Models for Optimizing the Supply Chain in Support of Biomass Co-Firing in Coal Plants

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Research Motivations & Objectives

Motivations

- *Coal-fired power plants in the US consume 1.1 to 1.2 billion tons of coal annually.*
- *Co-firing biomass reduces Green House Gas emissions.*
- *Co-firing biomass is a near term, low-cost option for electricity generation.*

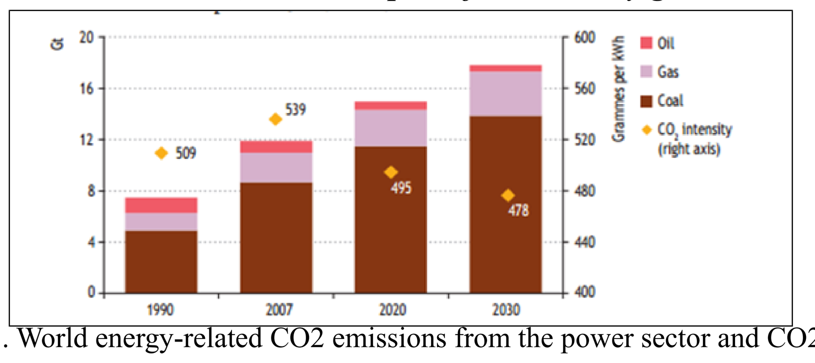

Figure 1. World energy-related CO2 emissions from the power sector and CO2 intensity

Objectives

- *Developing optimization models for minimizing costs and maximizing savings due to co-fire*
- *Evaluating the impact of Production Tax Credit (PTC) on biomass usage in power plants*

Problem Formulation

- **Amount of required coal and biomass**

$$M_j^{coal} = \frac{Q_j^0 * OH_j * C^{wb}}{LHV_j^{coal}}$$

Annual heat rate; Lower Heating Value

$$M_j^{bm} = \frac{\beta_j}{1-\beta_j\alpha_j} * \frac{Q_j^0 * OH_j * C^{wb}}{LHV_j^{coal}} * \frac{\rho_j^b}{\rho_j^b - EL_j}$$

Biomass usage percentage; Efficiency loss

- **Investment Costs**

$$\beta_j\% \le 4\% \longrightarrow I_j^{CAP} = I_j^{cap} * \frac{\beta_j}{1-\beta_j}$$

$\beta_j\% > 4\%$ →

Biomass storage costs: $I_j^S = I_j^s * \left(\frac{\beta_j}{1-\beta_j}\right)^{0.5575}$

Biomass handling costs: $I_j^H = I_j^h * \left(\frac{\beta_j}{1-\beta_j}\right)^{0.9554}$

Compress-dryers costs: $I_j^{CD} = I_j^{cd} * \left(\frac{\beta_j}{1-\beta_j}\right)^{0.5575}$

- **Operating Costs:** $\sum_{i\in S} c_i^{bm} M_j^{bm}$ — Biomass procurement price

- **Logistics Costs:** $\sum_{i\in S} c_{ij}^t M_j^{bm}$ — Transportation price between facilities

- **Savings due to:**

Displacement of coal: $\sigma_j^p = c_j^{coal} * \frac{LHV_j^{bm}}{LHV_j^{coal}}$ — Coal price per tone

Production Tax Credit (2.3 cents/kWh): $\sigma_j^t = 23 * \frac{LHV_j^{bm}}{C^{wb}}$

Non-linear Optimization Model

- **Decision Variables:**

B_j: *Biomass percentage in plant "j"*

X_{ij}: *Amount of biomass transported from facility "i" to plant "j" annually*

Y_j: *Binary variable which takes 1 if biomass percentage in plant "j" is <4%*

$$Maximize: Z = \sum_{j\in C}(\sigma_j^p + \sigma_j^t)\sum_{i\in S}X_{ij} - \sum_{i\in S, j\in C}(c_{ij}^t + c_i^{bm})X_{ij} - \sum_{j\in C}(I_j^s + I_j^{cd})(1-Y_j)\left(\frac{B_j}{1-B_j}\right)^{0.5575} - \sum_{j\in C} I_j^h(1-Y_j)\left(\frac{B_j}{1-B_j}\right)^{0.9554} - \sum_{j\in C} I_j^{cap}\left(\frac{B_j}{1-B_j}\right)Y_j$$

Subject to:

$$\sum_{j\in C} X_{ij} \le s_i \quad \forall i \in S$$

$$\sum_{i\in S} X_{ij} \le \frac{(Q_j^0 * OH_j * C^{wb} * \rho_j^b)/LHV_j^{coal}}{(1/B_j - \alpha_j)*(\rho_j^b - 0.0044B_j^2 - 0.0055)} \quad \forall j \in C$$

$$B_j - 0.04 \le M(1-Y_j) \quad \forall j \in C$$

$$0.04 - B_j < MY_j \quad \forall j \in C$$

$$X_{ij} \in R^+ \quad \forall j \in C, i \in S$$

$$B_j \in [0,1] \quad \forall j \in C$$

$$Y_j \in \{0,1\} \quad \forall j \in C$$

Linear Optimization Model

- *Problem is discretized for possible values of biomass percentage B.*
- *Let L={1, .., l, ... |L|} be the finite set of all potential values that B can take.*
- **Decision Variables:**

X_{ij}: *Amount of biomass transported from facility "i" to plant "j" annually.*

Y_{lj}: *Takes 1 if plant "j" would use the percentage of biomass indexed by "l"*

$$Max: Z = \sum_{j\in C}\left((\sigma_j^p + \sigma_j^t)\sum_{i\in S}X_{ij}\right) - \sum_{i\in S, j\in C}(c_{ij}^t + c_i^{bm})X_{ij} - \sum_{l\in L}\sum_{j\in C} I_{lj}Y_{lj}$$

Subject to:

$$\sum_{j\in C} X_{ij} \le s_i \quad \forall i \in S$$

$$\sum_{i\in S} X_{ij} \le \sum_{l\in L} M_{lj}^{bm} Y_{lj} \quad \forall j \in C$$

$$\sum_{l\in L} Y_{lj} \le 1 \quad \forall j \in C$$

$$X_{ij} \in R^+ \quad \forall j \in C, i \in S$$

$$Y_{lj} \in \{0,1\} \quad \forall j \in C, l \in L$$

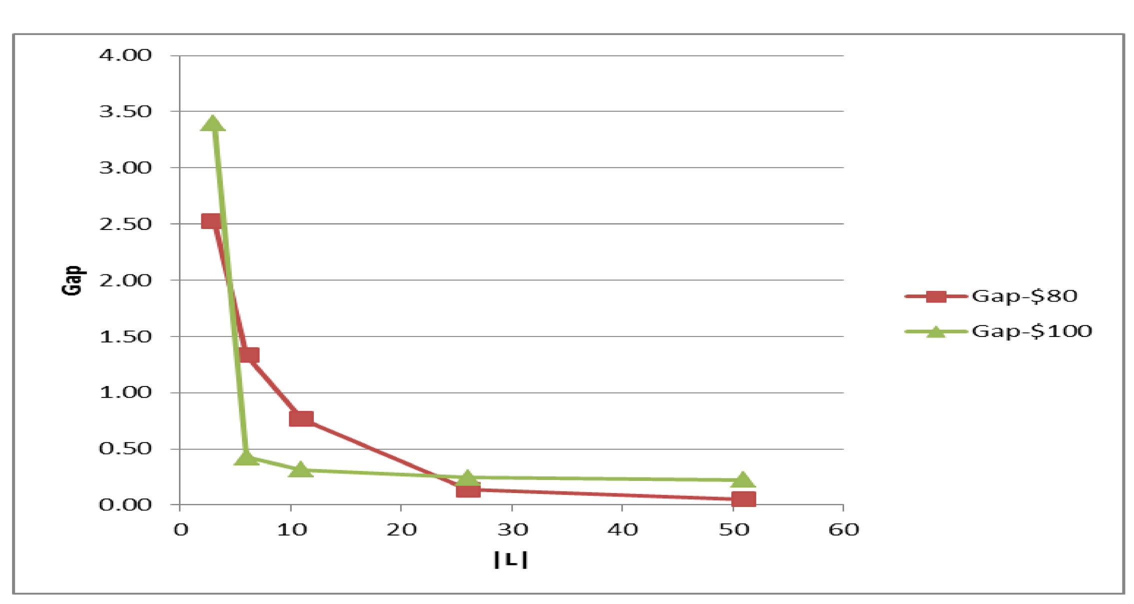

Figure 2. The gap between two models for different scenarios on set L

A Case Study

Price (in $/ton)	Biomass Available (in tons)	Price (in $/ton)	Biomass Available (in tons)
50	25,900	130	5,551,100
60	258,800	140	6,208,000
70	793,000	150	6,754,900
80	1,601,700	160	7,507,400
90	2,523,400	170	8,046,500
100	3,434,500	180	8,657,800
110	4,107,100	190	9,220,600
120	4,781,400	200	9,687,500

Table 1. Biomass Availability for the state of Mississippi (data from KDF)

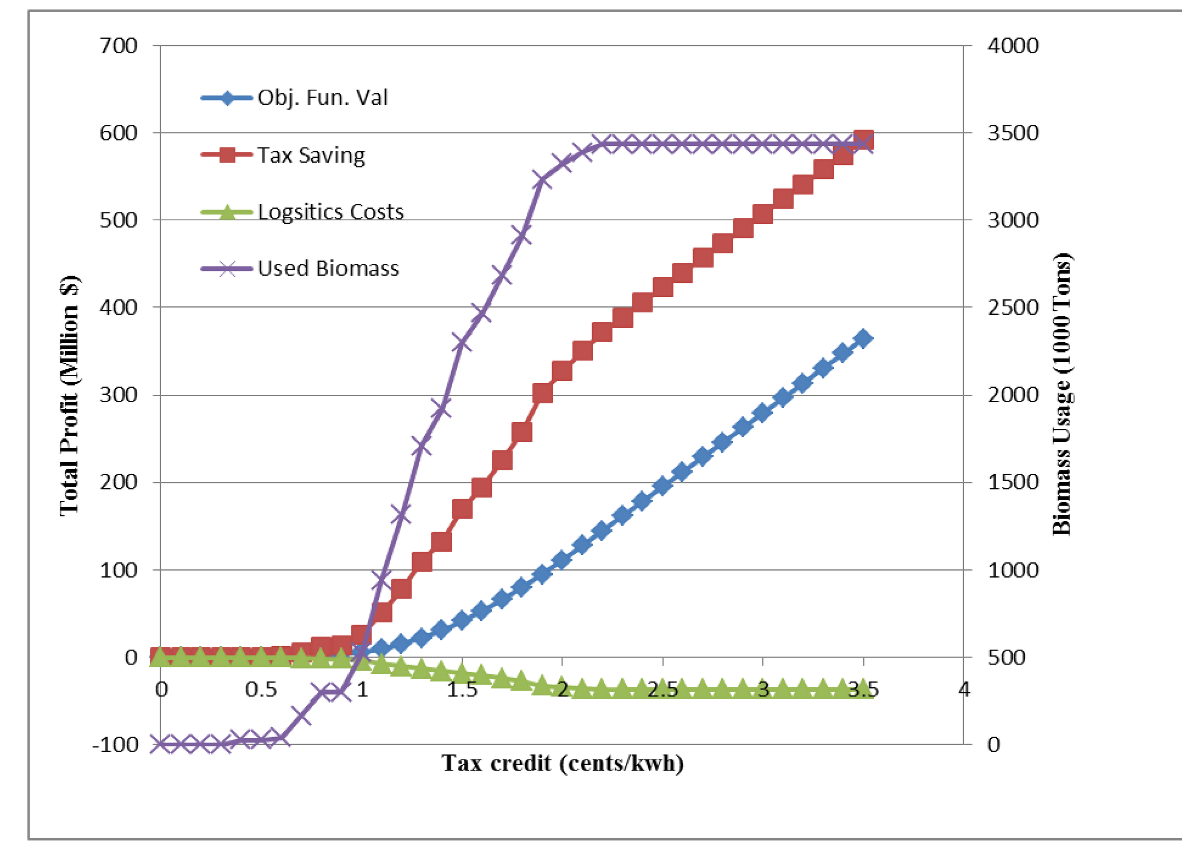

Figure 3. The impact of tax credits on profits and biomass usage

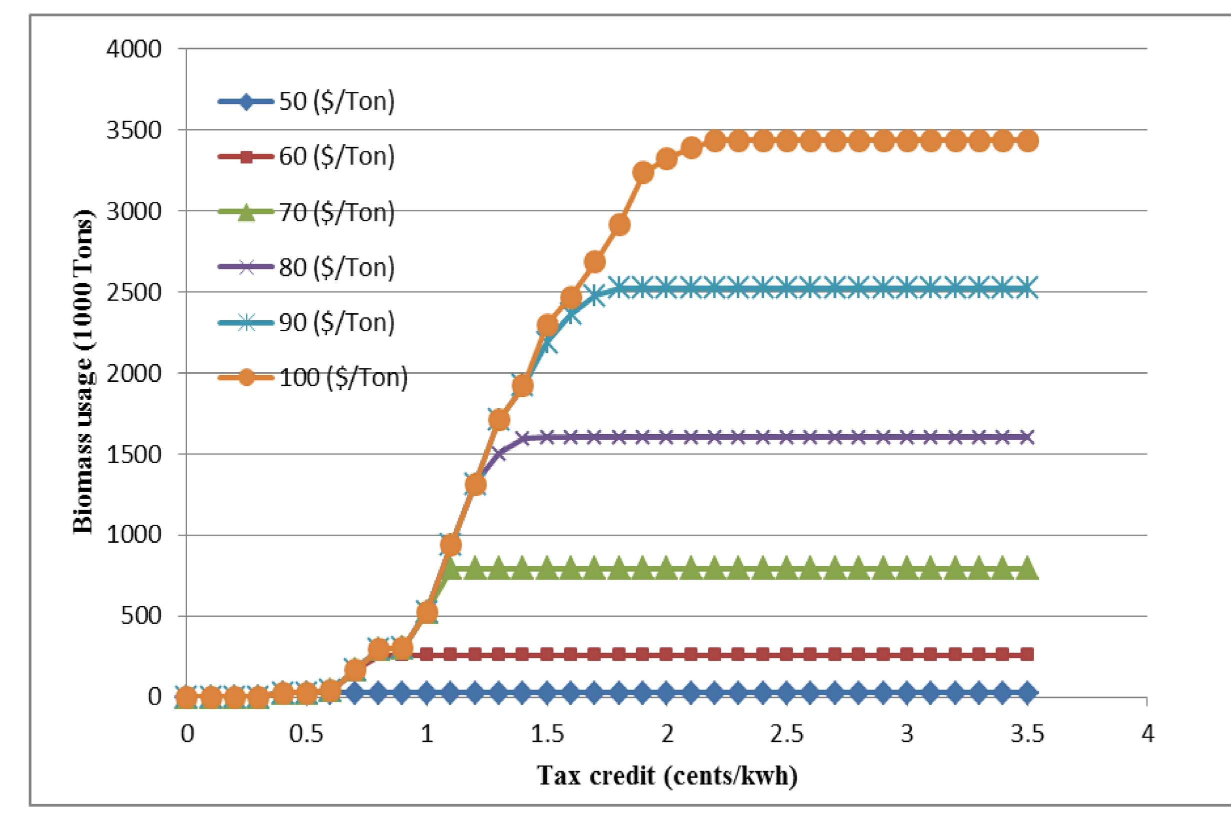

Figure 4. The impact of tax credit and targeted price on biomass usage

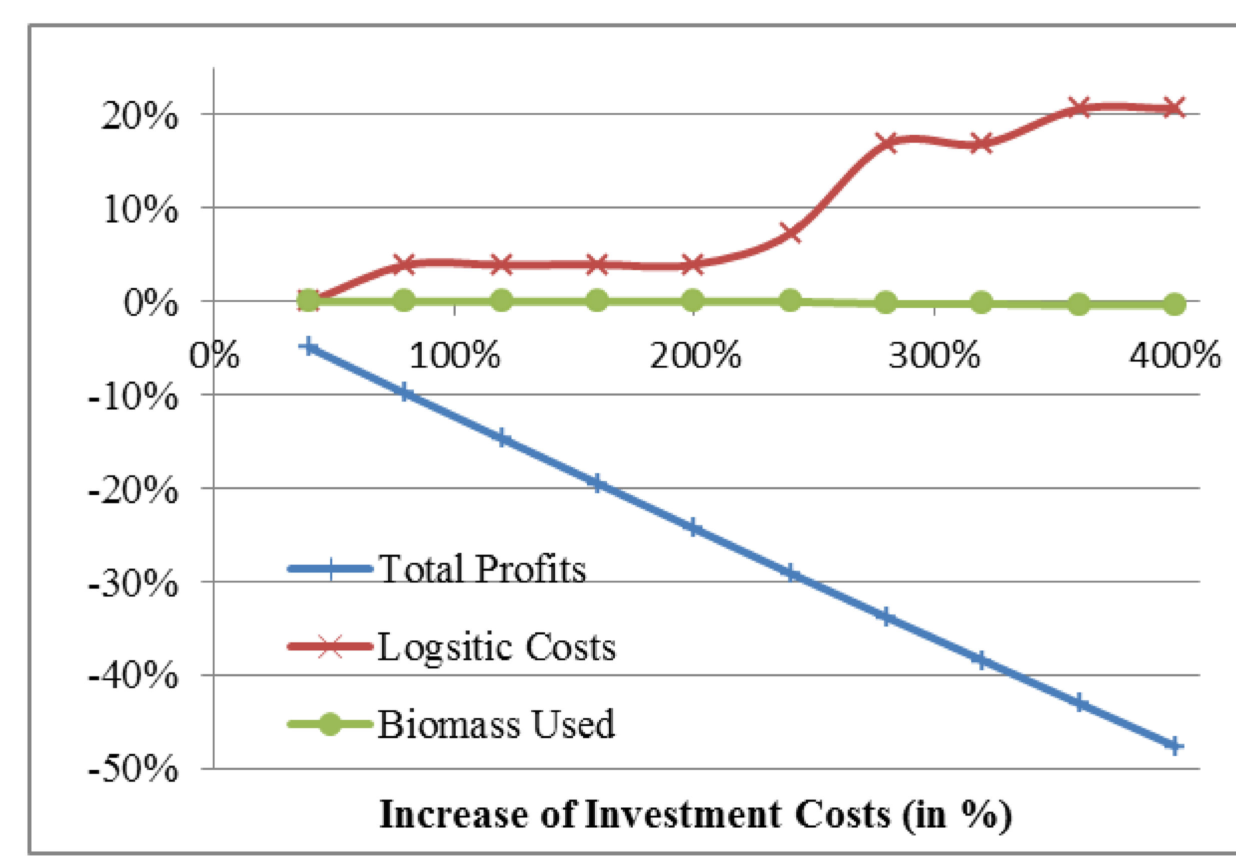

Figure 5. Relationship between investment costs, logistics costs, profits, biomass use

Summary & Conclusion

Summary

- *A nonlinear mixed integer programming model with biomass percentage as a variable*
- *A linear mixed integer programming model as an approximation for the other model*
- *A case study of biomass co-firing in the state of Mississippi power plant sector.*

Conclusion

- *Tax credits are necessary in order to increase the production of the renewable energy.*
- *The developed linear model is a good approximation of nonlinear model and could be used for future research in the subject.*
- *Tax credit should not be "one size fits all". Instead, tax credits could be a function of the amount of renewable electricity produced.*
- *Biomass availability in the USA differs by region. To optimize renewable energy production, the tax rate/production amount should be customized by region.*

Acknowledgement

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