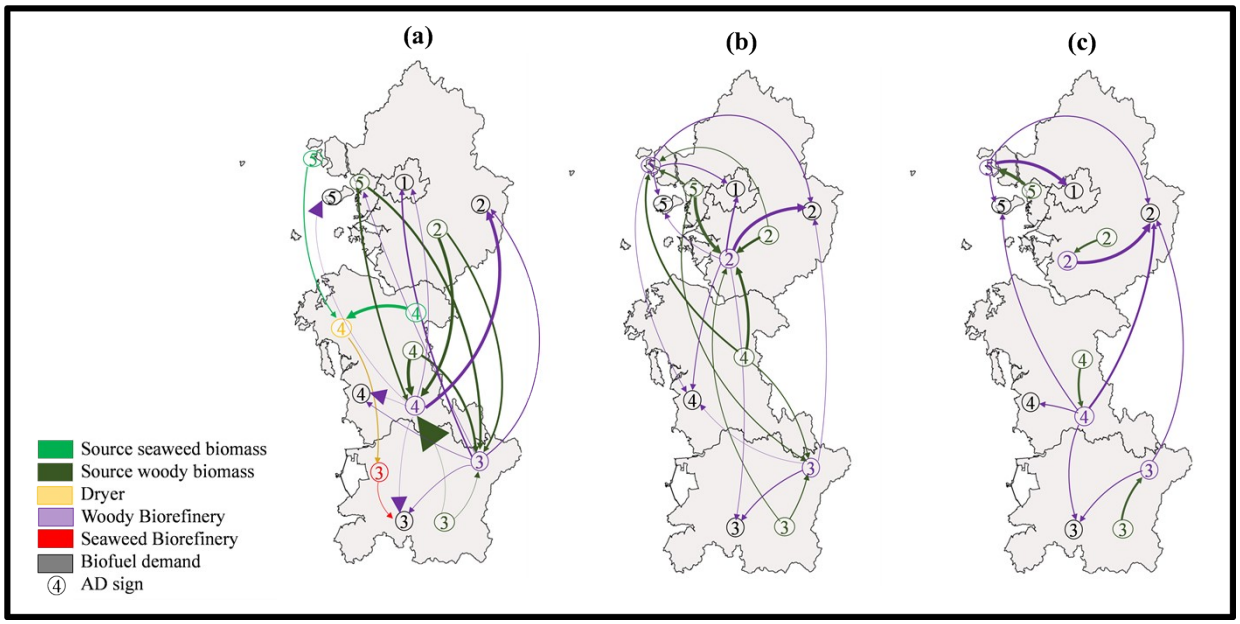

Figure III. Supply chain configuration at the end of time horizon under (a) economic, (b) efficient, and (c) environmental optimization.

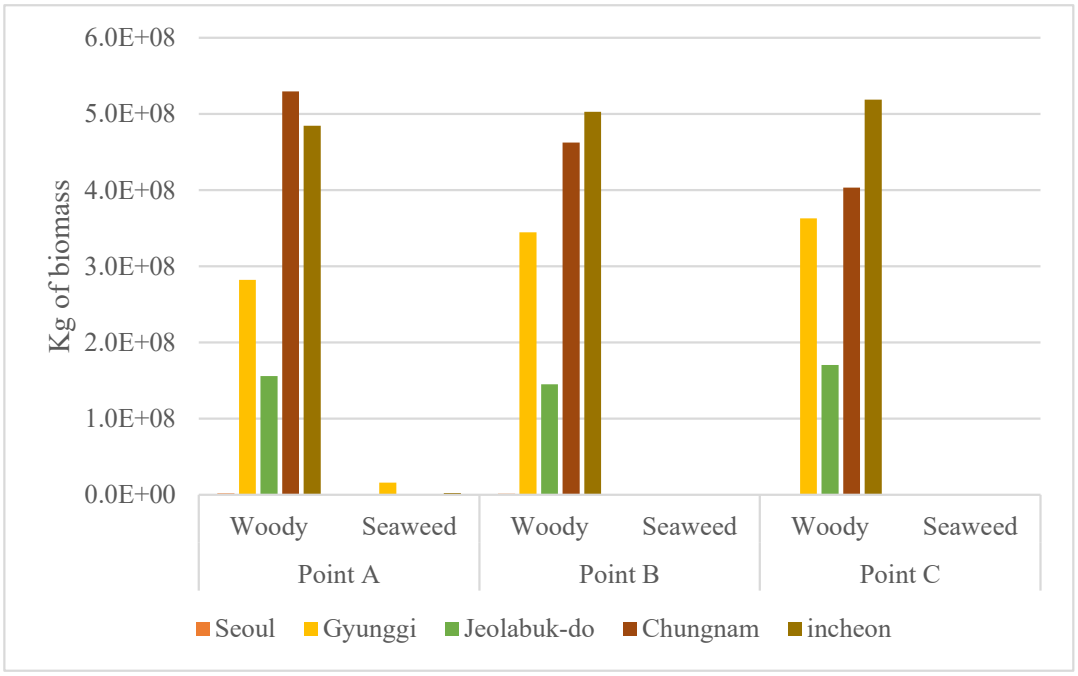

Figure IV. Amounts of seaweed and woody biomasses at each point.

Table I. Land information of ADs.

	Land cost ($/m^2)	Demand (1000 barrel/year)	Woody biomass (tones/year)	Algae biomass (tones/year)
Seoul	8623.7	9,998	1874.1667	0
Gyunggi	640.2402	21,387	363093.76	95210
Jeolabuk-do	102.8363	3,325	170335.05	214145
Gyeongnam	181.6263	5,914	597093.03	34915
incheon	1184.971	3,891	361089.2	14045

Table II. Distance between ADs (km).

	Seoul	Gyunggi	Jeolabuk-do	Gyeongnam	incheon
Seoul	1	46	217	379	37
Gyunggi	46	1	189	355	45
Jeolabuk-do	217	189	1	222	226
Gyeongnam	379	355	222	1	392
incheon	37	45	226	392	1

Table III. Dryer specifications.

maximum capacity (dry tons/year)	fixed cost (1000 dollar)
0.002	0.53
0.017	4.28
0.138	34.22
1.104	273.75
7.500	2190.03

Table IV. Biomass storage specifications.

Capacity (tones of biomass/month)	Fixed cost (1000 $)
5	1.25
20	2.50
160	6.67
2560	106.67
81920	3413.33

Table V. Biorefinery specifications.

	Capacity (MGY)	Fixed cost (million $)	Operational cost (million $/year)
3rd generation biorefinery	10	2.57	0.26
	20	6.83	0.80
	30	10.19	1.35
	40	12.85	2.08
	50	14.67	2.59
	100	25.76	4.92
2nd generation biorefinery	10	8.51	0.57
	20	12.91	1.14
	50	22.36	2.85
	90	31.80	5.1
	133	39.60	7.4
	164	44.50	8.9

Table VI. Biofuel storage specifications.

Volume(m^3)	fixed cost ($)
2000	80041.645
3000	104177.83
4000	125598.8
5000	145203.48
6000	163472.54

Table VII. transportation cost parameters.

Biomass transportation with a capacity of 6.37 m^3 (1 ton)		$ 0.318/km
Biofuel transportation	20000 litter	$ 381/truck
	24000 litter	$ 457/truck
	32000 litter	$ 609/truck

Table VIII. Environmental parameters (CO_2-equiv/kg).

GHG emission of cultivating and harvesting	0.136 (Algae) / 35 (Woody)
GHG emission of transporting biofuel	75
GHG emission of transporting biomass	75
GHG emission of producing biofuel	92.88
GHG emission of drying biomass	27.5

Nomenclature

Indices

b	Set of biomass feedstocks
H	Set of conversion technologies
d	Set of dryers
ld	Capacity level of dryer
K	Set of biorefineries
q	Set of conversion technologies
lr	Capacity level of biorefinery
m	Set of transportation modes
t	Set of time periods
f	Set of biofuel storage facilities

nf	Capacity level of biofuel storage
ng	capacity level of biomass storage
j	Set of demands
$\hat{j}$	Set of demands (using for transportation between administrative divisions)

Parameters

CRF	Capital recovery factor
CBD	Fixed cost of a dryer ($ million)
lc	Land cost ($ million)
FCI	Fixed cost of biorefinery facility ($ million)
HSB	Fixed cost of biomass storage facility ($ million)
ECB	Fixed cost of biofuel storage facility ($ million)
MBD	Unit operating cost of dryer ($ million/kg)
CPD	Coefficient of biofuel production ($ million/kg)
COL	Cost of manufacturing ($ million/kg of biofuel)
CUT	Cost of labor ($ million/kg of biofuel)

CRM	Cost of utilities ($ million)
TM	Unit transportation cost of biomass ($ million/km/vehicle)
TB	Unit transportation cost of biofeul ($ million km/vehicle)
DS	Distance (km)
EHV	Unit GHG emission of cultivating and harvesting (CO2-equiv/kg)
ETR	Unit GHG emission of transporting biofuel (CO2-equiv/kg)
$ETRB$	Unit GHG emission of transporting biomass (CO2-equiv/kg)
EPD	Unit GHG emission of producing biofuel (CO2-equiv/kg)
EDR	Unit GHG emission of drying biomass (CO2-equiv/kg)
BA	Biomass available (kg/month)
Dem	Demand (kg/month)
	Maximum number of facilities in administrative divisions
	Biomass storage capacity (kg/month)
	Biofuel storage capacity (kg/month)
	Capacity of biorefinery (kg/month)
	Capacity of a dryer (kg/month)

Continuous variables

harv	Harvested biomass (kg/month)
fhd	Biomass from harvesting site to a dryer (kg)
fhrw	Biomass from harvesting site to biorefinery (kg)
fhcw	Biomass from harvesting site to storage (kg)
fhr	Biomass from dryer to biorefinery (kg)
feed	Biomass aggregation from all pathways (kg)
fc	Biofuel produced (kg)
frb	Biofuel from biorefinery to demand (kg)
fst	Biofuel from biorefinery to storage (kg)
frs	Biofuel from storage to demand (kg)
l	Inventory level of biofuel at the end of the time period (kg)
l	Inventory level of biofuel at the beginning of the time period (kg)
$\imath s$	Inventory level of biomass at the beginning of the time period (kg)
$\imath s$	Inventory level of biomass at the end of the time period (kg)
imp	Biofuel import (kg)

$^{ex}_{v}$ Fixed cost of a dryer ($ million)

C_{dry}^{Opex} Operational cost of dryer ($ million)

C_{brf}^{Capex} Fixed cost of biorefinery ($ million)

C_{brf}^{Opex} Operational cost of biorefinery ($ million)

$C_{bfuel\ strg}$ Fixed cost of biofuel storage ($ million)

$C_{bmss\ strg}$ Fixed cost of biomass storage ($ million)

$C_{bfuel\ trnsprt}$ Biofuel transportation cost ($ million)

$C_{bmss\ trnsprt}$ Biomass transportation cost ($ million)

C_{imprt} Import cost ($ million)

E_{acq} GHG emission of biomass acquisition

$E_{bfuel\ trnsprt}$ GHG emission of biofuel transportation (CO2-equiv/year)

$E_{bmass\ trnsprt}$ GHG emission of biomass transportation (CO2-equiv/year)

E_{prod} GHG emission of biofuel production (CO2-equiv/year)

Integer variables

w Number of dryers

v Number of biorefineries

x	Number of biomass storage facilities
z	Number of biofuel storage facilities
n	Number of transit vehicles facilities