Exploring the Potential to Penetrate the Energy Markets for Tennessee-Produced Switchgrass

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Abstract

Growing biomass crops for energy production on low productivity lands that are not used for food production has been suggested as an alternative to reduce dependence on fossil fuels and to mitigate greenhouse gas emissions from transportation fuel. Switchgrass is considered a potential feedstock in various states, including Tennessee, because of its good yields on poor soils. However, its low density relative to its energy value and resulting high logistics costs impedes the profitability of switchgrass-based bioenergy. The objective of this study is to determine the optimal logistics configuration for a collection/distribution hub to market Tennessee-produced switchgrass for bioenergy production. A mathematical programming model integrated with the geographic information system is used to maximize the net present value (NPV) of profit of the hub that serves switchgrass producers and bioenergy markets. A total of six logistics configurations delivering switchgrass to local or international bioenergy markets are evaluated. The results highlight the economic challenges of penetrating the energy market for the collection/distribution hub of switchgrass: only one logistics configuration for the local market is profitable. However, serving international markets becomes feasible when investment risk is lowered. This information implies that certainty of bioenergy policies is crucial to the development of biomass feedstock for bioenergy industry.

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1. INTRODUCTION

Growing concerns about energy security and greenhouse gas (GHG) emissions have motivated the demand for renewable energy. Energy produced from biomass is considered as a promising alternative energy because bioenergy not only reduces GHG emissions but also creates positive socio-economic benefits through employment and infrastructure improvements (Monique et al 2003, Domac et al 2005). Currently, the major source of biofuels comes from field grain crops. The second generation biofuels derived from lignocellulosic biomass (LCB), e.g. perennial grasses, crop residues, and woody residues, have gained increasing attention because of less linkage to food prices compared to crop feedstock (Samson et al. 2005).

Realizing the potentials of bioenergy to enhance national energy, economy, and the environment, many countries have developed mandates and policies to accelerate the implementation of biofuel/bioenergy systems (McCormick and Kåberger 2007). Several policies to promote the use of renewable sources of energy including LCB have been implemented in the US and the European Union (EU) (Zegada-Lizarazu et al 2013). In the United States, the development of LCB-based energy is being driven in large by the Energy Independence and Security Act of 2007 (EISA). According to mandate issued in the Renewable Fuel Standard, biofuel production is expected to reach 36 billion gallons in 2022, with at least 16 billion gallons derived from LCB (U.S. Congress 2007). Similarly, the EU has set targets of replacing 24% of transport fuel, 14% of bioelectricity, and 62% of heat using biomass by 2020 (AEBIOM 2010).

Switchgrass (*Panicum virgatum*), a warm season perennial grass, is considered a potential LCB energy crop (Fike et al. 2006), owing to its very hardy nature and ability to grow well in a wide range of environments throughout the US with relatively low inputs compared to traditional field crops (Jensen et al. 2007). Switchgrass can be used to produce biofuel and is viewed as a potential long-term biofuel feedstock to replace corn (Keshwani and Cheng 2009). Heat or electricity can be produced using switchgrass through combustion, either alone or by co-firing with coal or other fossil fuels with a potential of reducing GHG emissions (Tillman 2000). The EU is considered as an emerging market of switchgrass pellets for commercial heating applications (Grbovic 2010, Samson et al. 2008). Currently wood pellets hold the largest share in the international trade of biomass-based energy feedstock (Sikkema et al 2011). Switchgrass pellets have the potential to penetrate this market as they are next to wood pellets in terms of suitability to large heat and power generation plants (Sultana et al 2010).

Despite its potential for energy production, switchgrass is not currently produced commercially on a large scale for energy use in the US. One of the major barriers to the development of this bioenergy sector is the technical challenges and associated high cost related to the handling and transportation of the low density feedstock from farm to conversion facility. Due to high costs, market penetration becomes difficult and costs inhibit competition with the traditional energy sources like fossil fuels (Wee et al 2012). Logistics has been recognized as a significant cost component of bioenergy sector (Rentizelas et al 2009). Optimization of all the logistical components in the supply chain of switchgrass is essential to minimize the total cost or maximize the total profit (de Lourdes Bravo et al 2012).

Several states in US created various incentive programs to develop local bioenergy industry. The Tennessee Biofuels Initiative (TBI), a state sponsored program, allocated $70 million in 2007 to establish a switchgrass-based energy sector. Under the TBI, a pilot LCB-based ethanol plant with a capacity of 250,000 gallons of biofuel per year was constructed by DuPont Cellulosic Ethanol and Genera Energy Inc. and has been in operation in Vonore, TN, since January 2010. Genera Energy contracted with 61 local farmers to supply switchgrass by establishing about 5,100 acres of switchgrass within a 50 miles radius of the pilot refinery (Tiller 2011). These contracts expired at the end of harvesting season in 2013 as the state funded payment had been exhausted while the market for switchgrass had not been developed. Thus, it is crucial to explore the potential to penetrate energy markets for Tennessee-produced switchgrass to encourage farmers' continuous participation and maintain the operation of Genera Energy for the goal of developing a bioenergy sector in the state.

The objective of the study is to determine the optimum logistics pathway to penetrate bioenergy markets via a collection hub/depot with Genera Energy as an example in this study. Genera Energy is responsible for managing the feedstock logistics to serve both feedstock producers and bioenergy markets. This study is expected to provide useful information for policy makers to expedite the development of the LCB-based energy industry and for investors to make decisions regarding investment in bioenergy.

2. LITERATURE REVIEW

With the development of bioenergy as a focus of national energy and environmental plans, an array of studies has been conducted to analyze the potential of biomass for energy production as well as related opportunities and challenges. To establish bioenergy sector in a particular region, knowing the potential of using local biomass feedstock for existing energy demand and the feasibility of producing energy from the biomass feedstock within the region is important. In addition, the efficiency of the feedstock supply chain which connects producers of the bulky biomass with bioenergy plants is a crucial factor. Thus, the present study focuses on the literature in three areas: the potential of using biomass for energy, the biomass supply chain costs, and the economic feasibility of bioenergy production.

2.1 Using biomass for energy

Global trade in biomass feedstock is growing at a fast pace owing to energy security and reducing GHG emissions (Heinimö and Junginger 2009). Biomass is considered to be an attractive renewable fuel to supplement coal combustion in utility boilers (Hughes 1998). The co-firing of biomass and coal is a promising technology for efficiently converting biomass to electricity in existing coal-fired boilers without major capital investments (Nicholls and Zerbe 2012). Table 1 summarizes a few studies evaluating the economic and environmental advantages of using biomass for energy production.

When compared to wood pellets based on energy content and conversion efficiency, switchgrass pellets have an equivalent energy content of 19.0 Giga Joules/tonne and the same conversion efficiency of 82% (Jannasch et al. 2001). Currently, the EU is one of the leading markets in wood pellets. The EU 2020 policy targets for renewable energy sources and GHG emissions reduction are the main drivers of a booming pellet market in the EU (Qian and McDow 2013). That said, although the wood pellets are considered to be the most economically efficient means to displace fossil fuels, large scale of wood cannot be harvested because of ecological and supply constraints (Faaij and Domac 2006). As switchgrass pellets have energy content comparable to wood pellets (Jannasch et al 2001), switchgrass pellets have the potential to penetrate the EU's bioenergy market and meet the increasing demand for pellets.

2.2 Determining the biomass supply chain cost

The biomass supply chain includes the processes from harvesting to transportation to the end user (e.g., conversion facility). At every step of supply chain, the cost and energy efficiency of biomass can be influenced, such as by the type of harvesting method used, choice of preprocessing operation, storage method used, and mode of transportation. A number of studies have been conducted to analyze the biomass supply chain from farm to bioenergy conversion facility with respect to logistical performance and challenges (Table 2). Various researchers used the GIS integrated with mathematical programming or the GIS-based environmental decision support system (EDSS) to meet their objectives. Some researchers evaluated the switchgrass supply chain specifically (Cundiff et al 1997; Zhu et al 2011; Zhang et al 2012) which involves planting, harvesting, preprocessing, storing, and transportation to conversion facilities.

Switchgrass is assumed to have production cycle of 10 years and can be harvested annually. In Tennessee, switchgrass is harvested once per year (from November to February) as it minimizes the replacement of nutrients (Larson et al 2010). Harvest form of switchgrass is selected based on the storage or transportation cost or on customer needs (Sokhansanj and Hess 2009). Storage costs mainly depend on three factors: storage location, storage system, and storage forms. Many researchers have assumed on-field biomass storage to calculate the delivered cost of biomass (Allen et al. 1998, Sokhansanj et al. 2006). Some authors have proposed intermediate storage sites between the farm and the power plant, so-called satellite storage locations (SSLs) (Ravula et al. 2008, Tatsiopoulos and Tolis 2003) to serve as temporary storage locations.

Additionally, some researchers have studied feedstock storage in different forms, including chips, square bales, and round bales. Searcy and Hess (2010) discussed the storage of wood chips in the form of a pile using circular stacker reclaimer. Switchgrass can be stored as square or round bales as well. Square bales are cost efficient as they are easy to handle and transport (Larson et al. 2010) but have more dry matter loss as compared to round bales.

The low bulk density of switchgrass also increases logistics costs. Feedstock density can be increased substantially through various preprocessing methods. The major preprocessing methods are drying, densifying, stretch-wrap bale, pelletization, pyrolysis, and torrefaction. The density of pelletized feedstock ranges from 30 to 40 lbs/ft3 (Mani et al. 2006), and the compact size of pellet is an advantage for long distance transportation (Selkimäki et al. 2010).

Preprocessing can occur with harvesting operations or at separate preprocessing facilities known as preprocessing depots or hubs (Wright et al 2006; Carolan et al 2007; Eranki et al 2011; Bals and Dale 2012). Yu et al. (2011) evaluated the potential value of including preprocessing in the biomass feedstock supply chain for a biorefinery in East Tennessee using a spatial oriented mixed-integer mathematical programming model. The results showed that stretch-wrap bale preprocessing technology could reduce the total delivered cost of switchgrass for large scale biorefineries.

The transportation costs of biomass constitute one of the major cost components in the entire supply system contributing 25-40% to the total delivery cost of biomass depending on the form and location of biomass resource (Hamelinck et al. 2005). One of the solutions to reduce transportation cost is densification of biomass into pellets, cubes, or briquettes with bulk density of more than 25lb/ft^3 (Sokhansanj and Turhollow 2004). Mode of transportation also affects the transportation cost. Truck transportation is appropriate for short distances of 100 miles but for longer distances, intermodal transportation has cost advantages (Sokhansanj et al. 2009; Gold and Seuring 2011).

2.3 Assessing the economic feasibility of biomass for bioenergy

Many researches have been carried out to analyze the economic feasibility of bioenergy production from biomass. A cost-benefit analysis carried out by O'Mahoney et al (2013) in Ireland to assess the feasibility of achieving the target of 30% co-firing of peat and biomass by 2015. The results showed that the co-firing was not the least cost option and government participation in terms of policies is needed to meet the targets. Rentizelas et al (2009) developed an optimization model with an objective of maximizing the NPV of an investment in bioenergy systems. The results indicated that the interest rate had the highest impact on project costs, and biomass cost had little impact on the NPV because of cheap availability of biomass in the region. Another study carried out by Van Dam et al (2009) for analyzing the economic feasibility of large-scale bioenergy production from soybeans and switchgrass showed that transportation costs, cultivation costs, preprocessing costs, and crop prices were the key parameters affecting economic performance.

The environmental impact, cost, and net GHG emissions of replacing coal with switchgrass were assessed by Qin et al (2011). Different production methods and transportations methods were analyzed, showing that switchgrass for bioenergy was competitive with coal only in case of high coal prices, lower production costs, or with an emission price for CO2. Similar results were found by Aravindhakshan et al (2010) when evaluating the economics of switchgrass and the miscanthus relative to coal for electricity generation in an experimental station in Oklahoma. The results showed that a carbon emissions tax makes the feedstock competitive with coal.

Although biomass energy production and associated supply chains for feedstock have been studied previously, little attention has been given to exploring the optimum logistics pathway as managed by a collection/distribution hub in regard to energy market penetration for Tennessee-produced switchgrass. Therefore, the present study fills a gap in the literature by providing the systematic evaluation of different logistics configurations, including different harvest, storage, and preprocessing means, for a case study of switchgrass in Tennessee.

3. METHOD AND DATA

A cost-minimization switchgrass logistics model (Larson et al. 2015, Gao 2011) was modified to maximize the net present value (NPV) for the collection/distribution hub for delivering Tennessee-produced switchgrass to energy markets. The present study was a case study assuming Genera Energy as the collection/distribution hub between the potential producers and markets. The model was used to determine the costs associated with various switchgrass supply systems and the revenue generated from targeted markets. The GIS was integrated with the mathematical programming model to select the optimal biomass supply region.

The feedstock supply region was determined given the geographical relationship with Genera Energy and was divided into 1,138 five square-mile hexagons (i.e. crop zones) (Figure 1). Traditional croplands were considered for potential switchgrass production area. The crop yield was obtained from the soil survey geographical (SSURGO) database at the sub-county level (USDA 2012). The area under each crop zone for each crop type was derived from the cropland layer database (USDA National Agricultural Statistics Service, 2011). The prices of traditional crops were obtained by taking a three year average (2010-2012) from the National Agricultural Statistics Service, USDA (2013). The POLYSYS model was used to obtain the production cost of traditional crops (Ugarte and Ray 2000). Budgets for the equipment, materials, and labor used for the establishment, annual maintenance, harvest, storage and transportation of switchgrass were obtained from the budgets produced by the University of Tennessee Department of Agricultural and Resource Economics and data from Larson et al (2010). The diesel price was assumed to $3.5 per gallon when estimating machinery costs.

The study used existing biomass-energy producers as targeted local markets within 70 miles of Genera Energy (Table 3). Switchgrass was assumed to be delivered to local markets in bale or chopped form, and the quality of either form was assumed to be the same. The industrial wood pellet market in the Netherland and Belgium, which serve as the largest market for industrial use of wood pellets, was considered as the international market. The total US export of wood pellets to these countries amounted to 500,000 tons per year (Sikkema et al 2012). It was assumed that Genera Energy would capture 20% of the total exports amounting to 100,000 tons of switchgrass pellets per year. Switchgrass pellets quality was assumed to be of utility grade, which can be used for industrial purposes.

Following Larson et al (2010), cost of switchgrass production included opportunity costs on land, establishment costs incurred in the first year of production, and recurring annual costs for fertilizer, pest control, harvest, preprocessing, storage, and transportation of the feedstock. The establishment costs included the costs of seed, fertilizers, and machinery used for establishing switchgrass. It was amortized annually using a capital recovery factor at an interest rate (r) of 10% over a 10 year time period (T). All the machinery costs were calculated following American Society of Agricultural Engineers Standards (ASAE, 2006). In case of industrial machinery, like pelletizing equipment, stretch-wrap bale equipment, and a stacker-reclaimer, salvage value was assumed to be zero. Taxes, insurance, and housing (TIH) were calculated based on the property assessment ratio (0.4) and property rate (2.01) in Vonore, TN. The values were obtained from the Monroe County Trustee website (2014).

Costs and revenue were estimated for each year for the period of 10 years. Profit was calculated for each year. To estimate the NPV, profit was discounted using constant present value annuity factor ($PVAF$), which is given by:

$$PVAF = \frac{(1+r)^T - 1}{r(1+r)^T} \qquad (1)$$

and NPV is formulated in equation (2):

$$NPV = \{(P * Q - TC)\} * PVAF \qquad (2)$$

where P is the price of switchgrass in the energy market, and Q is the quantity sold.

For local markets, price of delivered switchgrass was assumed to be \$60 per ton. This price is based on the estimate by U.S. Department of Energy (2011), which suggested that a market price of \$60 per dry ton can attract a sufficient supply of biomass feedstock to replace 30% of transportation fuel use by 2030. The quantity delivered was based on the demand of local markets. The CIF price (cost, insurance, and freight price) of the wood pellets in Rotterdam was assumed to be the price for switchgrass pellets for the international market. The price was assumed to be \$175/ ton, calculated by taking the average of monthly price of wood pellets from March 2011 to Nov 2011 (Qian and McDow 2013). It was assumed that 100,000 tons of switchgrass pellets were transported to international markets annually.

Total costs (TC) can be written as equation (3) where $OppCst$, $ProdCst$, $HarCst$, $StrgCst$, $PPCst$, and $TrnsCst$ represent the total opportunity, production, harvest, storage, preprocessing, and transportation costs respectively.

$$TC = OppCst + ProdCst + HarCst + StrgCst + PPCst + TrnsCst \qquad (3)$$

Opportunity cost: The opportunity cost ($OppCst$) for switchgrass production was equal to the income from a traditional crop type grown on that land. If the profit from the traditional crop grown was less than the land rent, then the opportunity cost was equal to the land rent. The relationship is presented in equation (4):

$$OppCst = \begin{cases} \sum_{icb} \left(\frac{P_{ic} * Y_{ic} - PC_{ic}}{y_{ib}} * XC_{icb} \right), & \text{if } (P_{ic} * Y_{ic} - PC_{ic}) \geq LR_{ic} \\ \sum_{ic} \left(\frac{LR_{ic}}{y_{ib}} * XC_{icb} \right), & \text{if } (P_{ic} * Y_{ic} - PC_{ic}) < LR_{ic} \end{cases} \qquad (4)$$

where P_{ic}, Y_{ic}, PC_{ic}, LR_{ic} represented price of the traditional crop, yield of the crop, production costs and land rent associated with each crop zone; XC_{icb} represented switchgrass production; and y_{ib} was the yield of switchgrass. The switchgrass yield varied across the state with an average of 7.26 tons/acre and 6.56 tons/acre for round and square bales, respectively. For chopped switchgrass the yield was assumed to be the same as that of round bales. The average yield for square bales was lower than the round bales because of higher dry matter loss during storage in the case of square bales as compared to round bales. The annual dry matter loss was incorporated into the yield of switchgrass used in the study. The subscript $i, c,$ and b represent crop zones, type of crop, and form respectively.

Production Cost: The production cost ($ProdCst$) for switchgrass produced (XC_{icb}) consisted of the establishment costs (Est) as well as the annual maintenance costs (AMC) (equation (5)).

$$ProdCst = \sum_{icb} \left(\frac{\text{Est} + \text{AMC}}{y_{ib}} * XC_{icb} \right) \qquad (5)$$

Harvest Cost: The harvest cost ($HarCst$) constituted labor, fuel and machinery costs for switchgrass harvest. Three harvest technologies were assumed in this study including square baler, round baler, and chopper. The chopper was equipped with a rotary header and had a throughput capacity of 20 tons per hour. Harvest technologies influenced the cost since different machineries with different fuel consumption rates were used in equation (6).

$$HarCst = \sum\nolimits_{icb} \left(\frac{\mathrm{Sigma}_{ic}}{y_{ib}} \times XH_{icb} \right) \qquad (6)$$

where Sigma_{ic} represents the cost of harvest per ton and XH_{icb} the tons of switchgrass harvested.

Storage Cost: Storage cost for switchgrass ($StrgCst$) consisted of the costs of materials used and the cost from equipment and labor used in storage operations. Square bales were stored using pallet and tarp, while in the case of round bales, only tarp was used. The chopped switchgrass was either preprocessed (stretch wrap bales or pellets) before storage or stored as such using stacker reclaimer at Genera Energy. The machinery costs and total cost of handling switchgrass with a stacker-reclaimer are obtained from Jackson (2014). The storage cost ($StrgCst$) was given by equation (7).

$$StrgCst = \sum\nolimits_{icbs} \gamma_{ibs} * XS_{icbs} \qquad (7)$$

where s represents the storage method used, γ_{ibs} is the storage cost per ton, and XS_{icbs} is tons of switchgrass stored. The storage cost of preprocessed switchgrass in the form of stretch wrap bale or pellets was incorporated in the preprocessing cost.

Preprocessing Cost: Switchgrass was either preprocessed as stretch wrap bale or pellet. The preprocessing cost ($PPCst$) of switchgrass to stretch wrap bale was given by equation (8)

$$PPCst = \sum\nolimits_{j} (FCP_j \times PF_j) + \sum\nolimits_{icj} (VCP_j \times XTP_{icj}) \qquad (8)$$

It constituted the fixed cost (FCP_j) and the variable cost (VCP_j) of tons of switchgrass (XTP_{icj}) to be preprocessed (equation (8)). PF_j represents preprocessing facility at location j. Fixed costs included the costs of land and building where the preprocessing facility was located. The variable cost consisted of total cost of film, net, and belt used to wrap the compact bales.

To calculate the preprocessing costs of switchgrass to pellets, costs parameters were used from the study done by Grbovic (2010). The preprocessing cost ($PPCst$) was given by equation (9) :

$$PPCst = \beta * \sum\nolimits_{icb} (XP_{icb}) \qquad (9)$$

where XP_{icb} is the amount of switchgrass preprocessed and β is the pelletizing cost per ton.

Transportation Cost: Switchgrass was transported to local markets, preprocessing facilities, and Genera Energy either by semi-tractor trailer or tandem axle truck depending upon the harvested form. The transportation cost consisted of loading and unloading costs, labor costs, and machinery costs. Following Duffy (2007), loading and unloading times for round and square bales were different, with round bales assumed to consume more time as compared to square bales. The transportation cost ($TrnsCst$) was calculated using equation (10).

$$TrnsCst = \sum\nolimits_{ibz} \theta_{ibz} * \frac{\sum_{ct} XT_{icbsz}}{1 - DML_{trans}} \qquad (10)$$

where XT_{icbsz} is the total tons of switchgrass transported, θ_{ibz} represents transportation costs per ton, DML_{trans} is the dry matter loss during transportation, and *z* represents the destination. Semi-tractor trailer was used for transporting baled switchgrass from farm to local markets. The loading capacity of the trailer was assumed to be different for both types of bales, i.e., 16.01 tons/load for square bales and 13.18 tons/load for round bales. The speed of the trailer was assumed to be 50 miles per hour. Chopped switchgrass was transported to market or preprocessing facilities using a tandem-axle truck. The capacity of the truck was assumed to be 3.37 tons/ load. The speed of the tandem-axle truck used in this study was 25 miles/hour. The transportation time was estimated by considering the speed and distance between two points.

Tonnage loss during transportation (2%) was also incorporated in the transportation cost (Kumar and Sokhansanj 2007).

Pelletized switchgrass was transported by rail to the domestic port i.e., Savannah in this case, and from the port it was shipped to an international port which was assumed to be Rotterdam. To calculate the rail cost from Genera Energy to Savannah, the formula used by Dornburg (2008) was used ((equations (11) and (12)) :

$$TC_{pellets} = \sum d_k * stc_k \qquad (11)$$

$$stc_k = ec_k + mc_k + lc_k \qquad (12)$$

where, $TC_{pellets}$ is the transportation cost of pellets (\$/ton); k is the transportation mode, d_k the distance by transportation mode (km), stc_k the specific transport cost by mode, ec_k the specific energy cost of transport mode (\$/Mg/km), mc_k the management cost of the transport mode (\$/Mg/km), and lc_k the specific loading/unloading cost of the transport mode (\$/Mg). The study presented the values in Euro, and those were converted to dollars based on the exchange rate. As the Panama City port was the only port listing tariffs for wood pellets, tariff rates from Panama City port were used to calculate the ocean freight for the transportation of switchgrass pellets (Panama City Port Authorities).

Based on different harvesting, storage, preprocessing, and transportation methods used, the present study considered six different logistic systems (one baseline and five alternative harvest and preprocessing options) for delivering switchgrass to potential energy markets. Table 4 summarizes the operation a sequence of supplying switchgrass to the potential markets in each logistics system. The definition of each scenario is listed as follows:

- **Baseline**: In this scenario, switchgrass was mowed, baled by a round baler or a square baler, and delivered to local markets. One-third of the harvested switchgrass bales were loaded onto a semi-tractor trailer by a tractor with a front-end loader and transported to local markets directly during harvesting season. The remaining two-thirds of the harvested switchgrass bales were moved to the field edge by a tractor with a front-end loader for storage and delivered to the local markets during the off-harvest season.

- **C_SWB**: Switchgrass was harvested as chopped feedstock, preprocessed using stretch-wrap bale (SWB) technology, and delivered to local markets. Switchgrass was harvested using self-propelled forage chopper without prior mowing. The harvest dry matter loss was assumed to be zero in this scenario. As chopped feedstock cannot be stored at the farm, the preprocessing option i.e. SWB was incorporated which could handle the chopped feedstock and store it to use in the off-harvest season. One-third of the chopped switchgrass was delivered directly to the market, and two-third was delivered to the preprocessing facilities using a tandem-axle truck. The stretch-wrap bales were assumed to be stored at the preprocessing facility and delivered to market during off-harvest season. The stretch-wrap bales were loaded onto a semi-tractor trailer by a tractor with a front-end loader and transported to market during the off-harvest season.
- **C_SR**: Switchgrass was harvested as chopped feedstock, stored at Genera Energy using a stacker-reclaimer (SR), and delivered to local markets. One-third of the chopped feedstock was delivered to market during harvesting season and two-thirds was delivered to Genera Energy during the off-harvest season using a tandem-axle truck. The whole system constituted a receiving station, conveyance, a dust collection system, and a stacking and reclaiming unit.
- **B_P**: Switchgrass was harvested as square bales. One third of the harvested switchgrass was delivered to Genera Energy during harvest season. Two-thirds of the switchgrass was

stored at the farm site before delivery to market during the off-harvest season. The harvested switchgrass was preprocessed into pellets at Genera Energy before delivery to international market. Pellets were considered to be more suitable for long distance transportation as international markets were considered to be the potential market under this scenario. Transportation of the switchgrass from farm to Genera energy was by a semi-tractor trailer as the distance was less than 50 miles. The mode of transportation from Genera Energy to the domestic port was rail. The distance of domestic port from Genera Energy was more than 300 miles, making rail transport the more suitable mode of transportation. Transportation from the domestic port to international port was done via sea as it is cheapest mode of transportation for long distances.

- **C_SWB_P**: In this scenario, it was assumed that switchgrass was harvested as chopped material and thus there was no storage at the farm site. One-third of the harvested switchgrass was delivered to Genera Energy for preprocessing (pelletization) during the harvest season. Two-thirds was sent to preprocessing facilities for preprocessing as stretch-wrap bale and storage before being delivery to Genera Energy for pelletization. The market assumption was same as in B_P scenario.
- **C_SR_P**: In this scenario, it was assumed that switchgrass was harvested as chopped material. One-third of the switchgrass was preprocessed immediately to pellets at Genera Energy during the harvest season and two-thirds of the switchgrass was stored at Genera Energy during the off-harvest season using a stacker-reclaimer. The entire amount of switchgrass was delivered to Genera Energy and was preprocessed to pellets before deliver to international markets.

The sensitivity analysis was carried to evaluate the effects of the variation of some parameters on the total profit earned in the different scenarios. Although the real interest rate in US is about 4%, the high interest rate of 10% was assumed based on the assumption that with no existing market for the switchgrass the investment would have high risk associations. To estimate the sensitivity of the profit to this interest rate, 6% and 3% interest rates were also used.

Change in diesel prices affect machinery costs and hence would impact the logistics cost of switchgrass. To estimate the sensitivity of costs to diesel price fluctuation, diesel price was changed to ±10% from the benchmark value. The impact of fuel price on crop price has increased considerably since 2006 (Tyner 2010). The correlation between fuel price and crops was estimated for the 2007-2013 period (Table 5). For example, when the diesel fuel price increased by 10%, the corn price increased by 7.8% (=10% × 0.78). The impact of a change in fuel price and crop prices on total profit was also analyzed.

4. RESULTS AND DISCUSSION

In the baseline scenario, the total revenue generated was equal to \$33,405,540. For both round and square bales, the total delivered cost was higher than the received revenue, resulting in a net loss in both the cases and negative NPV. The total delivered cost of switchgrass to market in C_SWB scenario was \$33,147,144. The total logistic cost was 22% lower than the Baseline scenario. Although this scenario was capital intensive as compared to Baseline but savings in harvest and transportation costs outweighed the capital investment and the operation cost. The estimated revenue in this scenario was \$33,405,540. A profit of \$258,396 was earned and the NPV over 10 years was \$1,587,732. This scenario was profitable mainly because of the low harvest cost using chopping and preprocessing of switchgrass.

The total logistics costs were high in C_SR scenario when compared to the Baseline. High storage costs using stacker-reclaimer and high transportation cost of delivering chopped feedstock from one point to other resulted in increased logistics costs as compared to Baseline. There was net loss of $8,959,357 in this scenario. The estimated NPV was negative in this case. The revenue for B_P scenario was estimated to be $17,500,000. The total logistics costs were high as compared to the revenue generated. Harvest form was similar with the baseline scenario but there was additional cost of pelletization and transportation cost to international markets. There was overall loss of $2,952,356 in this scenario. Increased number of operations in the supply chain led to high logistics costs in this scenario. International transport also added up to the total costs. The net present value was less than zero in this scenario.

There was a loss of $1,243,503 in C_SWB_P scenario. The loss in this scenario was less compared to the B_P scenario in spite of additional preprocessing in this scenario because of less harvest cost in case of chopped feedstock as compared to baled one and low transportation cost in case of stretch-wrap bales delivered to Genera Energy. NPV was less than zero in this scenario. In C_SR_P scenario, there was storage of switchgrass during off harvest-season at Genera Energy using stacker-reclaimer. Revenue in this scenario was $17,500,000. There was a loss of $2,173,721 in this scenario and the net present value was negative.

Figure 2 shows the NPV and profit earned in each scenario. The figure shows that for the local market, C_SWB was the only scenario which showed the potential of penetrating energy market with positive NPV. The baseline and C_SR scenario required considerable improvements in the logistics systems to make profits for Genera Energy. For the EU market, all the scenarios showed negative NPV. The C_SWB_P scenario showed higher potential of penetrating the market profitably; while B_P scenario had the least likelihood to reach the EU market.

Figure 3 shows the breakeven market price for each scenario. In the scenarios dealing with local markets: only C_SWB scenario showed lower breakeven market price than the price assumed for switchgrass in the local market ($60 per ton) but for Baseline scenario and C_SR scenario breakeven market prices were $75 and $76 respectively. In the case of international markets, breakeven market price ranged from $187 per ton to $224 per ton. The price range was higher than assumed for the international markets ($175 per ton). Thus all the four logistics configurations for international markets showed negative NPV.

The sensitivity analysis showed that there was significant increase in NPV when the interest rate was reduced from 10% to 6% and 3%. Figure 4 shows the increase in NPV in each scenario with decrease in interest rate to 6% and 3% from benchmark value. With decrease in interest rates NPV increased for each scenario. For the scenarios serving local markets, NPV improved with decrease in interest rate as costs of machinery used in every operation decreased significantly. For the scenarios dealing with international markets, the changes in NPV with interest rate were relatively moderate as compared to the scenarios serving local markets. The less impact of interest rate on NPV of profit observed in the scenarios for international markets was due to the minimal changes in international transportation cost that is, one of the major cost components in international logistics.

There was around three percent change in total costs among all scenarios with ±10% change in fuel price from benchmark value. When the fuel price was decreased 10%, the logistics costs were reduced for each scenario. Although the logistics costs for each scenario decreased but still only C_SWB scenario showed positive NPV. The C_SWB_P scenario showed little potential of penetrating the market with decrease in fuel price. Logistics costs increased around 3% in each scenario with increase in fuel price. With increase in fuel price none of the scenario was profitable. All the scenarios showed negative NPV. NPV increased with decrease in fuel price and vice-versa. When compared with the NPV at benchmark value, the change in NPV with change in fuel price was not so significant among all the scenarios (Figure 5).

5. CONCLUSIONS

Energy derived from biomass is a renewable energy source with growing potential because it emits less GHG compared to fossil fuels. Switchgrass, a perennial grass, is considered a promising feedstock for the bioenergy market; however, the logistics challenges of its low bulk density pose a major constraint in developing the switchgrass-based energy market. The objective of this study was to optimize the feedstock logistics pathway managed by a collection/distribution hub for Tennessee produced switchgrass to penetrate energy markets.

A mathematical programming model in integration with the GIS was used to maximize the profit of Genera Energy Inc., a collection hub/depot of switchgrass located in east Tennessee. Six logistics scenarios were evaluated: the Baseline scenario utilized the conventional baler harvest and storage system to serve the local market 70 miles from Genera Energy. One scenario applied a stretch-wrap bale technology to increase the density of chopped feedstock for local market and another scenario incorporated an outdoor storage system for chopped feedstock to serve the local market. The remaining four scenarios utilized pelletization to increase feedstock density along with various harvest and storage methods to reach the EU market.

The results showed that only one out of the six evaluated logistics configurations was found to be profitable for the collection hub/depot under the given assumptions, which confirms the challenging issues of feedstock logistics for the biomass energy industry. The finding is consistent with Larson et al (2010) that concluded that utilizing the stretch-wrap bale technology in the satellite sites is more cost effective when compared to conventional baler methods in the southeastern US. Increasing feedstock density provides the benefits of feedstock handling and storage efficiency but could be capital intensive. The high capital and operating costs of pelletization dominated the efficiency gains from storage and transportation of the densified feedstock in the present study. An outdoor bulk storage system, such as stacker-reclaimer, handled the loose feedstock efficiently but the high initial investment increased the total costs. In the case of local market, the estimated breakeven market price for the baseline and the bulk outdoor storage system was around 26% higher than the assumed price. For the EU market, the gap between breakeven price and assumed market price ranged from 7% to 28%. The sensitivity analysis based on different interest rates showed that lowering the investment risk in the emerging biomass energy sector can help the collection/distribution hub penetrate switchgrass-based energy market. Government incentives or policies could boost the confidence of investors in this industry and expedite the development of the bioenergy industry.

Although most of scenarios were not profitable in the analysis, several factors may change the findings and can be studied further. First, the potential market prices for switchgrass in local and international market could be higher than what were assumed in the study. The local switchgrass price of $60 per ton was based on certain assumptions of productivity for biomass feedstock in the Billion Ton study (US DOE 2011). US DOE is not an active participant in markets so the price assumption could differ from the real market. In addition, switchgrass pellets price was based on the price of wood pellets and the price of wood pellets in international markets fluctuates depending upon the season and demand. Also, the present study assumed Netherland and Belgium to be the major potential international markets. Other potential international markets that prompt grass-based feedstock for energy, such as UK, can also be explored if the price data is available. Second, feedstock quality was not considered in the present study. The impact of quality of switchgrass delivered to markets on the total profit earned requires further study.

Finally, the impact of change in throughput of different machineries on the total profits by logistics configurations in the study was not analyzed. Variations in throughput of the machineries can affect the total costs and potentially the results of the total profit. Exploring different options of harvest, storage, preprocessing, and transportation to penetrate energy markets profitably is also necessary.

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Table 1: Research on Biomass for Energy Production

Reference	Objective	Feedstock	Region	Findings
Amos et al (2002)	To evaluate boiler efficiency and emissions from co-firing biomass with coal	switchgrass	Iowa	no impact on boiler efficiency; 4% reduction in emissions
Boylan et al (2000)	To evaluate feasibility, costs, and benefits of co-firing biomass feedstocks with coal	switchgrass	Alabama	switchgrass co-firing in existing coal fired units as one of the low cost renewable energy options
English et al (2007)	To examine the economic impacts of co-firing biomass feedstocks with coal	forest residues, mill waste, agricultural residues, switchgrass, and urban wood wastes	Southeastern US	co-firing biomass at 2% (by weight) with coal is economical
Samson et al (2000)	To compare various biofuel production pathways: co-firing, ethanol, heat energy from pellets	switchgrass	North America	pelletized switchgrass had higher energy conversion rate
Schmer et al (2008)	To evaluate switchgrass as bioenergy crop in terms of net energy and GHG emissions	switchgrass	Mid-continental US	switchgrass produced more energy than consumed and has significant environmental benefits
Sultana and Kumar (2012)	To evaluate biomass feedstock based pellets based on environmental, economical, and technical factors	wood, straw, switchgrass, alfalfa, and poultry litter	-	switchgrass pellets were found similar to wood pellets in terms of suitability for use in large heat and power generation plants
Vadas et al (2008)	To assess energy conversion efficiency by comparing different cropping systems	corn, alfalfa, and switchgrass	Wisconsin	net energy produced by switchgrass was greatest

Table 2: Research on Biomass Supply Chain

Reference	Logistics component							Analytical Method
	*FS	*CH	*PR	*ST	*FT	*CF	*BD	
Alfonso et al (2009)	X	X	X	X	X	X	X	GIS*+Cost min*+GHG min*
Cundiff et al (1997)		X		X				LP*+Cost min
Dal-Mas et al (2011)	X	X	X		X	X	X	GIS+MILP+Inv. Risk Min*
Dunnett et al (2007)		X		X	X	X		MILP+Cost min
Ekşioğlu et al (2009)	X	X	X	X	X	X	X	MILP+Cost min
Freppaz et al (2004)		X				X		DSS*+GIS+MILP+Cost min
Frombo et al (2009)		X	X			X		EDSS*+GIS+MILP+Cost min
Gonzalez et al 2011	X	X			X			Financial model+NPV+IRR*
Mukunda et al (2006)		X			X			LP+Distance Min
Rentizelas et al (2009)	X	X			X	X		DSS+Cost min
Sokhansanj et al (2010)		X	X		X			Enterprise Budgeting
Tatsiopoulos and Tolis (2003)		X		X	X			LP+Cost min
Tembo et al (2003)	X		X	X	X			MILP+NPWM
Wang et al (2012)	X	X	X		X	X	X	MILP+Cost min
Zhang et al (2012)	X	X	X	X	X	X	X	MILP+Cost min

*FS-Feedstock source, *CH-Collection/Harvest, *PR-Pre-processing, *ST-Storage, *FT-Feedstock transportation, *CF-Conversion facility, *BD-Biofuel distribution, GIS*-Geographic information system, Cost min*-cost minimization, GHG min*-Greenhouse gas minimization, MILP*- Mixed-integer linear programming, LP*- Linear programming, Inv. Risk Min*-Investment risk minimization, DSS*- Decision support system, EDSS*-Environmental decision support system, IRR- Internal rate of return

Table 3: List of Potential Local Markets (within 70 miles of Genera Energy)

Facility Name	Facility Type	Capacity (tons)
Resolute Fibers/Bowater Southern Paper Corporation	Use cogen/Wood energy user	520,000
Oak Ridge National Lab Gasification Plant (ORNL)	Use biomass to produce power	28,470
Maryville College	Use wood for energy	5,000
DuPont Danisco Cellulosic Ethanol (DDCE)	Cellulosic ethanol producer - Pilot / Demonstration facility	3,289

Source: Wood2Energy (http://www.wood2energy.org/Studies.htm)

Table 4: Operations Sequences for each Scenario

Operation	**Baseline**	**C_SWB**	**C_SR**	**B_P**	**C_SWB_P**	**C_SR_P**
Mow	1	-	-	1	-	-
Bale	2	-	-	2	-	-
Chop	-	1	1	-	1	1
Haul by tandem-axle truck to preprocessing facility	-	2	-	-	2	-
Haul by tandem-axle truck to Genera Energy	-	-	2	3	3	2
Storage at farm	3	-	-	4	-	-
Dump in holding area	-	3	3	-	4	3
Front-end load into conveyer	-	4	4	-	5	4
Compact/bale/wrap	-	5	-	-	6	-
Storage at preprocessing facility	-	6	-	-	7	-
Storage at Genera Energy (Stacker-Reclaimer)	-	-	5	-	-	5
Pelletization	-	-	-	5	8	6
Haul by semi-tractor trailer to domestic market	4	7	6	-	-	-
Transportation to international market	-	-	-	6	9	7

Table 5: Crop Prices and Diesel Fuel Price Correlations (Year: 2007-2013)

Correlation type (crop with diesel price)	Correlation
corn-diesel	0.78
cotton-diesel	0.69
hay-diesel	0.74
sorghum-diesel	0.80
soybeans-diesel	0.77
wheat-diesel	0.74

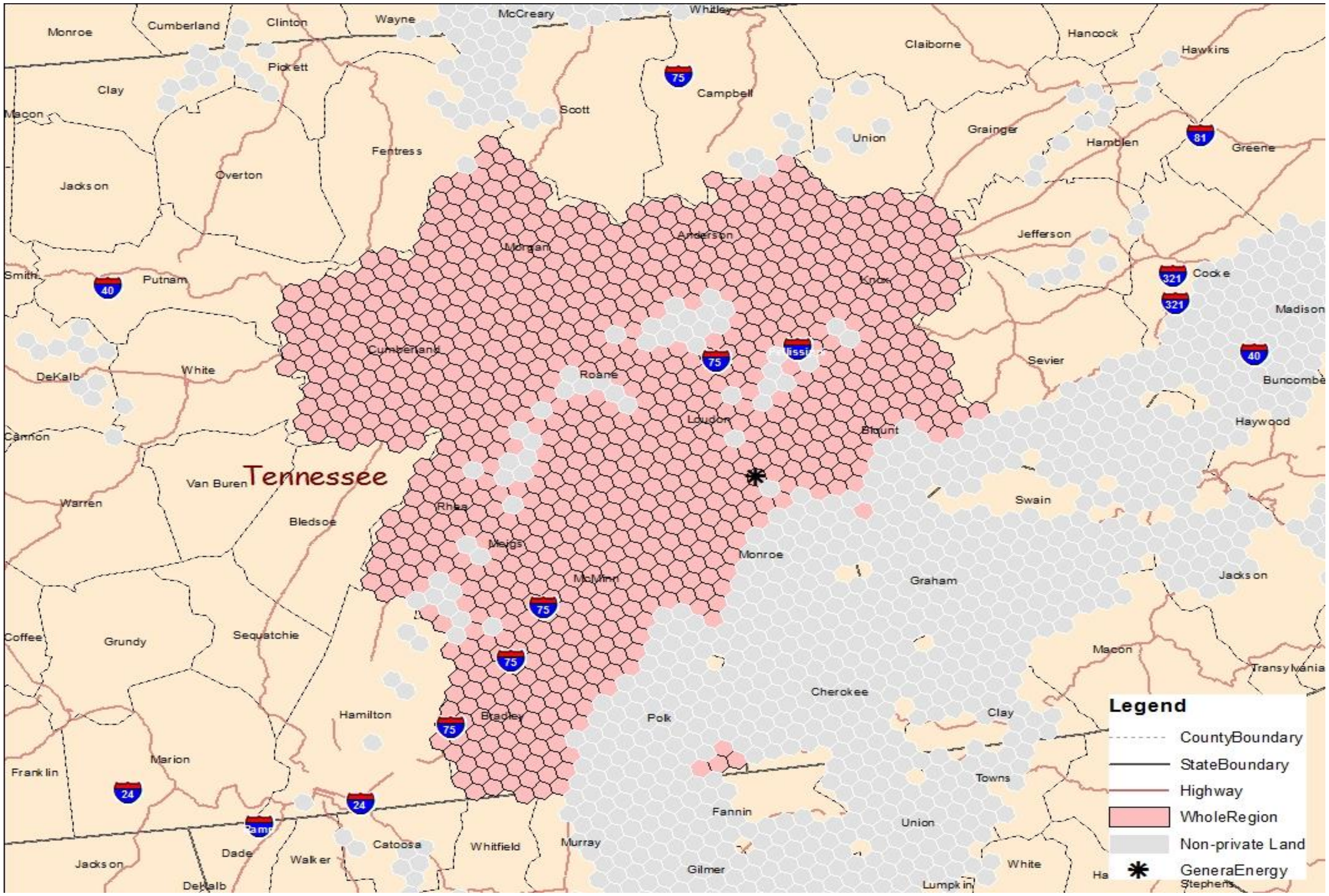

Figure 1 Location of Genera and study region

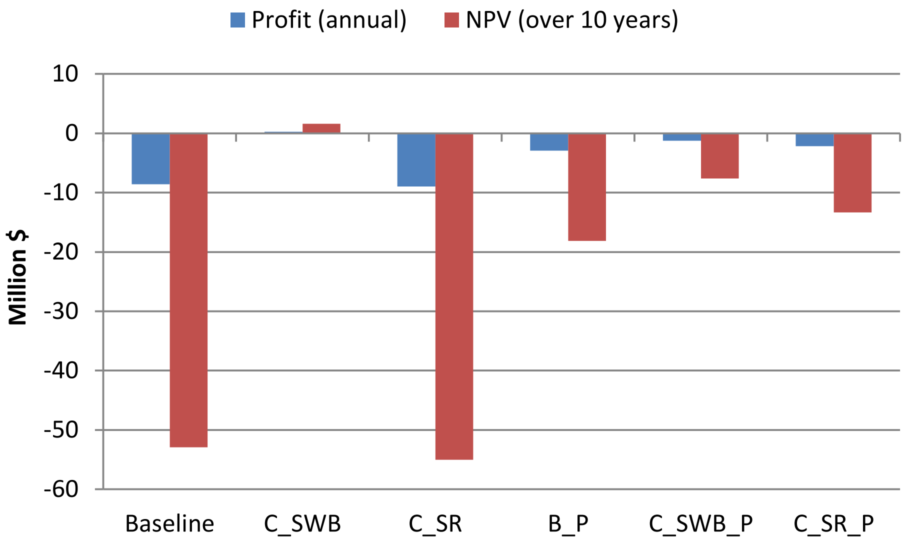

Figure 2: Profit and NPV in each scenario

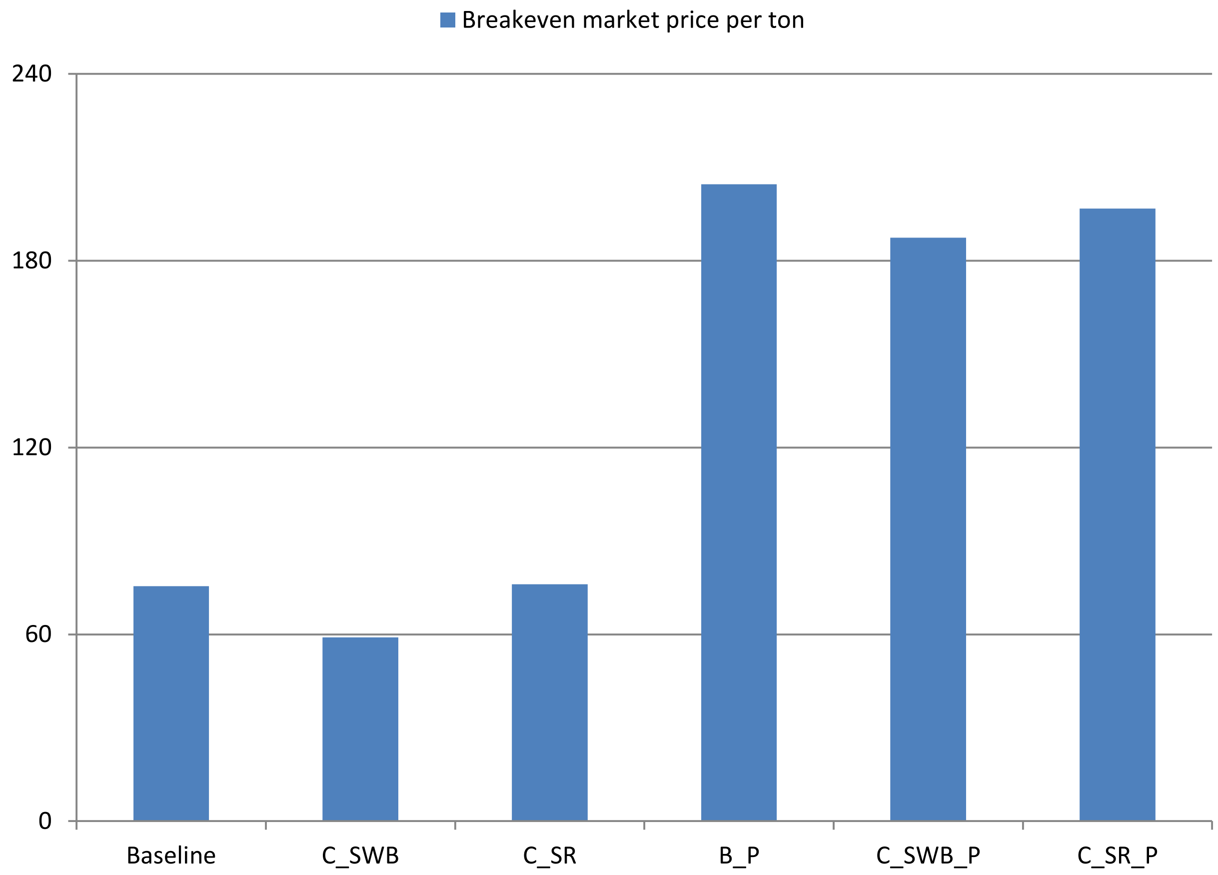

Figure 3: Breakeven market price in each scenario

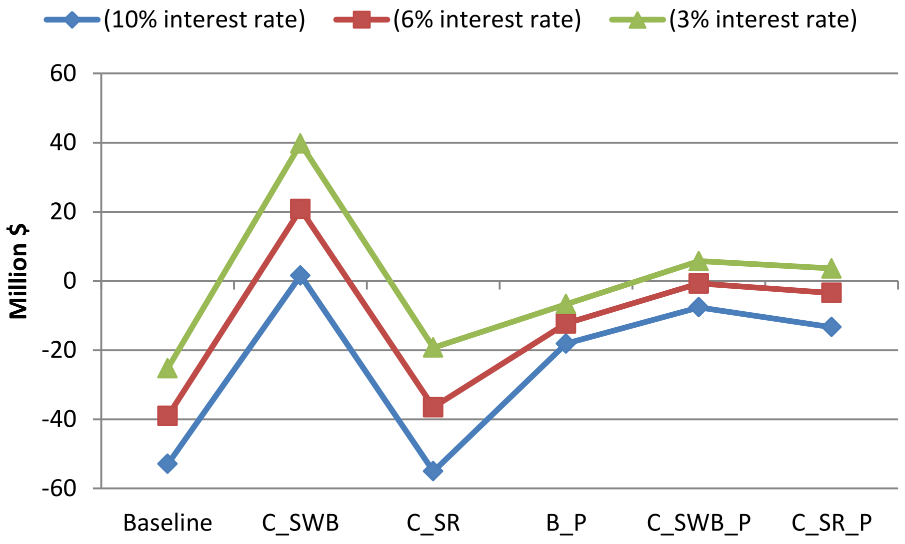

Figure 4: Comparison of NPV at different interest rates in each scenario

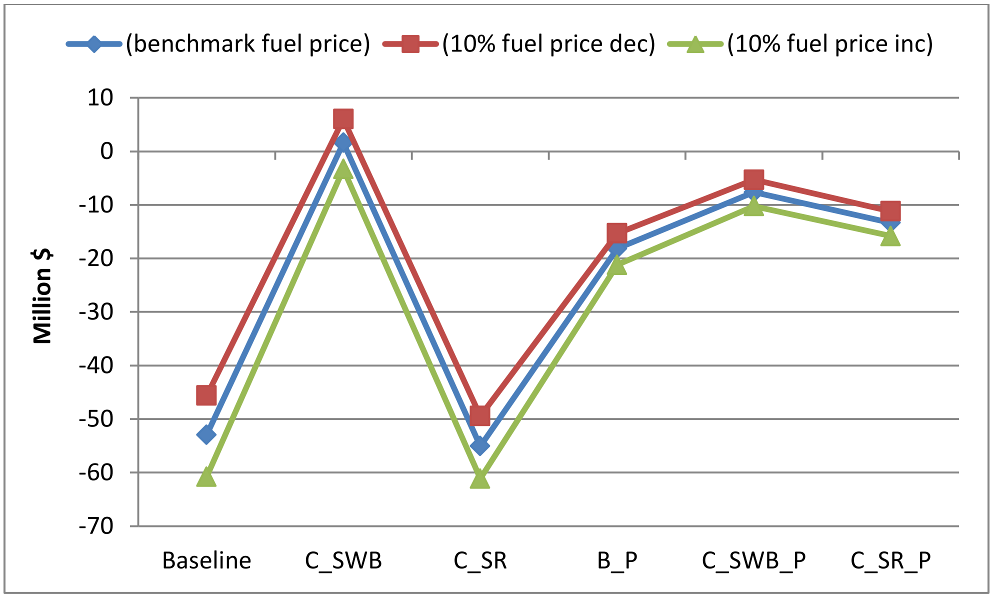

Figure 5: Comparison of NPV at different fuel prices