Decision Making in Manufacturing and Services
Vol. 14 • 2020 • No. 1 • pp. 57–80

Impact of Government Policies on Sustainable Petroleum Supply Chain (SPSC): A Case Study – Part II (The State of Nebraska)

Davoud Ghahremanlou* and Wieslaw Kubiak*

Abstract. The accompanying part I (Ghahremanlou and Kubiak, 2020) developed the Lean Model (LM), a two-stage stochastic programming model which incorporates Renewable Fuel Standard 2 (RFS2), Tax Credits, Tariffs, and Blend Wall (BW), to study the policy impact on the Sustainable Petroleum Supply Chain (SPSC) using cellulosic ethanol. The model enables us to study the impact by running computational experiments more efficiently and consequently by arriving at robust managerial insights much faster. In this paper, we present a case study of the policy impact on the SPSC in the State of Nebraska using the model. The case study uses available real-life data. The study shows that increasing RFS2 does not impact the amount of ethanol blended with gasoline but it might lead to the bankruptcy of the refineries. We recommend that the government consider increasing the BW because of its positive economic, environmental and social impacts. For the same reason, we recommend that the tax credit for blending the US produced ethanol with gasoline be at least 0.189 $\frac{\$}{\text{gal}}$ and the tariff for imported ethanol be at least 1.501 $\frac{\$}{\text{gal}}$. These also make the State independent of foreign ethanol thereby enhancing its energy security. Finally, the change in policy impacts the SPSC itself, most importantly it influences strategic decisions. However setting up a bio-refinery at York county and a blending site at Douglas county emerge as the most robust location decisions against the policy change in the study.

Keywords: sustainable petroleum supply chain, two-stage stochastic programming, government policies

Mathematics Subject Classification: 62K99, 97M10, 90C15

Submitted: January 31, 2020

Revised: April 25, 2020

1. INTRODUCTION

The US is the biggest corn exporter in the world according to Perlack *et al.* (2011), and Gupta and Verma (2015). Central Illinois / Indiana, northern Iowa/southern Minnesota, and the areas along the Platte River in Nebraska are most suitable for corn

* Faculty of Business Administration, Memorial University of Newfoundland, St. John's, NL, Canada

DOI: https://doi.org/10.7494/dmms.2020.14.1.3649

stover collection in the US (Wilhelm *et al.*, 2007). Nebraska is one of the states with the largest area of corn planted. Moreover, the states of Iowa and Nebraska have the largest ethanol nameplate capacity and operating production in the country (Renewable Fuels Association, 2018). The state of Iowa has been studied in the literature from the SPSC and biofuel supply chain perspective, yet not the policy impact perspective, see Li *et al.* (2014), Li and Hu (2014), Li *et al.* (2015), Zhang and Hu (2013), Gebreslassie *et al.* (2012), Shah (2013) and Kazemzadeh and Hu (2015). Therefore, we consider corn stover and the State of Nebraska as a feedstock and a geographical location respectively for the case study in this paper. To the best of our knowledge, no study has focused exclusively on the state of Nebraska thus far.

This case study contributes by characterizing those policies (1) for which there is no ethanol production in Nebraska; (2) for which most environmentally friendly fuel is produced in Nebraska; (3) which make Nebraska an ethanol dependent state, relying on foreign ethanol for producing environmentally friendly fuel; by identifying (4) the most robust counties in which to set up bio-refineries and blending sites; (5) the most robust capacities for bio-refineries and blending sites. The case study also determines, for each policy, a range of (6) annual expected profit; (7) the expected number of jobs created in Nebraska over 30 years for solutions that maximize the annual expected profit. The study also identifies (8) policies that result in several benefits at the same time: most environmentally friendly fuel, highest expected number of jobs created, positive annual expected profit with minimum government budget expenditure, and the independence from foreign ethanol.

The rest of the paper is organized as follows: Section 2 summarizes the background information and provides the data employed in this study. Section 3 details the design of computational experiments. Section 4 analyzes the results of the computational experiments, and provides strategic and managerial insights and recommendations for the design of the SPSC. Section 5 summarizes policy recommendations, and provides conclusions and opportunities for further research. Appendix 6.1 and 6.2 provide data about annual corn stover and fuel demand in Nebraska.

2. CASE STUDY

2.1. Distances Between Counties

We used ArcGIS 10.5 to find the direct distances between centers of the $N = 93$ counties of Nebraska.

2.2. Harvesting Site and Feedstock

The corn production in each county is reported by the United States Department of Agriculture in bushels U.S. Department of Agriculture (2012). Each bushel (bu) of corn is equal to 21.5 kg of dry corn, and the corn mass to corn stover mass ratio is estimated as 1:1 (Graham *et al.*, 2007). Therefore, we calculated the amount of corn stover for each county accordingly, A_j, and report it in Table 8 in the Appendix.

2.3. Bio-refineries and Blending Sites

The base cost for establishing a bio-refinery (cellulosic ethanol) with base capacity $U_1 = 772,151.89\ \frac{MT}{\mathrm{y}}$ is $C_1 = 422.5\ M\$$, (Humbird *et al.*, 2011). Furthermore, the base capacity and the base cost for a blending site are $H_1 = 36.59\ \frac{M\mathrm{gal}}{\mathrm{y}}$ (Wight Hat Ltd., 2003b) and $W_1 = 2.6\ M\$$ respectively (U.S. Environmental Protection Agency, 1980). We apply the following formula below to estimate the costs for bio-refineries and blending sites (Wright and Brown, 2007):

$$\text{cost-level}_k = k^{0.6}\text{base cost}. \tag{1}$$

We considered *three* different capacity levels for bio-refineries. These are obtained by multiplying the base capacity by $k = 1$, 2, and 3 respectively. The multipliers are determined to provide a good fit with the distribution of feedstock for different scenarios. Consequently, the costs in million dollars ($M\$$) for the capacities $U_1 = 772,151.89$, $U_2 = 1,544,303.78$, and $U_3 = 2,316,455.67\ \frac{MT}{\mathrm{y}}$ (these were rounded for the computation) of bio-refineries are $C_1 = 422.5$, $C_2 = 640.39$, and $C_3 = 816.77$ respectively. Similarly, we calculate the costs for blending sites with *six* different capacity levels, by multiplying the base capacity by $k = 1$, 3, 5, 7, 9, 11 and denoting them by W_n for $n = 1, ..., 6$ respectively. The multipliers are determined to provide a good fit with the distribution of demand in different scenarios. Consequently, the costs in million dollars for the capacities $H_1 = 36.59$, $H_2 = 109.77$, $H_3 = 182.95$, $H_4 = 256.13$, $H_5 = 329.31$, and $H_6 = 402.49\ \frac{M\mathrm{gal}}{\mathrm{y}}$ of blending sites are $W_1 = 2.6$, $W_2 = 5.03$, $W_3 = 6.83$, $W_4 = 8.36$, $W_5 = 9.72$, and $W_6 = 10.96$ respectively.

The *cap* on loan to establish bio-refineries and blending sites is assumed $B = 5.25$ $B\$$, with $\phi = 8\%$ interest rate, and $t = 30$ years return time. To calculate the cap, we considered 5 $B\$$ cap to establish bio-refineries as it was done in Kazemzadeh and Hu (2015) for Iowa with higher than Nebraska ethanol production; we then added 0.25 $B\$$ cap to establish blending sites (this amount is derived by finding a good fit with the distribution of demand for different scenarios).

According to Humbird *et al.* (2011), by investing $C_1 = 422.5\ M\$$ to establish a bio-refinery of size U_1 one creates 60 jobs annually necessary to run that bio-refinery. Thus $J^{FE} = \frac{60}{422.5\cdot 10^6}$. According to U.S. Environmental Protection Agency (1980), by investing $W_1 = 2.6\ M\$$ to establish a blending site of size H_1 one creates 24 jobs annually necessary to run that blending site. Thus $J^B = \frac{24}{2.6\cdot 10^6}$. Furthermore, Kim and Dale (2015) shows 6.48 full time construction jobs per million dollars in construction of bio-refinery are created. Thus $J^{Co} = 6.48$.

Furthermore, the price of the fuel produced by blending sites is set to $P = \$1.96$, which is the average price of E85 and gasoline during 2016 (E85 Prices, 2016). We found $E = 39.75 \cdot 10^6\ \frac{\mathrm{gal}}{\mathrm{y}}$ by calculating the amount of corn stover available in the US (excluding Nebraska) and multiplying it by conversion factor V, see Table 1. Finally, there are three commercial cellulosic ethanol plants in the US, ABEGOA BIOENERGY, DuPont and POET-DSM, which the cheapest price is offered by DuPont, $P^{EI} = \$3.45$ (Lux Research Inc., 2016).

2.4. Demand

By U.S. Environmental Protection Agency (1980), we estimated the D_i fuel demand for each county of Nebraska, according to the formula below. The detailed data are in Table 9 in the Appendix.

$$D_i = \left(\frac{Population\ of\ county\ i}{Population\ of\ Nebraska}\right) \cdot Total\ gasoline\ consumption\ in\ Nebraska \quad (2)$$

2.5. Transportation

The cost for transportation of ethanol and fuel includes distance-fixed cost and distance-variable cost, $C^{FTE} = 0.02\ \frac{\$}{\text{gal}}$ and $C^{VTE} = 16.2 \cdot 10^{-5}\ \frac{\$}{\text{gal}\cdot\text{mi}}$ respectively (the variable cost=1.3 $\frac{\$}{\text{mi}\cdot truckload}$ and truck capacity= 8000 gal) (Chen and Fan 2012). Likewise, the cost for transportation of feedstock includes distance-fixed cost and distance-variable cost $C^{FTF} = 4.39\ \frac{\$}{MT}$ and $C^{VTF} = 0 \cdot 19\ \frac{\$}{MT\cdot\text{mi}}$, respectively (Searcy *et al.*, 2007). The jobs created for the transportation of feedstock (corn stover) $J = 1.35 \cdot 10^{-6}$ $\frac{job}{MT\cdot\text{mi}}$ (Kim and Dale, 2015). The jobs created for transportation of ethanol and fuel are almost $J^{TE} = 3.98 \cdot 10^{-9}$ and $J^{TEG} = 3.72 \cdot 10^{-9}$ respectively; we calculated these numbers by converting J to the appropriate unit using their density (ethanol density= 6.5 $\frac{\text{lb}}{\text{gal}}$ (CAMEO Chemicals, 2010), 1 $MT := 2204.62$ lb (Wight Hat, Ltd., 2003a), and fuel density= 6.073 $\frac{\text{lb}}{\text{gal}}$ (Wikimedia Foundation, Inc., 2017)). The rest of the information about the parameters given in the problem is summarized in Table 1.

Table 1. *Parameters information*

Parameters	Amount (Unit)	References
Bio-refineries and blending sites – design		
B	$5.25 \cdot 10^9$ (\$)	Assumption
t	30 (y)	Kazemzadeh and Hu (2015)
ϕ	8%	Humbird *et al.* (2011) and Kazemzadeh and Hu (2015)
Q	30 (y)	Humbird *et al.* (2011)
Bio-refineries and blending sites – operation		
C^{FE}	0.864 (\$/gal)	Humbird *et al.* (2011)
V	79 (gal/MT)	Humbird *et al.* (2011)
C^B	0.00327 (\$/gal)	U.S. Environmental Protection Agency (1980)
E	$39.75 \cdot 10^6$ (gal/y)	U.S. Department of Agriculture (2012) and Humbird *et al.* (2011)
Unit prices		
P^F	60 (\$/MT)	Klein-Marcuschamer *et al.* (2010)
P^E	2.15 (\$/gal)	Humbird *et al.* (2011)
P^G	2.085 (\$/gal)	AAA Gas Prices (2017)
P^R	1.33 (\$/RIN)	U.S. Environmental Protection Agency (2016)
P^{EE}	2.17 (\$/gal)	Tsanova (2016)

Table 1. (cont'd)

Harvesting sites		
F	72%	Kazemzadeh and Hu (2015)
L	5%	Tong *et al.* (2013)
Transportation		
C^{FTF}	4.39 ($\$/MT$)	Searcy *et al.* (2007)
C^{VTF}	0.19 ($\$/MT \cdot \mathrm{mi}$)	Searcy *et al.* (2007)
C^{FTEG}	0.02 ($/gal)	Chen and Fan (2012)
C^{VTEG}	$16.2 \cdot 10^{-5}$ ($\$/\mathrm{gal} \cdot \mathrm{mi}$)	Chen and Fan (2012)
C^{FTE}	0.02 ($/gal)	Chen and Fan (2012)
C^{VTE}	$16.2 \cdot 10^{-5}$ ($\$/\mathrm{gal} \cdot \mathrm{mi}$)	Chen and Fan (2012)
τ	1.29	Kazemzadeh and Hu (2015)
Policies		
$\overline{R}$	10.1%	U.S. Environmental Protection Agency (2017a)
$\overline{\overline{R}}$	0.128%	U.S. Environmental Protection Agency (2017a)
T	0.45 ($/gal)	Duffield *et al.* (2008)
$\overline{T}$	0.54 ($/gal)	Duffield *et al.* (2008)

2.6. Scenario Generation

The uncertain parameters in this study are: feedstock availability (A_j), feedstock price (P^F), variable transportation cost (C^{VTF}, C^{VTE}, and C^{VTEG}), ethanol import prices (P^{EI} and P^{EE}), fuel price (P), gasoline price (P^G), ethanol exporting price (P^E), number of jobs created (J^{Co}, J, J^{TE}, J^{TEG}, J^{FE}, and J^B) and fuel demand (D_i). We group the uncertain parameters based on their correlations (Table 2) (Tong *et al.*, 2013; Carneiro *et al.*, 2010). In the Technology Evolution group, the uncertain parameters are J^{Co}, J, J^{TE}, J^{TEG}, J^{FE}, and J^B. The research shows routine manual jobs and routine cognitive jobs have stagnated between 1980 and 2014. Martin Ford, a futurist, warns that in future most of the jobs will be broken and allocated to the machines to be done (The Economist, 2016). In the Prices and Costs category, the uncertain parameters are P^F, C^{VTF}, C^{VTE}, C^{VTEG}, P^{EI}, P^{EE}, P, P^G, and P^E. Gasoline and diesel (for transportation) are produced from crude oil, therefore their prices follow the same pattern (Independent Statistics & Analysis, U.S. Energy Information Administration, 2017). Furthermore, (Wisner, 2009) shows that the prices of feedstock, gasoline and ethanol follow almost the same trend. Also, price of any ethanol-gasoline blend (fuel) follows the prices of gasoline and ethanol. Therefore, we conclude that all uncertain parameters in the category of Prices and Costs in Table 2 follow the same trend.

Each scenario $s \in S$ is a potential realization of an uncertain parameter. The scenarios are generated based on the average values of the parameters, historical data and estimation. For probability of each scenario we follow the study performed by (Tong *et al.*, 2013).

We consider three scenarios for A_j, namely, Base (25%), High (50%) and Low (25%), which means with a probability of 0.25 the A_j stays the same, with probability 0.5 the A_j increases, and with the probability 0.25 the A_j decreases. This convention is applied to all other scenarios generated. For the Base scenario, we take the corn stover production given in Table 8. In the High scenario we assume a 28% increase in production and in the Low scenario we assume 5% decrease in the production as compared to the Base scenario. The increase and decrease in the High and the Low scenarios respectively are the best and worst case corn production observed in the US from 2012 to 2017 (University of Nebraska, Lincoln, n.d.).

Table 2. *Uncertain Parameters grouping*

Group number	Group name	Uncertain Parameters
1	Feedstock Availability	1. Feedstock availability
2	Technology Evolution	1. Number of jobs created \$ spend on construction of bio-refineries and blending sites 2. Number of jobs created by conversion operation 3. Number of jobs created by blending operation 4. Number of jobs created $MT \cdot$ mi feedstock transported 5. Number of jobs created $jobs \cdot$ gal $\cdot$ mi fuel blend transported 6. Number of jobs created gal $\cdot$ mi of ethanol transported
3	Prices and Costs	1. Price of ethanol sold to the exporter 2. Price of ethanol purchased from other states 3. Price of ethanol purchased from other countries 4. Price of petroleum gasoline purchased 5. Price of fuel (ethanol-gasoline blend) sold 6. Feedstock price 7. Feedstock variable transportation cost 8. Fuel variable transportation cost 9. Ethanol variable transportation cost
4	Fuel Demand	1. Fuel demand

Likewise, for the Technology Evolution we also consider three scenarios: Base (25%), High (50%) and Low (25%). In the Base scenario we use the values we have already mentioned for the six uncertain parameters in the Technology Evolution group; for the High and the Low scenarios we assume 7% and 4% reduction respectively in those values due to automation and reduced dependency upon human resources. Regarding the prices and costs, we have already mentioned, we consider two scenarios: High (50%) and Low (50%). In the High scenario the prices (1–6) and the costs (7–9) in this category increase by 10% and 1.5% respectively; while in the Low scenario the prices and the costs increase by 7% and 1% respectively (Tong *et al.*, 2013). We consider two scenarios for fuel demand in the counties of Nebraska: High (70%) and Low (30%). In the High scenario and Low scenario, fuel demand increases 31% and decreases 15% respectively. These amounts are the maximum and minimum growth and decline of the fuel demand at Nebraska during 2006 to 2015, and their related probabilities are calculated based on the annual demand (Nebraska Department of Revenue, 2017). All 36 possible scenarios and their probability (ω) distribution are given in Table 3.

Table 3. *Scenarios*

Feedstock availability	Technology evolution	Prices and Costs	Fuel demand	Scenarios	Probability
Base (25%)	Base (25%)	High (50%)	High (70%)	1	0.021875
			Low (30%)	2	0.009375
		Low (50%)	High (70%)	3	0.021875
			Low (30%)	4	0.009375
	High (50%)	High (50%)	High (70%)	5	0.04375
			Low (30%)	6	0.01875
		Low (50%)	High (70%)	7	0.04375
			Low (30%)	8	0.01875
	Low (25%)	High (50%)	High (70%)	9	0.021875
			Low (30%)	10	0.009375
		Low (50%)	High (70%)	11	0.021875
			Low (30%)	12	0.009375
High (50%)	Base (25%)	High (50%)	High (70%)	13	0.04375
			Low (30%)	14	0.01875
		Low (50%)	High (70%)	15	0.04375
			Low (30%)	16	0.01875
	High (50%)	High (50%)	High (70%)	17	0.0875
			Low (30%)	18	0.0375
		Low (50%)	High (70%)	19	0.0875
			Low (30%)	20	0.0375
	Low (25%)	High (50%)	High (70%)	21	0.04375
			Low (30%)	22	0.01875
		Low (50%)	High (70%)	23	0.04375
			Low (30%)	24	0.01875
Low (25%)	Base (25%)	High (50%)	High (70%)	25	0.021875
			Low (30%)	26	0.009375
		Low (50%)	High (70%)	27	0.021875
			Low (30%)	28	0.009375
	High (50%)	High (50%)	High (70%)	29	0.04375
			Low (30%)	30	0.01875
		Low (50%)	High (70%)	31	0.04375
			Low (30%)	32	0.01875
	Low (25%)	High (50%)	High (70%)	33	0.021875
			Low (30%)	34	0.009375
		Low (50%)	High (70%)	35	0.021875
			Low (30%)	36	0.009375

It is worth pointing out that all the scenarios are generated for a single year, although the project life time is $Q = 30$ years. The reason being that the multi-period planning horizon, e.g., 30 years, in stochastic programming significantly increases the size of the scenario tree, Table 3. Exponential growth has often been observed, see for instance (Huang, 2005). In this paper we have 36 scenarios for 17 uncertain factors, see Table 2, thus for the 30 years planning horizon, there would be 36^{30} scenarios instead of 36. This would significantly increase the time complexity of the problem, which is already intractable for a single period.

3. DESIGN OF COMPUTATIONAL EXPERIMENTS

We run the tests to examine the impact of government policies on the SPSC. In particular we examine the effects of changing the following factors:

- Tax Credit for Local ethanol blended with gasoline ($TCL = \eta \cdot T$, $\forall \eta \geqslant 0$)
- Tax Credit for Imported ethanol from abroad blended with gasoline ($TCI = \theta \cdot \overline{T}$, $\forall \theta \geqslant 0$)
- Tariff for Local ethanol blended with gasoline ($TL = -\eta \cdot T$, $\forall \eta \leqslant 0$)
- Tariff for Imported ethanol from abroad blended with gasoline ($TI = -\theta \cdot \overline{T}$, $\forall \theta \leqslant 0$)
- RFS2 mandate for cellulosic ethanol ($\beta \cdot \overline{\overline{R}}$)
- Blend Wall (α).

The BW, α, is set to 10%, 15% or 85%. The cellulosic biofuel mandates specified in RFS2 for 2022 and 2016 (to improve the readability we use the abbreviations 22 and 16 instead of 2022 and 2016 respectively in the superscripts below) are $\overline{\overline{R}}^{22} \cdot g^{22} = 16$ and $\overline{\overline{R}}^{16} \cdot g^{16} = 4.25$ billion gallons respectively (United States Environmental Protection Agency EPA, 2017), where g^{22} and g^{16} are gasoline consumptions for 2022 and 2016 respectively. Thus, we get $\overline{\overline{R}}^{22} = (\frac{16}{4.25} \cdot \frac{g^{16}}{g^{22}}) \cdot \overline{\overline{R}}^{16}$. We set $\overline{\overline{R}}^{16} = \overline{\overline{R}} = 0.128\%$, see Table 1. For an upper bound on $\overline{\overline{R}}^{22}$, we set $g^{22} = g^{16}$. Thus, $\beta \cdot \overline{\overline{R}} \leqslant \overline{\overline{R}}^{22}$, where $\beta \leqslant \frac{16}{4.25} \approx 3.76$. However, the government may possibly reduce the mandate to 0, thus $0 \leqslant \beta$. Therefore, we consider $0 \leqslant \beta \leqslant 3.76$, and discretize it by setting $\beta = 0.3 \cdot k$, when $k = 0, 1, ..., 12$, and by adding 3.76 to the discretized set. The reason for considering 0.3 as the coefficient for k is that β has increased 3.76 times over 7 years, which means an increase of 0.54 per year. Since RFS2 was ratified in 2007, planned for cellulosic mandate in 2016, which currently seems optimistic due to the lack of cellulosic ethanol production, this resulted in the government mandate waiver. Therefore, we have considered a 50% waiver for cellulosic ethanol, $\frac{0.54}{2} = 0.27$, which is rounded up to 0.3.

Tax Credit for one gallon of local ethanol blended with gasoline, TCL, is $T = \$0.45$ see Table 1. We assume the credit would not exceed the price $P^E = \$2.15$ of one gallon of ethanol produced locally in the US, otherwise the government would actually be paying for the ethanol produced locally and provide it free to the blenders. Thus, the Tax Credit T can only increase up to $\frac{P^E}{T} = \frac{2.15}{0.45} \approx 4.78$ times. Therefore, $0 \leqslant \eta \leqslant 4.78$. Similarly, we assume the Tariff for one gallon of local ethanol blended with gasoline, TL, would not exceed the price $P^E = \$2.15$, otherwise the local ethanol producers would be paying for the ethanol produced locally and provide it free to the blenders. Thus, the Tariff T can only increase up to $\frac{P^E}{T} = \frac{2.15}{0.45} \approx 4.78$ times, which gives $-4.78 \leqslant \eta \leqslant 0$.

Since one equation would cover the Tax Credit and Tariff, we have $-4.78 \leqslant \eta \leqslant 4.78$. In a similar fashion, for the imported ethanol blended with gasoline, $\frac{P^E}{\overline{T}} = \frac{2.15}{0.54} \approx 3.98$. This results in $-3.98 \leqslant \theta \leqslant 3.98$. The intervals for η, $[-4.78, 4.78]$, and θ, $[-3.98, 3.98]$, are discretized as follows, $\eta = -4.77+0.4 \cdot k$, where $k = 0, 1, ..., 23$ and $\theta = -3.98+0.4 \cdot k$, where $k = 0, 1, ..., 19$ respectively. Finally, the values 4.78 and 3.98 are added to the discretized sets of η and θ respectively. To calculate a step for η and θ we look at the monetary difference between the Tax Credits $\overline{T} - T = 0.54 - 0.45 = 0.09$. The 0.09 $\frac{\$}{\text{gal}}$ is then considered as a value that the government might use as a step for the increase or decrease of $\overline{T}$ and T. Therefore, $\frac{\overline{T}-T}{T} = \frac{0.54-0.45}{0.45} = 0.2$ is dollar change relative to T, and $\frac{\overline{T}-T}{\overline{T}} = \frac{0.54-0.45}{0.54} \approx 0.17$ is dollar change relative to $\overline{T}$. Thus $\frac{0.2+0.17}{2} = 0.185$ is the average relative dollar change. Then, $\frac{0.185}{0.45} \approx 0.41$ is the average dollar change relative to T, and $\frac{0.185}{0.54} \approx 0.35$ is the average dollar change relative to $\overline{T}$. Therefore, we take $\theta = \eta = 0.4$ which is between 0.35 and 0.41, and which is the only multiple of 0.1 in that interval.

We ran the experiments to calculate $L_1(X_{\min})$ and $L_2(X_{\max})$, see (Ghahremanlou and Kubiak, 2020) for definitions of $L_1, L_2, X_{\min}$, and $X_{\max}$, for all possible combinations of α, β, θ, and η. This results in $2 \cdot 3 \cdot 14 \cdot 25 \cdot 21 = 44,100$ different runs of the LM. The LM consists of 30,546 continuous variables, 2,520 binary variables, and 1,467 constraints. The model is coded in Python 2.7 (Software Foundation, Python, 2001), and it is solved to optimality using Gurobi 7.0 (Gurobi Optimizer, 2008). The experiments were performed on a Dell computer with an Intel Core i5-2400 3.10 GHz CPU and 8 GB RAM.

4. ANALYSIS OF RESULTS, AND RECOMMENDATIONS

This section discusses the impact of the policy change on the SPSC. We report on the economic, environmental, and social impact in the following three subsections. The results presented in these subsections are derived by solving the LM with two objective functions: L_1 and L_2. Since the investment is required to create the SPSC, we consider the annual expected profit maximization objective function, L_1, as the primary objective, and solve the LM with L_1 to optimality. We approximate $\bar{d}$ in L_1 with $\delta = \min_{i \neq j} d_{ij} > 0$ and $\Delta = \max_{i \neq j} d_{ij} > 0$ (see Section 3.3 in (Ghahremanlou and Kubiak, 2020)), to obtain two optimal solutions $X_{\min}$ and $X_{\max}$ respectively. The $X_{\min}$ and $X_{\max}$ are referred to as the best case and the worst case respectively since by Observation 3 in (Ghahremanlou and Kubiak, 2020), $L_1(X_{\min}) \geqslant L_1(X_{\max})$ and investors prefer to have maximum expected profit, $L_1(X_{\min})$, not the minimum expected profit, $L_1(X_{\max})$. To calculate the value of L_2, we plug $X_{\min}$ and $X_{\max}$ in L_2 to obtain the metrics $L_2(X_{\min})$ and $L_2(X_{\max})$. We have already observed that the *maximization* of L_2 by itself is not affected by the policy change for the RFS2 mandates, the Blend Wall, the Tax Credits, and the Tariffs. Therefore, the maximization of L_2 by itself would make no sense in studying the impact. However, by choosing the solutions $X_{\min}$ and $X_{\max}$ to evaluate L_2 we make its value *sensitive* to the policy changes since both solutions are sensitive to those changes. This allows us to investigate the social aspect resulting from those solutions.

4.1. Economic Aspect

It is crucial to realize that without private investment, the government policy could not be easily carried out. Figures 1 and 2 show the maximum expected profit, L_1, for investors in the best case, $L_1(X_{\min})$, and the worst case, $L_1(X_{\max})$, respectively. The $L_1(X_{\min})$ and $L_1(X_{\max})$ are sensitive to α, β, θ, and η, which is explained in the following paragraphs.

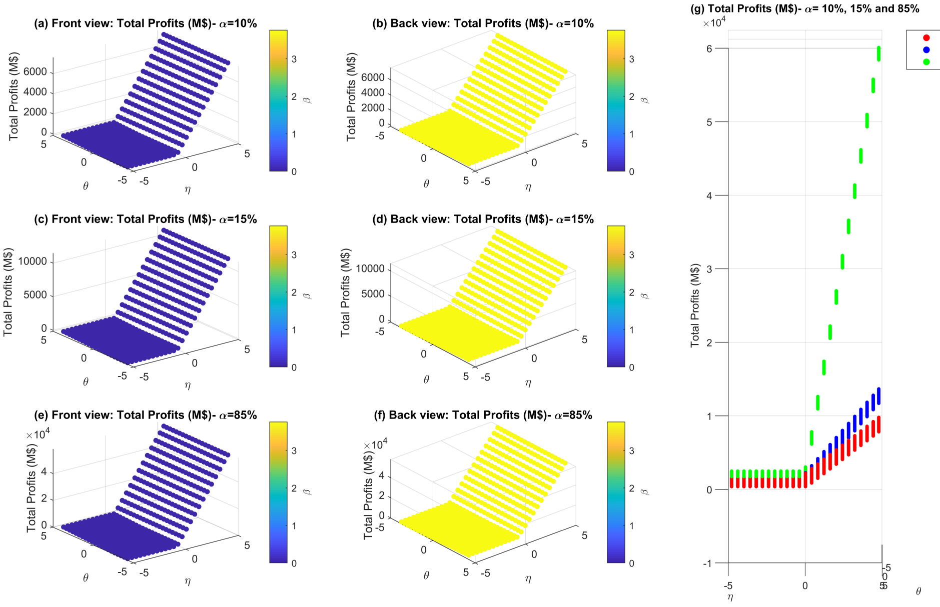

Fig. 1. *Expected profit for the best case, $L_1(X_{min})$, $\alpha = 10\%, 15\%$ and 85%*

A side-by-side examination of plots (a) and (b), (c) and (d), (e) and (f) illustrates that for any α, θ, and η the expected profits $L_1(X_{\min})$ and $L_1(X_{\max})$ decrease when β, represented by the colorbar, increases (as the back views are colored yellow, which represents the highest values of β, and the front views are colored blue, which represents the lowest values of β). The comparison of the two figures for any α (e.g., plots (a) in Figures 1 and 2 for $\alpha = 10\%$) reveals that $L_1(X_{\min})$ and $L_1(X_{\max})$ follow the same pattern though $L_1(X_{\min}) \geqslant L_1(X_{\max})$ for any α, β, θ, and η, one should observe, however, that for any α, $L_1(X_{\min})$ and $L_1(X_{\max})$ are different, and that the transportation costs components, (69-71) in (Ghahremanlou and Kubiak, 2020), of the objective function L_1 are indeed not redundant. To show the numerical differences between $L_1(X_{\min})$ and $L_1(X_{\max})$ for each $\alpha = 10\%, 15\%$ and 85%, we define the maximum difference $MaxD^\alpha = \max_i\{L_1(X_{\min}(\alpha, i)) - L_1(X_{\max}(\alpha, i))\}$, the minimum difference $MinD^\alpha = \min_i\{L_1(X_{\min}(\alpha, i)) - L_1(X_{\max}(\alpha, i))\}$, and the average difference

$$AD^\alpha = \frac{\sum_{i=1}^{i=7350} [L_1(X_{\min}(\alpha, i)) - L_1(X_{\max}(\alpha, i))]}{7350} \tag{3}$$

where the $X_{\min}(\alpha, i)$ and $X_{\max}(\alpha, i)$ are the optimal solutions for the best and the worst case respectively with $\alpha = 10\%, 15\%$ and 85%, and with the i-th combination of β, θ, and η for $i = 1, 2, ..., 7350$; the 7350 in equation (3) is the number of combinations of β, θ, and η for any α, $14 \cdot 25 \cdot 21 = 7350$, see Section 3. We obtain the following in our experiments $MaxD^{10\%} = 190.32$, $MaxD^{15\%} = 226.37$ and $MaxD^{85\%} = 694.47$; $MinD^{10\%} = 102.11$, $MinD^{\alpha=15\%} = 102.11$, and $MinD^{\alpha=85\%} = 102.11$; $AD^{10\%} = 146.08$, $AD^{15\%} = 146.09$, and $AD^{85\%} = 397.23$.

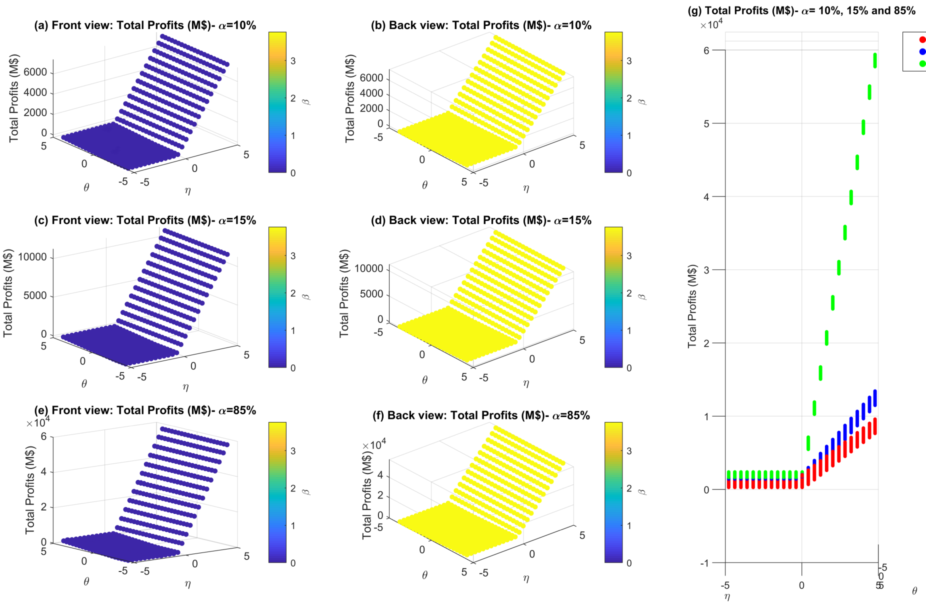

Fig. 2. *Expected profit for the worst case, $L_1(X_{max})$, $\alpha = 10\%, 15\%$ and 85%*

To show the influence of changing α on $L_1(X_{\min})$ and $L_1(X_{\max})$, plots (g) in Figures 1 and 2 are drawn. The three plots in red, blue and green are the three projections for $\alpha = 10\%$, 15% and 85% respectively of the expected profit L_1 for fixed β and θ and variable η. To better understand the difference between values of $L_1(X_{\min})$ for $\alpha = 10\%, 15\%$ and 85%, and the difference between values of $L_1(X_{\max})$ for $\alpha = 10\%, 15\%$ and 85%, for any β, θ and η, we compare them directly by defining

- $MaxP_1^{\alpha_1\alpha_2} = \max_i\{L_1(X_{\max}(\alpha_2, i)) - L_1(X_{\max}(\alpha_1, i))\}$: $MaxP_1^{10\%15\%} = 3835.520$, $MaxP_1^{15\%85\%} = 46244.449$ in the experiments.
- $MaxP_2^{\alpha_1\alpha_2} = \max_i\{L_1(X_{\min}(\alpha_2, i)) - L_1(X_{\min}(\alpha_1, i))\}$: $MaxP_2^{10\%15\%} = 3871.566$, $MaxP_2^{15\%85\%} = 46712.547$ in the experiments.
- $MinP_1^{\alpha_1\alpha_2} = \min_i\{L_1(X_{\max}(\alpha_2, i)) - L_1(X_{\max}(\alpha_1, i))\}$: $MaxP_1^{10\%15\%} = 0$, $MaxP_1^{15\%85\%} = 0$ in the experiments.
- $MinP_2^{\alpha_1\alpha_2} = \min_i\{L_1(X_{\min}(\alpha_2, i)) - L_1(X_{\min}(\alpha_1, i))\}$: $MaxP_2^{10\%15\%} = 0$, $MaxP_2^{15\%85\%} = 0$ in the experiments.

We observe that $MinP_1^{\alpha_1\alpha_2} = MinP_2^{\alpha_1\alpha_2} = 0$, whenever there is no ethanol blended with gasoline, $B^\alpha = 0$, see Table 5. Thus the increase of α results in the increase of L_1 whenever there is ethanol blended with gasoline $B^\alpha \neq 0$, see Table 5; however, L_1 does not change if there is no ethanol blended with gasoline, $B^\alpha = 0$, see Table 5. Also, we observe that the increase in α reduces the relative increment in L_1: $\frac{MaxP_1^{10\%15\%}}{15-10} = 767.104$ and $\frac{MaxP_1^{15\%85\%}}{85-15} = 660.635$, or $\frac{MaxP_2^{10\%15\%}}{15-10} = 774.313$ and $\frac{MaxP_2^{15\%,85\%}}{85-15} = 667.322$. We actually observe that a stronger condition holds, namely, for any $i = 1, 2, ..., 7350$, $P(10\%, 15\%, i) \geqslant P(15\%, 85\%, i)$, where $P(10\%, 15\%, i) = \frac{L_1(X_{\max}(15\%,i)) - L_1(X_{\max}(10\%,i))}{15-10}$ and $P(15\%, 85\%, i) = \frac{L_1(X_{\max}(85\%,i)) - L_1(X_{\max}(15\%,i))}{85-15}$. Similarly, $Q(10\%, 15\%, i) \geqslant Q(15\%, 85\%, i)$, for any $i = 1, 2, ..., 7350$, where $Q(10\%, 15\%, i) = \frac{L_1(X_{\min}(15\%,i)) - L_1(X_{\min}(10\%,i))}{15-10}$ and $Q(15\%, 85\%, i) = \frac{L_1(X_{\min}(85\%,i)) - L_1(X_{\min}(15\%,i))}{85-15}$.

Moreover, when US ethanol is blended with gasoline, for any α, β, and θ with increasing $\eta \geqslant 0.02$, see Table 5, $L_1(X_{\min})$ and $L_1(X_{\max})$ will increase. Likewise, when foreign ethanol is blended with gasoline, for any α, β, and $\eta \leqslant -0.38$ with increasing $\theta \leqslant -2.38$, see Table 5, $L_1(X_{\min})$ and $L_1(X_{\max})$ will increase.

In order to simplify the presentation of multidimensional data, we define *Minimum* $\eta(\alpha, \beta, \theta)$ to be the minimum η, if any, such that $L_1(X_{\min}) > 0$ (or $L_1(X_{\max}) > 0$) for given α, θ, and β. The investors expect their business profit to be always positive, i.e. find an optimal solution X, if any, such that $L_1(X) > 0$, on the other hand, the government attempts to utilize its budget, while meeting its goals. For instance, the government may not extend the Tax Credit for US ethanol, TCL, and foreign ethanol, TCI, by keeping θ and η unchanged, due to the allocation of funds, which might otherwise have been given to ethanol and gasoline blenders as TCL and TCI from the budget, to other higher priority projects. Although, this might reduce the profitability of the investment, it should not lead to a loss, $L_1 < 0$, or even worse to bankruptcy, as this would not help the government to meet its goals, for instance of creating more environmentally friendly fuels. The *Minimum* $\eta(\alpha, \beta, \theta)$ is insensitive to β, so it is being omitted from Table 4.

Table 4. *Minimum* $\eta(\alpha, \beta, \theta)$ *for the best case and the worst case,* $\alpha = 10\%, 15\%$ *and* 85%

	Minimum $\eta(\alpha, \beta, \theta)$	
α	The worst case	The best case
10%	$\begin{cases} 0.42 & if\ \theta \in [-3.98, 3.22] \\ -4.78 & if\ \theta \in [3.62, 3.98] \end{cases}$	$\begin{cases} 0.42 & if\ \theta \in [-3.98, 0.82] \\ -4.78 & if\ \theta \in [1.22, 3.98] \end{cases}$
15%	$\begin{cases} 0.42 & if\ \theta \in [-3.98, 1.22] \\ -4.78 & if\ \theta \in [1.62, 3.98] \end{cases}$	$\begin{cases} 0.02 & if\ \theta \in [-3.98, -0.38] \\ -4.78 & if\ \theta \in [0.02, 3.98] \end{cases}$
85%	$\begin{cases} 0.02 & if\ \theta \in [-3.98, -1.98] \\ -4.78 & if\ \theta \in [-1.58, 3.98] \end{cases}$	$\begin{cases} 0.02 & if\ \theta \in [-3.98, -2.38] \\ -4.78 & if\ \theta \in [-1.98, 3.98] \end{cases}$

For $\alpha = 10\%$, for the best case and worst case, the $Minimum\ \eta(\alpha, \beta, \theta) = 0.42$ or -4.78. Similarly, for the best case and worst case, where $\alpha = 85\%$, the $Minimum\ \eta(\alpha, \beta, \theta) = 0.02$ or -4.78. While for the intermediate $\alpha = 15\%$ the $Minimum\ \eta(\alpha, \beta, \theta) = 0.42$ for the worst case (e.g., $\theta \in [-3.98, 3.22]$) is greater than the minimum 0.02 for the best case (e.g., $\theta \in [-3.98, 0.82]$). Generally, we observe that there are two minimum values of η to consider for each α, though they may be different for the worst and the best case. The switch from one to the other occurs once and the switch requires a higher θ for the worst case than for the best to occur.

4.2. Environmental Aspect

A key reason to create the SPSC is the GHG emission reduction. The US, where gasoline is the main transportation fuel, is no exception. Clearly, blending more ethanol with gasoline is environmentally friendlier due to reducing GHG. We define the average amount of ethanol blended with gasoline over 36 scenarios (see Table 3 for the definition of scenarios) for each experiment, i.e. the quadruple α, β, θ and η, as follows

$$B^{\alpha} = \left(\frac{\sum_{s=1}^{36} \frac{e_s + h_s + k_s}{D_s}}{36} \right) \cdot 100. \tag{4}$$

This value is calculated for the best case and the worst case in our experiments. Table 5 reports the average B^{α} over all experiments. The average is not sensitive to β, so this parameter is omitted from Table 5, however both θ and η impact the average. The best case and the worst case have the same average B^{α}, for each α, so they are omitted from the table.

Table 5. *B^{α} for the best case and the worst case, $\alpha = 10\%, 15\%$ and 85%*

<table>
<tr><td></td><td>$\alpha = 10\%$</td><td colspan="3">η</td></tr>
<tr><td></td><td>$\alpha = 15\%$</td><td>$[-4.78, -0.38]$</td><td colspan="2">$[0.02, 4.78]$</td></tr>
<tr><td rowspan="2">θ</td><td>$[-3.98, -2.78]$</td><td>$B^{10\%} = B^{15\%} = 0\%$</td><td colspan="2"></td></tr>
<tr><td>$[-2.38, 3.98]$</td><td colspan="3">$B^{10\%} = 10\%, B^{15\%} = 15\%$</td></tr>
<tr><td></td><td rowspan="2">$\alpha = 85\%$</td><td colspan="3">η</td></tr>
<tr><td></td><td>$[-4.78, -0.38]$</td><td>0.02</td><td>$[0.42, 4.78]$</td></tr>
<tr><td rowspan="2">θ</td><td>$[-3.98, -2.78]$</td><td>$B^{85\%} = 0\%$</td><td>$B^{85\%} = 76.81\%$</td><td>$B^{85\%} = 77.12\%$</td></tr>
<tr><td>$[-2.38, 3.98]$</td><td colspan="3">$B^{85\%} = 85\%$</td></tr>
</table>

We observe that for $\alpha = 10\%$ and 15%, B^{α} follows the same pattern shown in the upper section of Table 5, where for $\alpha = 10\%$ and 15%, if $\eta \in [0.02, 4.78]$ or $\theta \in [-2.38, 3.98]$, the amount achieves the BW, $\alpha = 10\%$ or 15%. Otherwise, the average equals 0, which means that the policy results in no blending, and the SPSC is not created. For $\alpha = 85\%$ the pattern is different, there are two intermediate blends, $B^{85\%} = 76.81\%$ for $\theta \in [-3.98, -2.78]$ and $\eta = 0.02$, and $B^{85\%} = 77.12\%$ for $\theta \in [-3.98, -2.78]$ and $\eta \in [0.42, 4.78]$. Also, for any η and $\theta \in [-2.38, 3.98]$, $B^{85\%}$ reaches the BW, α.

4.3. Social Aspect

The creation of the SPSC, in response to the legislation, would generate jobs in construction, transportation, and operations. In particular it would aid in the development of rural areas through the construction and operation of bio-refineries typically established closer to farms, the source of corn stover, in order to reduce its transportation cost. This is important because of corn stover low density. Tables 6 and 7 report the numbers of blending sites, b_n, and bio-refineries, r_m, established for each capacity, and the expected number of jobs created, L_2, in Nebraska during a 30 year time frame set for the SPSC.

Table 6. *Strategic decisions and number of jobs created for the worst case and the best case, $\alpha = 10\%$ and 15%*

<table>
<tr><td colspan="2"></td><td colspan="3">The worst case</td></tr>
<tr><td rowspan="2"></td><td>$\alpha = 10\%$</td><td colspan="3">η</td></tr>
<tr><td>$\alpha = 15\%$</td><td>$[-4.78, -0.38]$</td><td>0.02</td><td>$[0.42, 4.78]$</td></tr>
<tr><td rowspan="4">θ</td><td>$[-3.98, -1.98]$</td><td rowspan="4">$r_1 = 0, b_1 = 45$
$b_6 = 0, L_2 = 40325$</td><td colspan="2">$r_1 = 2, b_1 = 43$
$b_6 = 2, L_2^{10\%} = 65940$
$L_2^{15\%} = 74501$</td></tr>
<tr><td>-1.58</td><td>$r_1^{10\%} = 1, b_1^{10\%} = 44$
$b_6^{10\%} = 1, L_2^{10\%} = 59776$
$r_1^{15\%} = 2, b_1^{15\%} = 43$
$b_6^{15\%} = 2, L_2^{15\%} = 74501$</td><td rowspan="3"></td></tr>
<tr><td>-1.18</td><td>$r_1 = 1, b_1 = 44$
$b_6 = 1, L_2 = 59776$</td></tr>
<tr><td>$[-0.78, 3.98]$</td><td></td></tr>
<tr><td colspan="5">* $r_2 = r_3 = b_4 = 0, b_2 = b_3 = b_5 = 1, \forall \eta, \theta$</td></tr>
<tr><td colspan="2"></td><td colspan="3">The best case</td></tr>
<tr><td rowspan="2"></td><td>$\alpha = 10\%$</td><td colspan="3">η</td></tr>
<tr><td>$\alpha = 15\%$</td><td>$[-4.78, -0.38]$</td><td>0.02</td><td>$[0.42, 4.78]$</td></tr>
<tr><td rowspan="2">θ</td><td>$[-3.98, 0.42]$</td><td rowspan="2">$L_2 = 36949$</td><td>$L_2^{10\%} = 37101$
$L_2^{15\%} = 37178$</td><td rowspan="2"></td></tr>
<tr><td>$[0.82, 3.98]$</td><td></td></tr>
<tr><td colspan="5">* $r_1 = r_2 = b_1 = b_3 = b_4 = b_5 = 0, r_3 = 3, b_2 = 1, b_6 = 2, \forall \eta, \theta$</td></tr>
</table>

Table 7. *Strategic decisions and number of jobs created for the worst case and the best case,* $\alpha = 85\%$

<table>
<tr><td colspan="2"></td><td colspan="3">The worst case</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">$\alpha = 85\%$</td><td colspan="3">η</td></tr>
<tr><td>$[-4.78, -0.38]$</td><td>0.02</td><td>$[0.42, 4.78]$</td></tr>
<tr><td rowspan="4">θ</td><td>$[-3.98, -2.38]$</td><td rowspan="3">$r_1 = 0, b_1 = 45$
$b_2 = 1, L_2 = 40325$</td><td>$r_1 = 11, b_1 = 35$
$b_2 = 12, L_2 = 202866$</td><td rowspan="4">$r_1 = 12, b_1 = 35$
$b_2 = 12, L_2 = 204742$</td></tr>
<tr><td>$[-1.98, -1.58]$</td><td>$r_1 = 9, b_1 = 36$
$b_2 = 10, L_2 = 188953$</td></tr>
<tr><td>-1.18</td><td>$r_1 = 7, b_1 = 38$
$b_2 = 8, L_2 = 160738$</td></tr>
<tr><td>$[-0.78, 3.98]$</td><td colspan="2"></td></tr>
<tr><td colspan="5">* $r_2 = r_3 = b_4 = b_6 = 0, b_3 = b_5 = 1, \forall \eta, \theta$</td></tr>
<tr><td colspan="2"></td><td colspan="3">The best case</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">$\alpha = 85\%$</td><td colspan="3">η</td></tr>
<tr><td>$[-4.78, -0.38]$</td><td>0.02</td><td>$[0.42, 4.78]$</td></tr>
<tr><td rowspan="3">θ</td><td>$[-3.98, -0.38]$</td><td rowspan="2">$r_2 = 0, r_3 = 3$
$b_2 = 1, b_3 = 0$
$b_4 = 0, b_6 = 2$
$L_2 = 36949$</td><td>$r_2 = 1, r_3 = 3$
$b_2 = 0, b_3 = 1$
$b_4 = 3, b_6 = 0$
$L_2 = 45566$</td><td rowspan="3">$r_2 = 0, r_3 = 4$
$b_2 = 0, b_3 = 1$
$b_4 = 3, b_6 = 0$
$L_2 = 47453$</td></tr>
<tr><td>$[0.02, 0.42]$</td><td>$r_2 = 0, r_3 = 3$
$b_2 = 0, b_3 = 1$
$b_4 = 3, b_6 = 0$
$L_2 = 38564$</td></tr>
<tr><td>$[0.82, 3.98]$</td><td colspan="2"></td></tr>
<tr><td colspan="5">* $r_1 = b_1 = b_5 = 0, \forall \eta, \theta$</td></tr>
</table>

Recall that the L_2 does not depend directly on either α or β or θ, or η since neither of them occurs in the definition of L_2. The number of jobs created, L_2, is a secondary objective function in our experiments, thus $L_2(X_{\max})$ and $L_2(X_{\min})$ are calculated by plugging optimal solutions $X_{\max}$ and $X_{\min}$ to L_2 respectively. The $X_{\max}$ and $X_{\min}$ depend on α, β, θ, and η. Therefore the values $L_2(X_{\max})$ and $L_2(X_{\min})$ depend on the parameters α, β, θ, and η indirectly.

The highest positive social impact occurs for $\eta \in [0.42, 4.78]$, regardless of α, θ and transportation costs. Therefore, to have the highest positive social impact, while having the most environmentally friendly fuel ($B^\alpha = \alpha$, see Table 5), and having a positive expected profit with minimum incentive from the government, see Table 4, we recommend that the government considers $0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$ tax credit for the US ethanol, TCL, which gets blended with gasoline, regardless of other policy factors.

4.4. Further Strategic and Managerial Insights

Now, in Sections 4.4.1 and 4.4.2, we compare the results of Tables 6 and 7 to identify the most robust decisions insensitive to policies and transportation costs. To summarize, if ($TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637\ \frac{\$}{\text{gal}}$ and $TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009\ \frac{\$}{\text{gal}}$) or ($TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$), we recommend that investors establish a bio-refinery at York county so that it could process the amount of corn stover from U_1 to U_3. Also, investors should set up a blending site at Douglas county so that it could deliver the amount of fuel from H_3 to H_6.

4.4.1. For $\boldsymbol{\alpha} = \mathbf{10\%}$ and $\mathbf{15\%}$

Table 6 displays b_n, r_m, and L_2 for $\alpha = 10\%$ and 15%. The b_n, r_m, and L_2 are insensitive to β, so it is omitted from the table. In the table, the b_n, r_m, and L_2 are almost same in the worst case for both $\alpha = 10\%$ and 15%. If they are not, they receive α as a superscript, which happens for ($TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637\ \frac{\$}{\text{gal}}$ and $TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009\ \frac{\$}{\text{gal}}$) or ($TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$), for instance, $r_1^{10\%} = 1$ and $r_1^{15\%} = 2$. In the best case, the b_n, r_m, and L_2 are completely the same. The comparison of the best and the worst case provides the following key insights that hold regardless of the case:

- *Bio-refineries.* For ($TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637\ \frac{\$}{\text{gal}}$ and $TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009\ \frac{\$}{\text{gal}}$) or ($TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$), a bio-refinery should be established in York county. This location is robust against both the transportation cost change and policy change. A prudent approach is to set up the bio-refinery in this location so that it could process the amount of corn stover from U_1 to U_3.
- *Blending sites.* The most robust locations for establishing blending sites are Sarpy, Lancaster, and Douglas counties. These locations are robust against both the transportation cost change and policy change. The blending site located in Sarpy county should have capacity H_2. This is the most robust blending site since it does not need any capacity change either. However, the blending site in Douglas should be set up so it could deliver amount of fuel from H_3 to H_6, the blending site in Lancaster should be setup so that it could deliver the amount of fuel between H_5 and H_6.
- *Other insights.* There is a considerable difference between the b_n and r_m in the worst and the best cases. The former results in more than forty blending sites with total blending capacity more than $60 \cdot H_1$, whereas the latter results in only three blending sites with total capacity $25 \cdot H_1$. The $25 \cdot H_1$ blending capacity is sufficient to handle fuel demand which is the same for both cases; this clearly shows that in order to reduce high fuel transportation costs the SPSC needs to establish more blending sites. On the other hand, for $TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637\ \frac{\$}{\text{gal}}$ and ($TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009\ \frac{\$}{\text{gal}}$ or $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$), the numbers of bio-refineries in the worst and best cases seem quite similar, though

the capacity of bio-refineries is more than four times higher in the best case than in the worst. This shows that the higher feedstock transportation costs, the less ethanol is produced in the state since it may not be worth shipping more corn stover from farms to bio-refineries due to the high transportation costs. Furthermore, since for $TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637 \ \frac{\$}{\text{gal}}$ and ($TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009 \ \frac{\$}{\text{gal}}$ or $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189 \ \frac{\$}{\text{gal}}$), the amount of ethanol blended with gasoline reaches the BW, $B^{\alpha} = \alpha$ in both the best and worst case, see Table 5, the extra amount of ethanol produced due to lower corn stover transportation costs will be sold to the exporters, see constraint (39) in (Ghahremanlou and Kubiak, 2020). Finally, to obtain a positive expected profit, highest social impact, and the most environmentally friendly fuel, we recommend that the tax credit for blending US ethanol with gasoline be at least $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189 \ \frac{\$}{\text{gal}}$. Then, only US ethanol is blended with gasoline which results in total ethanol independence.

4.4.2. For $\boldsymbol{\alpha = 85\%}$

Table 7 displays b_n, r_m, and L_2 for $\alpha = 85\%$. The b_n, r_m, and L_2 are insensitive to β, so it is omitted from the table. The comparison of the best and the worst case provides the following key insights that hold regardless of the case:

- *Bio-refineries.* For $TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637 \ \frac{\$}{\text{gal}}$ and ($TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009 \ \frac{\$}{\text{gal}}$ or $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189 \ \frac{\$}{\text{gal}}$), three bio-refineries should be established in York, Custer, and Buffalo counties. These locations are robust against both the transportation cost change and policy change. A prudent approach is to set up the bio-refinery in each of these locations so that it could process the amount of corn stover from U_1 to U_3.
- *Blending sites.* The most robust locations for establishing a blending site is Douglas county. Again, this is insensitive to the transportation cost change and policy change. The blending site located in Douglas county should be able to deliver the amount of fuel from H_4 to H_5.
- *Other insights.* Again there is a considerable difference between the b_n and r_m in the worst and best cases. The former results in more than forty blending sites with total blending capacity more than $50 \cdot H_1$, whereas the latter results in only three to four blending sites with total capacity of $25 \cdot H_1$ or $26 \cdot H_1$. The latter blending capacity is sufficient to meet fuel demand, which is the same for both cases. This clearly shows that in order to reduce high fuel transportation costs the SPSC needs to establish more blending sites, which remains consistent with the conclusion for $\alpha = 10\%$ and 15%. However, contrary to $\alpha = 10\%$ and 15%, for $TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637 \ \frac{\$}{\text{gal}}$ and ($TCL = 0.02 \cdot T = 0.02 \cdot 0.45 = 0.009 \ \frac{\$}{\text{gal}}$ or $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189 \ \frac{\$}{\text{gal}}$), the number of bio-refineries is approximately three times higher in the worst case than it is in the best case, which shows that in order to reduce high feedstock transportation costs the SPSC needs to establish more bio-refineries. Moreover, again contrary to $\alpha = 10\%$ and 15%, for $TI \geqslant 1.18 \cdot \overline{T} = 1.18 \cdot 0.54 = 0.637 \ \frac{\$}{\text{gal}}$ and ($TCL = 0.02 \cdot T =$

$0.02 \cdot 0.45 = 0.009\ \frac{\$}{\text{gal}}$ or $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$), the capacity of bio-refineries remain almost similar for both the best and worst cases. This shows that contrary to $\alpha = 10\%$ and 15% the higher feedstock transportation costs do not reduce the amount of ethanol produced in the state since all the produced ethanol is blended with gasoline and nothing extra is produced to be sold to the exporters. Another important insight is that, for $\alpha = 10\%$ and 15%, if $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$ only the US ethanol is blended with gasoline for any θ. However for $\alpha = 85\%$, if $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$ this happens only if $TI \geqslant 2.78 \cdot \overline{T} = 2.78 \cdot 0.54 = 1.501$, otherwise if $TI \leqslant 2.38 \cdot \overline{T} = 2.38 \cdot 0.54 = 1.285\ \frac{\$}{\text{gal}}$ also foreign imported ethanol needs to be blended with gasoline. Hence for $\alpha = 85\%$ even the total corn stover available in the US may not be enough to meet the amount of ethanol required by Nebraska if $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$ and $TI \leqslant 2.38 \cdot \overline{T} = 2.38 \cdot 0.54 = 1.285\ \frac{\$}{\text{gal}}$, see constraints (38–41) in (Ghahremanlou and Kubiak, 2020) and Appendix 2.3. Consequently, using corn stover as the only source of cellulosic ethanol production in the US may lead to a drastic ethanol dependence for the US. To reduce this dependence, other feedstock and more efficient ethanol production technologies are required for cellulosic ethanol production to attain $\alpha = 85\%$. To achieve ethanol independence with the corn stover supply available in the US, a tariff of at least $TI \geqslant 2.78 \cdot \overline{T} = 2.78 \cdot 0.54 = 1.501\ \frac{\$}{\text{gal}}$ for blending foreign ethanol with gasoline should be used. This would lead however to $B^{85\%} = 77.12\%$, which is below the BW, see Table 5. To obtain a positive expected profit, highest social impact, and the most environmentally friendly fuel ($B^{85\%} = 85\%$ see Table 5), we recommend that the tax credit for blending the US ethanol with gasoline to be at least $TCL \geqslant 0.42 \cdot T = 0.42 \cdot 0.45 = 0.189\ \frac{\$}{\text{gal}}$, and the tariff for foreign ethanol to be blended with ethanol to be at most $TI \leqslant 2.38 \cdot \overline{T} = 2.38 \cdot 0.54 = 1.285\ \frac{\$}{\text{gal}}$.

5. CONCLUSIONS AND FURTHER RESEARCH

We studied the impact of the Renewable Fuel Standard 2 (RFS2), Tax Credit (TCL and TCI), Tariff (TL and TI), and the Blend Wall (BW) on the SPSC including only cellulosic ethanol. This study is performed based on the two-stage stochastic programming model developed by (Ghahremanlou and Kubiak, 2020).

We conclude that if $TCL \geqslant 0.009\ \frac{\$}{\text{gal}}$ or $TI \leqslant 1.285\ \frac{\$}{\text{gal}}$, then ethanol is always blended with gasoline. Under these conditions an increase in the BW (α) for fixed β, η, and θ: (1) increases the expected annual profit of the SPSC, however, this increment is declining as α grows; (2) results in production of more environmentally friendly fuel; (3) keeps the expected number of jobs created steady or growing by keeping the numbers of bio-refineries and blending sites as well as their capacities steady or growing. Therefore, a strategy to increase the BW to 85%, for instance by having only Flex-Fuel Vehicles registered, emerges as a rather promising direction for the US government to pursue. This strategy appears consistent with its recent decision to increase the BW to 15%, and with general observations of (Vimmerstedt *et al.*, 2012) based on system dynamics.

Assuming α, η, and θ fixed, increasing RFS2, by increasing β: (1) reduces the expected profit by close to $P^R \cdot (1-\alpha) \cdot \beta \cdot \overline{\overline{R}} \cdot \sum_s D_s \cdot \omega_s$ whenever the blend gets close to the BW, α. This might result in bankruptcies if refineries are caught unprepared for the increase in RFS2; for instance, Philadelphia Energy Solutions, the largest U.S. East Coast oil refinery, blamed RFS2 for its bankruptcy (DiNapoli and Renshaw, 2018; Simeone, 2018; Stein, 2018). Therefore, increasing RFS2 should be well planned and communicated in order to prevent bankruptcies especially when the BW is low, e.g., $\alpha = 10\%$ and $TCL < 0.189\ \frac{\$}{\text{gal}}$; (2) does not increase the amount of ethanol blended with gasoline, does not create new jobs, and does not affect the number of bio-refineries and blending sites, and their capacities.

If $TCL \geqslant 0.009\ \frac{\$}{\text{gal}}$, then, assuming other policies fixed, increasing TCL, the tax credit for the US produced ethanol, by increasing $\eta \geqslant 0$: (1) increases the expected annual profit; (2) provides incentives to produce the most environmentally friendly blend and to attain the highest number of jobs created under the policies by increasing the number of bio-refineries and blending sites, and their capacities. In contrast, increasing TL, the tariff for the US produced ethanol, by decreasing $\eta \leqslant 0$, does not affect either the expected annual profit, or the blend, or the number of new jobs created, since no US produced ethanol is then blended with gasoline. We observe that $TL = 0.38 \cdot 0.45 = 0.171\ \frac{\$}{\text{gal}}$ or higher stops blending the US produced ethanol with gasoline. Therefore, if the government wants to replace cellulosic ethanol by other renewable transportation fuels, e.g., solar, it may consider $TL = 0.171\ \frac{\$}{\text{gal}}$ or higher. We conclude that the TCL is crucial for the creation of the SPSC, which is consistent with the general observation of (Vimmerstedt *et al.*, 2012), and that the TL is only a good leverage to prevent blending US produced cellulosic ethanol with gasoline.

Finally, if $TI \leqslant 1.285\ \frac{\$}{\text{gal}}$, then, assuming other policies fixed and $TCL \leqslant 0.009\ \frac{\$}{\text{gal}}$, increasing TCI, the tax credit for foreign ethanol, by increasing $\theta \geqslant 0$: (1) increases the expected annual profit although the number of bio-refineries and blending sites as well as their capacities may be reduced as foreign produced cellulosic ethanol becomes more competitive than US produced ethanol; (2) provides incentives to produce the most environmentally friendly blend; (3) does not create any new jobs in Nebraska. In contrast, increasing TI, the tariff for foreign imported ethanol blended with gasoline, by decreasing $\theta \leqslant 0$: (1) reduces the expected annual profit; (2) may reduce the environmental friendliness of the blend, since less ethanol is blended with gasoline; (3) may increase the number of jobs created, since there might be more bio-refineries set up in the State. To conclude, the government should be very careful while changing TCL, TL, TCI, and TI, since obtaining more environmentally friendly fuel may result in foreign ethanol dependency. To obtain a positive annual expected profit, higher social impact through new job creation, and more environmentally friendly blend, we recommend that the tax credit for blending the US produced ethanol be at least 0.189 $\frac{\$}{\text{gal}}$ ($TCL \geqslant 0.189$), and that the tariff on foreign produced ethanol not exceed 1.285 $\frac{\$}{\text{gal}}$ ($TI \leqslant 1.285$). However, by enacting these decisions the US would not be entirely ethanol independent from foreign ethanol. If the government wants also to achieve ethanol independence, it should consider $TI \geqslant 1.501\ \frac{\$}{\text{gal}}$. This would lead to the most environmentally friendly blend. Moreover, $TCL \geqslant 0.189\ \frac{\$}{\text{gal}}$ creates the most robust

SPSC. Under this condition, investors should establish a bio-refinery at York county so that it could process the amount of corn stover from U_1 to U_3. Also, the investors should set up a blending site at Douglas county so that it could deliver the amount of fuel from H_3 to H_6.

For further research, we recommend performing similar case studies for other countries with their own government policies impacting the SPSC, and their individual geography and feedstock. Also running the similar computational experiments for other states may result in new insights.

ACKNOWLEDGEMENT

This work was supported in part by the Natural Sciences and Engineering Research Council of Canada (NSERC) under Grant OPG0105675.

REFERENCES

AAA Gas Prices, 2017. National average gas prices. https://gasprices.aaa.com/?state=NE%20on%204/21/2017 [accessed on 04/21/2017].

CAMEO Chemicals, 2010. Ethanol. https://cameochemicals.noaa.gov/chemical/667 [accessed on 05/12/2017].

Carneiro, M. C., Ribas, G. P. and Hamacher, S., 2010. Risk management in the oil supply chain: a CVaR approach. *Industrial & Engineering Chemistry Research*, 49(7), pp. 3286–3294.

Chen, C.-W. and Fan, Y., 2012. Bioethanol supply chain system planning under supply and demand uncertainties. *Transportation Research Part E: Logistics and Transportation Review*, 48(1), pp. 150–164.

DiNapoli, J. and Renshaw, J., 2018. Exclusive: Philadelphia Energy Solutions to file for bankruptcy. https://www.reuters.com/article/us-philadelphiaenergysolutions-bankruptc/exclusive-philadelphia-energy-solutions-to-file-for-bankruptcy-memo-idUSKBN1FA18P [accessed on 01/21/2018].

Duffield, J. A., Xiarchos, I. M. and Halbrock, S. A., 2008. Ethanol policy: past, present, and future. *South Dakota Law Review*, 53, 425.

E85 Prices, 2016. E85 prices. https://e85prices.com/nebraska.html [accessed on 04/24/2017].

Gebreslassie, B. H., Yao, Y. and You, F., 2012. Design under uncertainty of hydrocarbon biorefinery supply chains: multiobjective stochastic programming models, decomposition algorithm, and a comparison between cvar and downside risk. *AIChE Journal*, 58(7), pp. 2155–2179.

Ghahremanlou, D. and W. Kubiak (2020). Impact of government policies on sustainable petroleum supply chain (SPSC): A case study – Part I (models). *Decision Making in Manufacturing and Services*, 14(1).

Graham, R. L., Nelson, R., Sheehan, J., Perlack, R. and Wright, L. L., 2007. Current and potential US corn stover supplies. *Agronomy Journal*, 99(1), pp. 1–11.

Gupta, A. and Verma, J. P., 2015. Sustainable bio-ethanol production from agro-residues: a review. *Renewable and Sustainable Energy Reviews*, 41, pp. 550–567.

Gurobi Optimizer LLC., 2008. Gurobi Optimizer Version 7.0. Houston, Texas: Gurobi Optimization, Inc. [accessed on 03/18/2018].

Huang, K., 2005. *Multi-stage stochastic programming models in production planning*. Ph. D. thesis, Georgia Institute of Technology.

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D., Aden, A., Schoen, P., Lukas, J., Olthof, B., Worley, M. et al., 2011. Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol: dilute-acid pretreatment and enzymatic hydrolysis of corn stover. Technical report, National Renewable Energy Laboratory (NREL), Golden, CO.

Kazemzadeh, N. and Hu, G., 2015. Evaluation of the impacts of governmental policies on the biofuels supply chain design under uncertainty. *International Journal of Sustainable Economy*, 7(3), pp. 203–219.

Kim, S. and Dale, B. E., 2015. Potential job creation in the cellulosic biofuel industry: the effect of feedstock price. *Biofuels, Bioproducts and Biorefining*, 9(6), pp.]639–647.

Klein-Marcuschamer, D., Oleskowicz-Popiel, P., Simmons, B. A. and Blanch, H. W., 2010. Technoeconomic analysis of biofuels: A wiki-based platform for lignocellulosic biorefineries. *Biomass and Bioenergy*, 34(12), pp. 1914–1921. Current and Potential Capabilities of Wood Production Systems in the Southeastern U.S.

Li, Q. and Hu, G., 2014. Supply chain design under uncertainty for advanced biofuel production based on bio-oil gasification. *Energy*, 74, pp. 576–584.

Li, Y., Brown, T. and Hu, G., 2014. Optimization model for a thermochemical biofuels supply network design. *Journal of Energy Engineering*, 140(4), 04014004.

Li, Y., Tseng, C.-L. and Hu, G., 2015. Is now a good time for Iowa to invest in cellulosic biofuels? a real options approach considering construction lead times. *International Journal of Production Economics*, 167, pp. 97–107.

Lux Research Inc., 2016. Cellulosic ethanol plants. http://www.luxresearchinc.com/sites/default/files/AF_KTA_1_16.pdf [accessed on 06/09/2016].

Nebraska Department of Revenue, 2017. Nebraska's gasoline consumption. http://www.neo.ne.gov/statshtml/37a.html [accessed on 06/17/2017].

Perlack, R. D., Eaton, L. M., Jr., A. F. T. and Langholtz, M. H., 2011. U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry. Technical report, U.S. Department of Energy.

Python Software Foundation, 2001. Welcome to Python.org. https://www.python.org/. (Accessed on 06/18/2018).

Renewable Fuels Association, 2018. Ethanol production capacity by state. http://www.neo.ne.gov/programs/stats/inf/121.htm [accessed on 03/21/2017].

Searcy, E., Flynn, P., Ghafoori, E. and Kumar, A., 2007. The relative cost of biomass energy transport. *Applied Biochemistry and Biotechnology*, 137, pp 639–652.

Shah, A., 2013. Techno-economic analysis and life cycle assessment of the corn stover biomass feedstock supply chain system for a Midwest-based first-generation cellulosic biorefinery. Ph. D. thesis, Iowa State University.

Simeone, C., 2018. Philadelphia Energy Solutions bankruptcy basics. https://kleinmanenergy.upenn.edu/blog/2018/02/02/part-1-philadelphia-energy-solutions-bankruptcy-basics [accessed on 02/05/2018].

Stein, K., 2018. An entirely predictable bankruptcy. https://www.instituteforenergyresearch.org/renewable/entirely-predictable-bankruptcy/ [accessed on 01/23/2018].

The Economist, 2016. Automation and anxiety – the impact on jobs. https://www.economist.com/special-report/2016/06/23/automation-and-anxiety [accessed on 05/12/2017].

Tong, K., Gong, J., Yue, D. and You, F., 2013. Stochastic programming approach to optimal design and operations of integrated hydrocarbon biofuel and petroleum supply chains. *ACS Sustainable Chemistry & Engineering*, 2(1), pp. 49–61.

Tsanova, T., 2016. Raizen makes cheapest cellulosic ethanol, feedstock is key – study. https://renewablesnow.com/news/raizen-makes-cheapest-cellulosic-ethanol-feedstock-is%5C%20-key-study-514409/ [accessed on 06/05/2016].

U.S. Department of Agriculture, 2012. USDA/NASS quickstats ad-hoc query tool. https://quickstats.nass.usda.gov/ [accessed on 12/27/2016].

U.S. Energy Information Administration, 2017. Petroleum & other liquids. https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm [accessed on 05/08/2017].

U.S. Environmental Protection Agency, 1980. Bulk gasoline terminals – background information for proposed standards [accessed on 08/15/2017].

U.S. Environmental Protection Agency, 2016. Notice of cellulosic waiver credit price calculation for 2016. https://www.epa.gov/renewable-fuel-standard-program/notice-cellulosic-waiver-credit-price-calculation-2016 [accessed on 06/25/2017].

U.S. Environmental Protection Agency, 2017a. Final Renewable Fuel Standards for 2014, 2015 and 2016, and the biomass-based diesel volume for 2017. https://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2014-2015-and-2016-and-biomass-based [accessed on 07/07/2017].

U.S. Environmental Protection Agency, 2017b. Overview for Renewable Fuel Standard – Renewable Fuel Standard program, https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard [accessed on June 17, 2017].

University of Nebraska, 2016. Nebraska crop reports - 2016. https://cropwatch.unl.edu/2016/nebraska-crop-reports-2016 [accessed on 04/27/2017].

Vimmerstedt, L.J., Bush, B. and Peterson, S., 2012. Ethanol distribution, dispensing, and use: Analysis of a portion of the biomass-to-biofuels supply chain using system dynamics. *PloS one*, 7(5), p.e35082.

Wight Hat Ltd., 2003a. Metric conversion charts and calculators. https://www.metric-conversions.org/weight/metric-tons-to-pounds.htm/#conversionTable?val=1 [accessed on 05/12/2017].

Wight Hat Ltd., 2003b. US gallons (liquid) to liters conversion. https://www.metric-conversions.org/volume/us-liquid-gallons-to-liters.htm [accessed on 04/02/2017].

Wikimedia Foundation Inc., 2017. Gasoline. https://en.wikipedia.org/wiki/Gasoline [accessed on 05/12/2017].

Wilhelm, W. W., Johnson, J. M., Karlen, D. L. and Lightle, D. T., 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. *Agronomy Journal*, 99(6), pp. 1665–1667.

Wisner, R., 2009. Corn, ethanol and crude oil prices relationships. https://www.agmrc.org/renewable-energy/ethanol/corn-ethanol-and-crude-oil-prices-relationships-implications-for-the-biofuels-industry [accessed on 05/12/2017].

Wright, M. and Brown, R. C., 2007. Establishing the optimal sizes of different kinds of biorefineries. *Biofuels, Bioproducts and Biorefining*, 1(3), pp. 191–200.

Zhang, L. and Hu, G., 2013. Supply chain design and operational planning models for biomass to drop-in fuel production. *Biomass and Bioenergy*, 58, pp. 238–250.

6. APPENDIX

6.1. Corn Stover in Nebraska

Table 8. *Corn and Corn Stover production for each county in Nebraska (2012)*

County	Corn Production (*bu*)	Corn Stover Production (MT/y)	County	Corn Production (*bu*)	Corn Stover Production (MT/y)
ADAMS	30,483,515	655,395.572	JEFFERSON	13,083,064	281,285.876
ANTELOPE	28,343,453	609,384.239	JOHNSON	3,717,106	79,917.779
ARTHUR	731,311	15,723.186	KEARNEY	26,745,156	575,020.854
BANNER	1,031,364	22,174.326	KEITH	14,069,787	302,500.420
BLAINE	356,582	7,666.513	KEYA PAHA	2,594,258	55,776.547
BOONE	22,377,218	481,110.187	KIMBALL	2,319,167	49,862.090
BOX BUTTE	8,759,886	188,337.549	KNOX	9,336,549	200,735.803
BOYD	1,087,708	23,385.722	LANCASTER	12,905,739	277,473.388
BROWN	4,345,453	93,427.239	LINCOLN	30,995,473	666,402.669
BUFFALO	34,718,498	746,447.707	LOGAN	3,081,790	66,258.485
BURT	14,992,221	322,332.751	LOUP	552,958	11,888.597
BUTLER	18,905,086	406,459.349	MADISON	14,399,309	309,585.143
CASS	12,047,078	259,012.177	MCPHERSON	330,660	7,109.19
CEDAR	17,307,388	372,108.842	MERRICK	17,971,471	386,386.626
CHASE	24,875,993	534,833.849	MORRILL	10,803,043	232,265.424
CHERRY	5,214,813	112,118.479	NANCE	7,384,287	158,762.170
CHEYENNE	4,953,382	106,497.713	NEMAHA	7,903,146	169,917.639
CLAY	25,411,112	546,338.908	NUCKOLLS	15,021,489	322,962.013
COLFAX	11,072,864	238,066.576	OTOE	11,131,722	239,332.023
CUMING	12,662,079	272,234.698	PAWNEE	4,128,138	88,754.967
CUSTER	35,567,025	764,691.037	PERKINS	22,673,105	487,471.757
DAKOTA	7,438,489	159,927.513	PHELPS	30,509,372	655,951.498
DAWES	864,463	18,585.954	PIERCE	15,904,085	341,937.827
DAWSON	32,718,282	703,443.063	PLATTE	24,904,119	535,438.558
DEUEL	2,554,325	54,917.987	POLK	17,395,817	374,010.065
DIXON	6,724,838	144,584.017	RED WILLOW	6,656,930	143,123.995
DODGE	19,969,493	429,344.099	RICHARDSON	10,041,640	215,895.26
DOUGLAS	4,265,616	91,710.744	ROCK	3,563,275	76,610.412
DUNDY	12,683,264	272,690.176	SALINE	19,136,024	411,424.516
FILLMORE	29,948,726	643,897.609	SARPY	4,278,624	91,990.416
FRANKLIN	11,674,498	251,001.707	SAUNDERS	21,099,076	453,630.134
FRONTIER	6,616,300	142,250.45	SCOTTS BLUFF	12,198,777	262,273.705
FURNAS	9,001,254	193,526.961	SEWARD	18,867,502	405,651.293
GAGE	15,033,856	323,227.904	SHERIDAN	4,927,216	105,935.144
GARDEN	3,291,520	70,767.68	SHERMAN	9,422,186	202,576.999
GARFIELD	2,140,111	46,012.386	SIOUX	2,323,374	49,952.541
GOSPER	12,896,553	277,275.889	STANTON	5,055,934	108,702.581
GRANT	0	0	THAYER	21,098,839	453,625.038
GREELEY	10,257,724	220,541.066	THOMAS	238,557	5,128.975
HALL	34,249,154	736,356.811	THURSTON	8,646,785	185,905.877
HAMILTON	34,678,560	745,589.04	VALLEY	10,207,594	219,463.271
HARLAN	13,247,036	284,811.274	WASHINGTON	8,949,375	192,411.562
HAYES	7,653,174	164,543.241	WAYNE	8,821,373	189,659.519
HITCHCOCK	2,915,946	62,692.839	WEBSTER	8,799,974	189,199.441
HOLT	33,211,151	714,039.746	WHEELER	4,444,482	95,556.363
HOOKER	0	0	YORK	37,406,032	804,229.688
HOWARD	13,186,780	283,515.77			

6.2. Population and Fuel Demand in Nebraska

Table 9. *Population and Fuel (ethanol-gasoline blend) consumption for each county in Nebraska (2016)*

County	Population	Fuel Consumption (Kgal/y)	County	Population	Fuel Consumption (Kgal/y)
ADAMS	31,684	11,318.45	JEFFERSON	7,177	2,563.83
ANTELOPE	6,329	2,260.90	JOHNSON	5,171	1,847.23
ARTHUR	469	167.54	KEARNEY	6,552	2,340.57
BANNER	798	285.07	KEITH	8,018	2,864.26
BLAINE	484	172.90	KEYA PAHA	791	282.57
BOONE	5,332	1,904.75	KIMBALL	3,679	1,314.25
BOX BUTTE	11,194	3,998.82	KNOX	8,571	3,061.81
BOYD	1,982	708.03	LANCASTER	309,637	110,611.38
BROWN	2,960	1,057.40	LINCOLN	35,550	12,699.50
BUFFALO	49,383	17,641.05	LOGAN	772	275.78
BURT	6,546	2,338.42	LOUP	591	211.12
BUTLER	8,052	2,876.41	MADISON	493	176.11
CASS	25,767	9,204.72	MCPHERSON	35,015	12,508.38
CEDAR	8,671	3,097.53	MERRICK	7,828	2,796.39
CHASE	3,937	1,406.41	MORRILL	4,787	1,710.06
CHERRY	5,832	2,083.36	NANCE	3,576	1,277.45
CHEYENNE	10,051	3,590.51	NEMAHA	6,971	2,490.24
CLAY	6,163	2,201.60	NUCKOLLS	4,265	1,523.58
COLFAX	10,414	3,720.18	OTOE	16,081	5,744.60
CUMING	9,016	3,220.78	PAWNEE	2,652	947.37
CUSTER	10,807	3,860.58	PERKINS	2,898	1,035.25
DAKOTA	20,465	7,310.70	PHELPS	9,266	3,310.09
DAWES	8,979	3,207.56	PIERCE	7,159	2,557.40
DAWSON	23,640	8,444.90	PLATTE	32,861	11,738.91
DEUEL	1,873	669.09	POLK	5,203	1,858.66
DIXON	5,762	2,058.35	RED WILLOW	10,722	3,830.21
DODGE	36,757	13,130.67	RICHARDSON	8,060	2,879.27
DOUGLAS	554,995	198,260.42	ROCK	1,390	496.55
DUNDY	1,831	654.09	SALINE	14,331	5119.45
FILLMORE	5,720	2,043.35	SARPY	179,023	63,952.24
FRANKLIN	3,014	1,076.69	SAUNDERS	21,038	7,515.39
FRONTIER	2,621	936.30	SCOTTS BLUFF	36,422	13,011.00
FURNAS	4,787	1,710.06	SEWARD	17,284	6,174.35
GAGE	21,799	7,787.24	SHERIDAN	5,234	1,869.74
GARDEN	1,930	689.45	SHERMAN	3,054	1,090.98
GARFIELD	2,011	718.39	SIOUX	1,242	443.68
GOSPER	1,971	704.10	STANTON	5,944	2,123.37
GRANT	641	228.98	THAYER	5,101	1,822.23
GREELEY	2,399	856.99	THOMAS	716	255.78
HALL	61,705	22,042.83	THURSTON	7,127	2,545.97
HAMILTON	9,186	3,281.51	VALLEY	4,184	1,494.65
HARLAN	3,473	1,240.66	WASHINGTON	20,603	7,359.99
HAYES	897	320.43	WAYNE	9,365	3,345.45
HITCHCOCK	2,825	1,009.17	WEBSTER	3,603	1,287.10
HOLT	10,250	3,661.60	WHEELER	776	277.21
HOOKER	708	252.92	YORK	13,794	4,927.62
HOWARD	6,429	2,296.63			