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Woody Biomass Processing: Potential Economic Impacts on Rural Regions

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Abstract

This paper reports on economic and environmental impacts of introducing woody biomass processing in an economically distressed area in central Appalachia, one of the more heavily forested areas in the U.S. Woody biomass is a readily available unconventional energy source that has the potential to boost the rural region's economy. We use a static regional computable general equilibrium model to assess regional economic impacts of two different WBP production pathways, biomass to ethanol and biomass to biofuel via fast pyrolysis. In an economy with a workforce approaching 160,000, we find that the introducing woody biomass ethanol or fast pyrolysis processing would increase regional output by 0.45% and 0.78%, boost jobs by 0.13% and 0.20%, and increase income by 0.16% to 0.26%, respectively. The results from the environmental assessment show that ethanol pathway is substantially more environmentally friendly than fast pyrolysis pathway.

Keywords: Woody biomass processing; computable general equilibrium models; central Appalachia; rural economic development
JEL Classification: R58, R15,Q51

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1 Introduction

Fossil fuels have been the dominant U.S. energy source throughout its history, with petroleum, natural gas, and coal providing more than 80% of total U.S. energy consumption during the last century (EIA, 2016b). Growing energy security, environmental quality, and climate change concerns have stimulated efforts to find more secure and environmentally friendly energy resources. In 2015, the U.S. registered its lowest fossil fuel energy consumption share in the past half-century, while energy consumption from renewable energy resources reached nearly 10%, its largest share since the 1930s (EIA, 2016b). In addition to solar and wind, liquid biofuels have begun to contribute to this growing share of renewable energy. According to the EPA, corn ethanol is now the dominant supply source for biofuels in the United States (EIA, 2016b).

The Renewable Fuel Standard[1] enacted in 2005 and expanded under the Energy Independence and Security Act of 2007, mandates increasing use of cellulosic biofuels, such as forestry biomass (Withers et al., 2015). Despite relatively abundant forests in the U.S., wood and wood- derivative fuels have contributed less than 2% of the U.S. energy supply (IEA, 2014). Woody biomass processing (WBP) is among the most promising renewable energy generation portfolios for potentially mitigating the climate impact of emissions and reducing energy dependency, and for revitalizing the economy of a region, especially in rural areas where alternative opportunities are limited (Favero and Mendelsohn, 2014; Jackson et al., 2016)

Coal's share in energy generation in the U.S. has fallen sharply in recent years, with the availability of cheaper natural gas playing an increasingly important role in this share reduction, and environmental regulations like the Mercury and Air Toxics Standards (MATS) set by the U.S. Environmental Protection Agency may also have contributed (EIA, 2014). As older coal-fired power generating plants are retired, regional economies that have relied heavily on the coal industry need to identify alternative economic activities to compensate for the decline in coal demand and to stabilize local income and employment. The Appalachian region has long been strongly dependent on coal, and coal's collapse in recent years has reduced the employment demand dramatically (Humphreys et al., 2014). Because central Appalachia is one of the more heavily forested areas in the U.S., it is a reliable and abundant source of woody biomass. Hence, WBP might provide a

[1]See the U.S. EPA RFS website, at https://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-standard-rfs2-final-rule

significant opportunity for boosting the region's economy and offsetting the steady declines in the coal industry (Wang et al., 2006).

Using a static regional computable general equilibrium (CGE) model, this study investigates the potential economic impacts of introducing WBP in an economically distressed but heavily forested central Appalachian study region. We examine two different WBP production pathways: biomass to ethanol (ETH) and biomass to biofuel via fast pyrolysis (FP). The two pathways are similar in their reliance on five logistic systems: biomass collection, transportation, storage, preprocessing and conversion. It is the conversion system that most strongly differentiates the two pathways, in both output composition and production process. We base conversion processes on Jones et al. (2009) for FP and on Phillips et al. (2007) for ETH, and we rely on Liu (2015) for region-specific conversion process data provision. Likewise, data on prices and quantities of inputs and outputs and the life cycle assessment (LCA) process matrix were formalized in consultation with Liu. These data allow us to create two separate production functions for WBP that can then be embedded within our regional SAM, following the LCA to IO conversion method in Cooper et al. (2013).

The CGE model evaluation of the impacts of the wood-to-fuel industry on the southern West Virginia study region's output, income, employment, and environment is intended to help inform regional policy makers who wish to assess the potential and value of WBP as an alternative sustainable economic development activity to help revitalize the economy and rebuild its economic foundation.

2 Background Literature Review

Environmental and energy security concerns have led to tremendous changes in energy production in recent years, and have brought increasing attention to unconventional energy sources. Woody biomass is a readily available unconventional energy resource, and is often suggested to have the added benefit of strong potential to boost rural regions' economies. In this section, we focus on the three areas that enter into discussions of woody biomass development for energy production: rural economic development, regional systems models, and biomass impact modeling.

2.1 Rural economic development

Rural and urban regions face very different economic development challenges even though, as pointed out by Schaeffer et al. (2014), in some ways they look more alike than ever. A recent report by the US Department of Agriculture (USDA, 2016b) corroborates this by showing the job mix between both types of regions in the country. Their industrial economic structures are very similar, but as expected, agriculture and mining plays a larger role in rural areas, while producer services are more important in urban areas. Yet despite apparent similarities in industrial composition, they still confront different challenges to improving economic growth and enhancing socioeconomic welfare.

The USDA (2016b) report shows that while urban population is growing steadily from 2000 to 2015, rural population has remained constant (net) from 2010 to 2015. The same report also shows that median earnings in rural areas were only 84% of their urban counterparts. This number represents a 7% improvement over the 2007 figure, but still reflects a substantial gap. Also, rural poverty and unemployment rates are higher than urban rates. Rural areas also have lower levels of adults holding bachelor's degrees than the national percentage and have lower college enrollments than urban areas (Provasnik et al., 2007). Rural areas have lower levels of high-school dropout than cities, but higher than suburban areas, and rural areas receive less public-school funding than urban areas. Duncan (2013) discusses current challenges of rural regions and possible opportunities, highlighting the low population density of rural regions as one of their main development barriers. Service provision can be more difficult in sparsely populated regions, and market-oriented businesses that depend on size for economies of scale are difficult to support in rural regions. The overall picture points to smaller populations with less dynamic and lower skilled rural labor force than that available in urban areas.

To try to boost rural regions, policy-makers have traditionally focused on place-based policies such as the Appalachian Development Highway System. Olfert and Partridge (2010) stress that rural regions with potential local capacity, along with poor economic outcomes, can be considered as candidates for place-based policies. However, there is mixed evidence on the outcomes of such placed-policies[2], and many suggest that they are ineffective for rural regions. Smith (1990) offered a common conclusion on place-based policies early on, noting that the Appalachian Development Highway System has not brought sustained growth, income, or jobs to the most distressed counties in the region. This result is consistent with the conclusions of Glaeser

[2] See Ellis and Biggs (2001) for a review of several general rural development studies. Other studies on the development of rural regions are Terluin (2003), Briedenhann and Wickens (2004), Gardner (2005), Kandilov and Renkow (2010) and Stephens et al. (2013)

and Gottlieb (2008) on these types of economies. However, Rephann and Isserman (1994) came to the opposite conclusion in their assessment of ARC transportation investment, and Sayago-Gomez et al. (2015) more recently find small but positive impacts from fifty years of ARC place-based non-highway investments. Kline and Moretti (2014) studying the place-based Tennessee Valley Authority project find positive direct impact in the region with last longing benefits, following on Ashley and Maxwell's (2001) idea of non-farm agriculture opportunity, as most positive impacts come from productive infrastructure and the manufacturing sector.

In her discussion, Duncan (2013) suggests the possibility that energy-related initiatives like wind-farms, biomass facilities and other alternative fuels might present major development opportunities. In this paper, we target the impacts of a woody biomass processing (WBP) facility in central Appalachia. While a WBP facility is not a placed-based policy, per se, it does represent a development focused on regional comparative advantages, including not only the abundance of woody-biomass as an input for the facility, but also the availability of low- to moderate-skill labor required for many of the activities in the WBP supply chain. Finally, our study area is of particular interest because as shown by the USDA (2016b) report, most of its counties are still dependent on the coal industry which has been in decline in recent decades, as discussed by (Hansen et al., 2016). As such, it is representative of traditionally resource-dependent rural regions distressed by a paucity of economic transition alternatives.

2.2 Regional Systems Models

FSystem wide economic impacts are most commonly evaluated by one of two methods, input-output (IO) analysis and computational general equilibrium models (CGE). Partial equilibrium models are sometimes applied in economic impact analysis[3], but by definition, partial assessments focus on evaluating impacts on one or a few specific sectors rather than on entire economic systems. We discuss fixed-price and flexible price model attributes below, and add a brief overview of CGE model structure in a flexible-price category. We then focus on biomass impact models and report their findings.

[3] Tokgoz et al. (2007) and Tyner and Taheripour (2008) are among studies that use a multi-product, multi-country deterministic partial equilibrium as well as an integrated partial equilibrium model to investigate the effects of biofuel on U.S. grain, oilseed, and livestock markets.

2.2.1 Fixed/flexible impact analysis models

Input-output (IO) models and social accounting matrix (SAM)) models are both very commonly applied 'fixed-price' modeling approaches. IO and SAM models are founded on accounting frameworks that track transactions among industries and other economic sectors in an economic system. The transactions are denominated in monetary units and provide an accounting of the flows during a given period of time, most commonly one year. Many of the underlying flows involve physical units, so the entries in the accounting frameworks are products of quantities and prices that are in effect in the economic system at during the accounting period, hence the prices are fixed. These fixed-price accounts characterize the inter-sectoral interdependencies among economic sectors, and when systems are shocked, typically by changing some element of system final demand, the systems respond by changing their output levels under the assumption that prices remain constant throughout the adjustment period. The behaviors are consistent with linear homogenous production functions (Trink et al., 2010). Because a necessary assumption in fixed-price models is that the relative prices of commodities remain constant, output, employment, and income respond with no impact on prices in response (Miller and Blair, 2009).

Fixed price models can produce quite reasonable impacts estimates when the size of the shock is unlikely to result in any substantial change in prices. Conway (2015) and others have made the case that most subnational economies are price-takers rather than price-setters, and that while there are differences across regions in prices for the same sector, these differences tend to persist over time and indeed, over fairly substantial economic changes. Others, however, hold that if shocks to the economy are large enough to notably effect the demand for labor, then it is likely that relative wage rates by sector will change, and these changes necessarily alter industrial production functions. Allan (2015) has provided a summary of interrelated issues concerning fixed-price modelling and assumptions of fixed coefficients. A further critique of fixed-price frameworks is their implicit assumption of constant return to scale, which rules out benefits of input substitution. Traditional fixed-price IO and SAM models also assume the absence of supply and capacity constraints, such that industry responses to demand shocks will always be linear and unconstrained in magnitude.

CGE frameworks are the most commonly applied system-wide flexible price models for economic impacts assessments. Flexible-price modeling is founded on equilibrium seeking behavior in all markets, so that goods prices, wage rates, and the price of capital (interest rates) adjust in response to goods, labor, and capital market supply and demand changes. Models can be specified with varying closure rules that effectively modulate the supply constraints that apply to the new equilibrium solutions that develop in response to economic shocks. This category of economic impact models captures feedback effects and more complex economic behaviors and interactions among economic actors (Trink et al., 2010). As a result of relaxing the fixed-price assumptions, a flexible-price model can lead to changes in the amount of material inputs or production factors, and thus generate results that many hold are more consistent with economic theory (Allan, 2015). The ability to capture additional behaviors, of course, comes at a price. CGE models typically require much more – and less accessible – data than do fixed-price models.

2.2.2 Geographical Scale

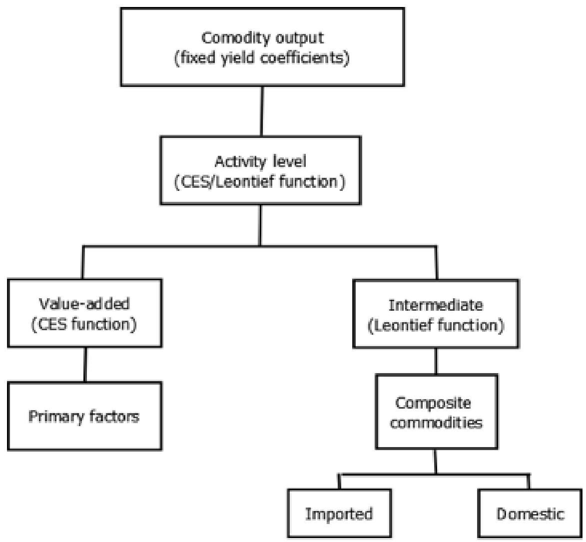
A CGE model includes a set of equations explaining behavior of economic actors in production, consumption, institutions and trade. There are numerous examples of impact analyses at national (e.g., Steininger and Voraberger, 2003; Dixon et al., 2007; Perry, 2008; Arndt et al., 2010; Gehlhar et al., 2010) and subnational levels (Partridge and Rickman, 2010).

For assessing the introduction of a new WBP industry, it is most appropriate to define the geographical scale of analysis to coincide with the extent of the host regional economy. The impacts of such a development when couched within a national model would be clearly be too small to register any detectable impact on relative prices, so the added time and resources needed to construct a CGE model would return very little in the way of realized benefits over a fixed-price national model. However, at the scale of a smaller region, WBP might represent a substantial enough economic shock to have impacts on some relative prices, so the additional effort might yield meaningful benefit. Smaller rural areas with low-income and few job opportunities might be particularly sensitive to new demands placed on local labor pools by the WBP activity.

2.2.3 Model Structure

Our CGE modeling framework is adapted from a framework established by Lofgren et al. (2002) and subsequently oriented to biomass scenarios by Holland et al. (2009). The model structure assumes that producers maximize profit with a two-level production technology. Specifically, it assumes a constant elasticity of substitution (CES) production function and a Leontief

Figure 1: Production Technology



function of the quantities of value-added and aggregate intermediate input. Institutions are composed of households, enterprises, the government, and the rest of the world. A linear expenditure system (LES) demand function represents the household consumption derived from maximization of a Stone-Geary utility function. A schematic version of the embedded production technology is presented in Figure 1.

In the model, the government receives taxes and transfers from other enterprises to purchase commodities for its consumption or transfer it to other institutions. Domestic output produced by industries is sold in the market. A CES function is applied to aggregate domestic output from different activities and then the output allocates to exports and domestic sales expressed by a constant elasticity of transformation (CET) function. Domestic market demand is modeled in the same way as domestic output.

2.3 Biomass Impact Modeling

As climate change and global warming draw more attention in the context of global society, the market has expanded to include more environmentally benign energy alternatives. Bioenergy has received increasing attention in recent years, emphasizing its role in rural development, energy security, and environmental concerns, and CGE models have been used often to measure its economic impacts. CGE analyses are applied to compare alternative scenarios corresponding to new industry, new technology, or new policy. Static CGE frameworks are ideally suited to comparing the impacts of different scenarios, and can provide valuable information for policy makers, especially in rural regions that suffer from high unemployment rates and poverty and need to be supported by revitalizing economic policies (McCullough et al. (2011). Kretschmer et al. (2009) and Wicke et al. (2015) categorize different approaches to incorporating bioenergy in a CGE framework, and Allan (2015) reviews analyses of regional economic impact of biofuels explicitly.

CGE modeling has been applied to evaluate the impacts of several policy alternatives related to emissions or changes in related commodity prices. Gan and Smith (2002, 2006) are pioneers in applying a national CGE model to evaluate the effects of carbon tax policies and energy security on energy price. The CGE model that they used is based on the Global Trade Analysis Project (GTAP). In their first study, the authors impose taxes on coal, oil, and natural gas in a system with three forms of energy production and three major energy cropping alternatives. The results show that none of the three energy crops in their model have cost advantages over coal in the absence of a carbon tax (Gan and Smith, 2002). Because there is a lack of available data on commercial operations of electricity and ethanol production using biomass, their results reflect national averages rather than region-specific values. In the second paper, Gan and Smith (2006) incorporate short-rotation woody biomass and logging residues from conventional forests in electricity generation and compare to coal. They use an average of national production cost and biomass yield, and find that without a CO2 emission tax, woody biomass cannot compete with coal. This study is focused more on the cost competitiveness of woody biomass relative to coal and does not assess economic and environmental impacts of switching to or introducing woody biomass as an alternative fuel source.

A number of other studies investigate the economic and in some cases emissions reduction impacts of different biomass and related energy policies (e.g., Evans, 2007; Küter et al., 2007; McCullough et al., 2011; Huang et al., 2012; Dandres et al., 2012; Hoefnagels et al., 2013; Smeets et al., 2014; Cai et al., 2015; Wicke et al., 2015; Tsiropoulos, 2016). The analysis that is most similar to ours is the CGE-based regional impact analysis of the introduction of WBP on a regional scale is limited to Hodges et al. (2010). They assess the economic impacts of woody biomass utilization on the bioenergy and forest product industries in Florida. The authors first simulate the impacts of increasing biomass fuel supply to generate electricity over a range of 1 to 80 million green tonnes of woody biomass with an average price of $30 per ton. Two other scenarios are then tested: the effects of a $0.010 or $0.011 per kilowatt-hour state and federal tax credit, and a 100% federal subsidy for biomass fuel production. Results show a relatively small increase in Florida Gross Domestic Product (GDP), overall employment, and state government revenues, and a modest decrease of imports of fossil fuels. Given their focus on the use of woody biomass for electric power generation, they modify the regional electric power sector production function in terms of intermediate input use, and test different levels of woody biomass that would be needed to meet Florida's Renewable Electricity Standard. They use a set of shift parameters to keep power generation output constant. Because our analysis models different WBP output and use, our approach as described in the next section is fundamentally different.

3 Analysis

We begin this section by describing the study region and its key structural features. We then provide more detail on the rural region CGE we use for the analysis, followed by a description of data and sources. The final subsection presents results and discussion.

3.1 Study region

Though[4] rich in natural resources, especially its abundant forests and substantial coal seams, Appalachia remains a region of high socio-economic distress and substantial poverty (James and James, 2015). In this study, we focus on a typical in central Appalachian rural economic region, one that faces many of the challenges of its distressed neighbors. Its 2010 population of 426,938 is less than 12% that of the state of Connecticut, which is roughly comparable in square miles. Eight of the eleven counties in our study region do not have a population center of 10,000 or more, and are classified as rural according to Ingram and Franco (2012). Beckley, in Raleigh County, WV is the largest city in the region is with a 2010 population of 17,614. The study region, shown in Figure 2, includes Boone, Lincoln, Logan, McDowell, Mercer, Mingo, Raleigh, Wayne, and Wyoming County in West Virginia, Buchanan County in Virginia, and Pike County in Kentucky.

[4]This section draws heavily on Jackson et al. (2016).

Figure 2: Map of the Study Region

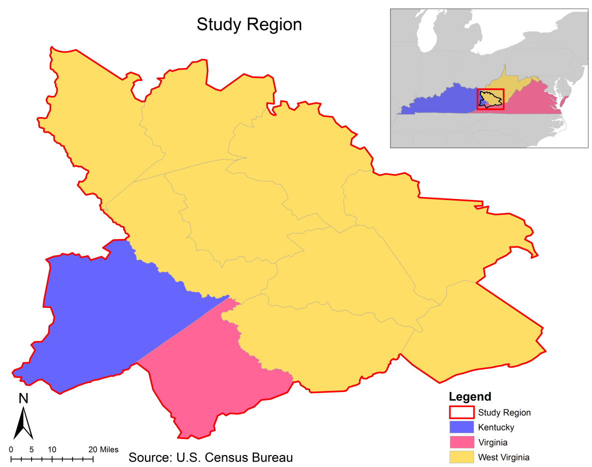


Table 1 shows the region's socioeconomic characteristics. Regional per capita income ($31,134) less than 75% of the corresponding U.S. per capita income value of $42,298. The average poverty rate between 2009 and 2013 in the region was 23%, which is nearly twice that of the average U.S. poverty rate of 15.4%.

Maciag (2016) listed "West Virginia among the five states that are losing people" in recent years, even as the country experiences overall population growth[5]. A lack of economic opportunities is the major driver of the declining trend in state population. The combination of a distressed economy, limited economic opportunities, poor accessibility, and the lack of industrial diversity that characterizes rural economies makes regional economic development a pressing issue (Jackson et al., 2016). With abundant regional forest related biomass, biofuel presents a real and tangible opportunity to create secure, long term jobs and revitalize the regional economy.

3.2 Regional Computable General Equilibrium Model

In this section, we describe more fully our adaptation of the Holland model used in our analysis. We identify the modifications and our assumptions, and we enumerate key CGE model parameters.

[5]http://www.governing.com/topics/mgmt/gov-states-losing-population-census.html

Table 1: Social-Economic statistics on the study region for 2011

County	State	Per Capita Income ($)	Labor Force*	Unemployment Rate* (%)	Poverty Rate (2009-2013)	Economic Status
Boone	WV	29,749	8,680	8.1	21.1	At-Risk
Lincoln	WV	25,837	7,678	10.7	26.5	Distressed
Logan	WV	33,201	12,913	8.9	19.6	At-Risk
McDowell	WV	26,990	6,671	11.9	35.2	Distressed
Mercer	WV	32,247	23,732	8.6	21.8	Transitional
Mingo	WV	30,563	9,201	8.6	23	Distressed
Raleigh	WV	37,276	33,020	7.2	17.1	Transitional
Wayne	WV	30,826	16,504	8.2	19.6	Transitional
Wyoming	WV	28,826	8,313	8.8	20.9	Distressed
Buchanan	VA	33,665	8,475	8.6	24	At-Risk
Pike	KY	33,292	24,323	9.2	24.1	At-Risk

Source: Appalachian Regional Commission, BLS*

3.2.1 Modified Washington biomass model

Holland developed for the state of Washington a model that was designed to serve as a highly generalizable framework using commercially available regional data. The result is a generalized base regional CGE structure, programmed using GAMS code, that is relatively easily adaptable to other regions. Thaiprasert et al. (2011), Fadali et al. (2012), Galinato et al. (2015), Nadreau (2015), among others, have adapted this initial model to specific problem domains, including a biomass framework that serves as the structure that we have modified and calibrated to our study region SAM. This model distinguishes households by nine income levels. It allows for imperfect substitution between state-produced goods, goods from the rest of the U.S. and goods from the rest of the world.

3.2.2 Fundamental assumptions and parameters

Static CGE models maximize a social welfare function subject to movement equations of capital stock and other stock variables (Alves and Pereira, 2006). Regional models are generally characterized by higher mobility factors of production than in national models because the costs of movement among regions are lower than among nations (Allan, 2015). In our model, capital and labor are assumed to be mobile and their endowment variable. Thus, we

Table 2: WBP CGE Model Parameters

Parameter	Value
Elasticity of demand for world export function	0.50
Elasticity of substitution for production	0.99
Elasticity of substitution (Armington) between regional output and imports	2.00
Elasticity of substitution (transformation) between domestic/regional and foreign demand	2.00
Elasticity of substitution (transformation) for exports between Rest of World and Rest of U.S.	2.00
Elasticity of substitution (Armington) of imports between Rest of World imports and Rest of U.S.	2.00
Income elasticity	1.00
Investment on commodities elasticity	1.00
Consumption flexibility (determines minimum subsistence level of consumption)	-1.00
Investment demand flexibility (-1 implies no minimum investment level)	-1.00
Demand elasticity for labor	4.00
Demand elasticity for capital	0.50

assume a long run equilibrium. We assume further that with the exception of own-facility use, the diesel, gasoline or ethanol output of biomass processing is responding to export demand in the rest of the U.S. rather than consumed within the region. Our model is calibrated to reproduce the baseline SAM for our Appalachian study region. Below we list key model parameters and their values.

3.3 Data

A range of data were required to develop the model and estimate the economic and environmental impacts of WBP. We relied on three main data sources, namely, IMPLAN[6], CEDA (Comprehensive Environmental Data Archive) and Liu (2015). We use IMPLAN 2011 data as the foundation for the regional social accounting matrix (SAM), at a level of detail originally distinguishing 430 industries. We used 2011 as the year for analysis because it was the most recent year for which all necessary project data were available. We used CEDA as a source for the CO2 emissions for all U.S. industries, and Liu (2015) provides information on cost and revenues of the woody biomass processes under study. Appendix 1 reports key model infor-

[6]Original data source (http://implan.com/company/).

mation on process revenues and costs. The production structures for FP and ETH also come from Liu (2015). Revenue is measured in barrels of output for each pathway. The spot prices per barrel of diesel, gasoline and ethanol in the U.S. Gulf Coast in 2011 come from EIA (2016a) and USDA(2016a). Facility operating cost is based on hourly employee wage rates, number of employees per shift and number of shifts per day, along with the life cycle analysis data provided by Liu (2015).

The SAM generated by the IO model is the primary input data to the CGE analysis. We aggregated economic and environmental data to 22 industrial sectors, retaining higher levels of detail on WBP related industries. Appendix 2 provides the correspondence between the 440 sectors in the original table, the 430 sectors in the environmental data, and the 22 aggregated sectors. LCA was the basis for the WBP production function and estimates of its direct environmental impacts[7]. We applied the Cooper et al. (2013) method to convert the LCA process matrices, one for each pathway, to SAM model format.

Table 3 presents the main differences in the process of each WBP pathway. The thermal conversion is process is the most striking and salient different between the two: the FP pathway relies on heat for its conversion process, while the ethanol pathway uses a fermentation process, and this is the primary driver of differences in economic and environmental impact. The two scenarios are directly comparable in amounts of daily energy production in megajoules (MJ). The Fast Pyrolysis scenario is used for the benchmark production level, based on the availability of feedstock and its greater feedstock intensity per MJ, and the output of the Ethanol pathway was adjusted to a level that would equate the MJ energy output from the two pathways. The resulting scenario production levels for FP and ETH were \$211.2M and \$157.3.M, respectively. Direct ETH employment and income are 22% less than respective FP values.

3.4 Application and results

To evaluate the two WBP regional impacts scenarios, we used the GAMS software with the Conopt[8] solver. We follow CGE model convention in presenting the results in terms of percentage changes in key interest variables impacts (i.e., output, employment, income, and environmental). This section is divided into three subsections. We first present a discussion of economic

[7] For more details on the WBP modelling and production function development and detail, see: http://rri.wvu.edu/wp-content/uploads/2015/06/WP_2016-04.pdf

[8] http://www.gams.com/help/index.jsp?topic=%2Fgams.doc%2Fsolvers%2Findex.html

Table 3: Key differences among each pathway process

Pathway	Inputs	Thermal Conversion	Output	GHG Impact (kg/barrel)
Fast Pyrolysis - FP	Woody Biomass	Pyrolysis	Gasoline and Diesel	146
Ehtanol - ETH	Woody Biomass	Fermentation	Ethanol	11

Source: Liu (2015)

impacts of the WBP pathways, then we discuss the environmental impacts, and finally we compare the CGE impacts to those from an IO analysis of the same scenario.

3.4.1 Economic impacts

Our economic analyses are presented in terms of output, income, and employment impacts. Although the areal extent of the region is large, there are less than 160,000 workers in the labor force. Table 4 shows the results of output, employment, and income impacts on the region, and its final row shows the direct shock share of base regional values. Because of the enforced equivalency in energy produced, the direct effects on output, employment, and income are larger for FP. While there is substantial sectoral redistribution, at this level of production, only FP adds to net gross regional output, and that addition is extremely small. The output effect of introducing ETH production is a net increase in gross output of only 0.46%. Employment and income also rise in both scenarios, albeit by somewhat smaller percentages due to the redistribution of employees from more to less labor-intensive and from higher to lower-wage industries, outcomes that are further reinforced by the size of the income multiplier relative to the smaller employment multiplier; where multipliers are computed as ratios of total impacts to direct shock values. We also see that FP multipliers are 26-28 percent larger than ETH multipliers. Specific multiplier values for FP and ETH for output, employment, and income are: 1.01 and 0.79, 1.83 and 1.46, and 2.27 and 1.79, respectively. Holding energy output constant, then, the FP pathway is generates greater regional economic benefit than the ETH pathway.

From a sectoral perspective, ETH has a larger positive impact on logging, but a slightly smaller impact on the Sawmill and Wood industry (wood chips as an input) than the FP pathway. The other large positive differences are on the Natural Gas and Power Generation industries, a difference due to the differences in conversion technology, where FP uses heat and ETH relies on fermentation. FP also uses substantially more Water Sewage services in support of its production process. Government, Construction, Retail, Waste Management, Misc. Services, and wholesale change by less than 0.1%, and virtually all other regional industries, essentially those not directly related to biomass production, experience 0.2% to 0.66% declines in output. The largest decline, interestingly enough, occurs in the mining sector, which is that sector that has been of greatest general concern in Appalachian coal regions. So, while the new WBP production might be seen to be competing with some sectors for labor, freed up labor from the declining mining sector is potentially being presented with new opportunities as a result of the new WBP activity. Indeed, although it is not captured in the model, surplus labor from Mining might also dampen the negative impacts on some of the other regional industries. In any event, the magnitude of any of these impacts is clearly quite small.

3.4.2 Environmental impacts

Table 5 shows the results in percent change in CO2 emissions of introducing WBP[9]. WBP-FP generates greater economic benefits, but because of its dramatically less energy-intensive fermentation production process, WBP-Ethanol is much more environmentally friendly, and generates substantially less system-wide CO2 emissions. There is a trade-off between economic impacts and environmental impacts of establishing WBP in terms of the choice of production pathway. Hence, regional "economic benefits come at the expense of environmental degradation" (Jackson et al., 2016).

3.4.3 Comparison with IO results

Because our CGE models are founded on input-output system representations that are the bases of SAMs, we can compare directly the economic and environmental impacts from two – often competing – models, each with different characteristics. Koks et al. (2016) note that direct comparisons are rare and "highly valuable from both a scientific and policy perspective"

[9]We are restricted to CO2 emissions due to the lack of data for other GHGs and pollutants associated with the production pathways. Also, note that we do not include in this analysis the use of the biofuels produced. This is effectively equivalent to assuming that in the absence of the new regional production, the corresponding amount of fuel would be sourced elsewhere and used. Since the fuel would be used irrespective of its source, there would be no change in use-based emissions.

Table 4: Percent differences in output, employment, and income of introducing WBP

	Output		**Employment**		**Income**	
Sector	FP	ETH	FP	ETH	FP	ETH
Logging	39.82	41.96	49.33	52.01	49.41	52.06
Natural Gas	13.28	-0.34	19.16	-0.34	19.22	-0.31
Sawmill and Wood	12.61	12.81	11.91	12.11	11.97	12.14
Truck Transport	5.23	4.52	5.28	4.58	5.34	4.61
Power Generation	4.35	-0.24	4.29	-0.14	4.34	-0.11
Water Sewage	2.53	0.13	13.53	0.61	13.59	0.65
Government	0.06	-0.02	-0.02	-0.06	0.03	-0.03
Construction	0.05	-0.13	0.00	-0.17	0.05	-0.14
Retail	0.02	-0.01	-0.01	-0.03	0.05	0.01
Waste Management	0.01	-0.06	0.01	-0.08	0.06	-0.04
Misc. Service	-0.03	-0.06	-0.06	-0.08	-0.01	-0.05
Wholesale	-0.08	-0.08	-0.08	-0.08	-0.03	-0.05
Machinery	-0.20	-0.24	-0.20	-0.24	-0.14	-0.20
FIRE	-0.20	-0.22	-0.11	-0.13	-0.05	-0.10
Agriculture	-0.29	-0.22	-0.24	-0.17	-0.19	-0.13
Other Manufacturing	-0.30	-0.19	-0.21	-0.12	-0.16	-0.09
Electrical Equip.	-0.30	-0.24	-0.27	-0.21	-0.22	-0.18
Fabricated Metals	-0.33	-0.26	-0.31	-0.25	-0.26	-0.21
Professional Service	-0.34	-0.34	-0.35	-0.34	-0.30	-0.31
Transport	-0.39	-0.53	-0.39	-0.54	-0.34	-0.51
Mining	-0.66	-0.62	-0.63	-0.57	-0.58	-0.54
Total	0.79	0.46	0.21	0.13	0.26	0.16
Direct Shock Share of Base Total	0.78	0.58	0.11	0.09	0.11	0.09

Table 5: Percent difference in CO_2 emissions of establishing WBP on the region (%)

	Sector	Fast Pyrolysis	Ethanol
1	Agriculture	-0.29	-0.22
2	Logging	39.82	41.96
3	WBP	-	-
4	Mining	-0.66	-0.62
5	Construction	0.05	-0.13
6	Other Manufacturing	-0.3	-0.19
7	Sawmill and Wood	12.61	12.81
8	Fabricated Metals	-0.33	-0.26
9	Machinery	-0.2	-0.24
10	Electrical Equip.	-0.3	-0.24
11	Wholesale	-0.08	-0.08
12	Retail	0.02	-0.01
13	Transport	-0.39	-0.53
14	Truck Transport	5.23	4.52
15	Power Generation	4.35	-0.24
16	Natural Gas	13.28	-0.34
17	Water Sewage	2.53	0.13
18	FIRE	-0.2	-0.22
19	Professional Service	-0.34	-0.34
20	Misc. Service	-0.03	-0.06
21	Waste Management	0.01	-0.06
22	Government	0.06	-0.02
	Total	4.73	0.05

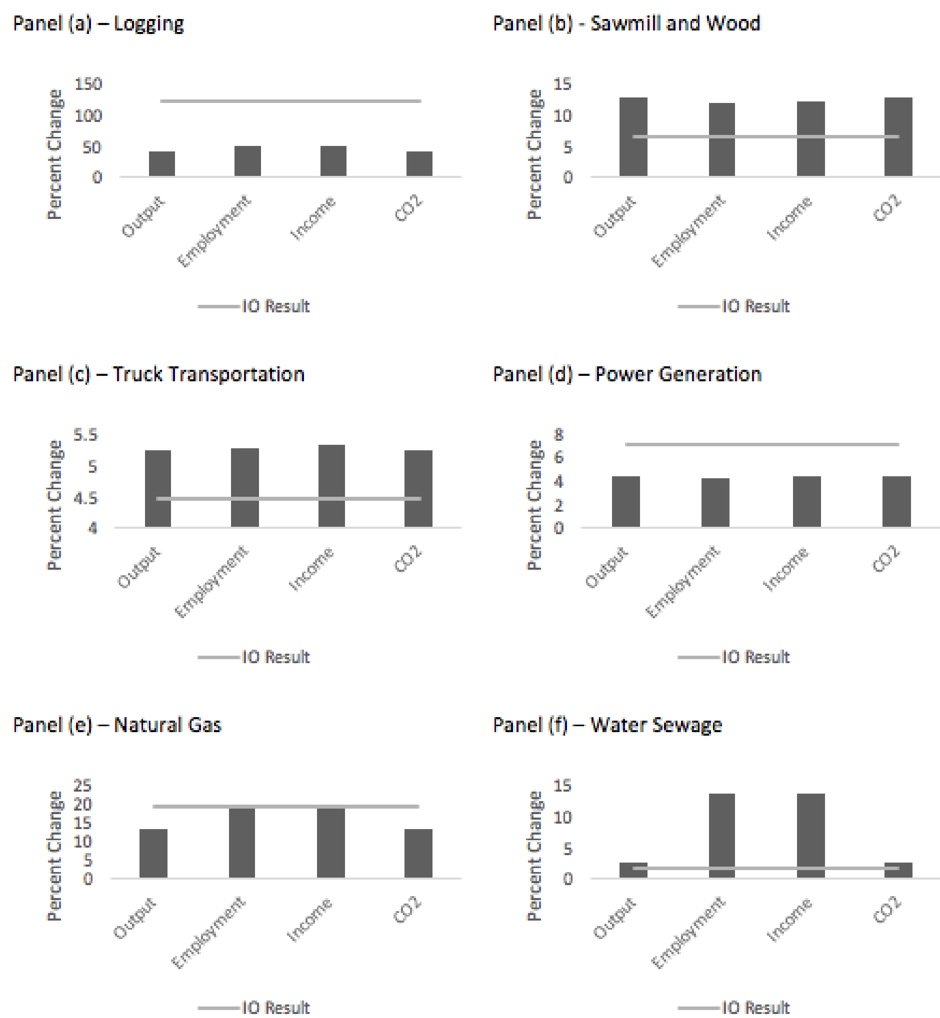
(p. 1911). The general finding from empirical studies that do carry out such comparisons is that CGE impacts estimates are generally smaller than corresponding IO estimates in total, but not necessarily for all sectors (e.g., Koks et al., 2016, Hu et al., 2014, and West, 1995). Input-output frameworks are fixed-price models and are not subject to supply constraints, while in CGE analyses, input and factor prices are not fixed, hence, the impacts are subject to price-induced behavioral changes. On the path to the CGE analysis reported here, Jackson et al. (2016) assessed the economic and environmental impacts of WBP on the region using an input-output based analysis. Figures 3 and 4 provide comparisons of economic and environmental impacts between the two methods for FP and Ethanol. Because the relationships among output, employment, income, and emissions are fixed for each industry in the IO model, their estimated percentage changes are equal. Hence, they are depicted by the horizontal lines in each panel.

The interest in comparing IO results and CGE results resides in the fact that the former capture a production shock effect, while the latter allows us to capture both production shock and substitution effects. We know that the shock to the economy in this case – the introduction of the new industry – is positive, but because of price adjustments and behavioral responses, there can be substitution effects that partly undermine or offset the direct effect, and in some cases, the substitution behavior can reinforce sector-specific positive direct and indirect impacts.

For the FP scenario, the industries with largest CGE-based regional economic impacts estimates are Logging (panel-a), Sawmill and Wood (panel-b), Truck Transportation (panel-c), Power Generation (panel-d), Natural Gas (panel-e) and Water sewage (panel-f). Comparing the impacts results for these industries with the IO impacts estimates, three sectors, namely Sawmill, Truck Transportation and Water Sewage have greater CGE-based impacts estimates, while for the others, the IO impacts estimates are larger. The price effect in the first three industries is reinforcing the shock effect, while for other three it is offsetting by redistributing sectoral activity or substituting imports for regional production. The largest offsetting effect is in the Logging industry, which can be explained, in part, by the complete lack of supply constraints on the IO logging industry, and the potential for imports in the CGE model.

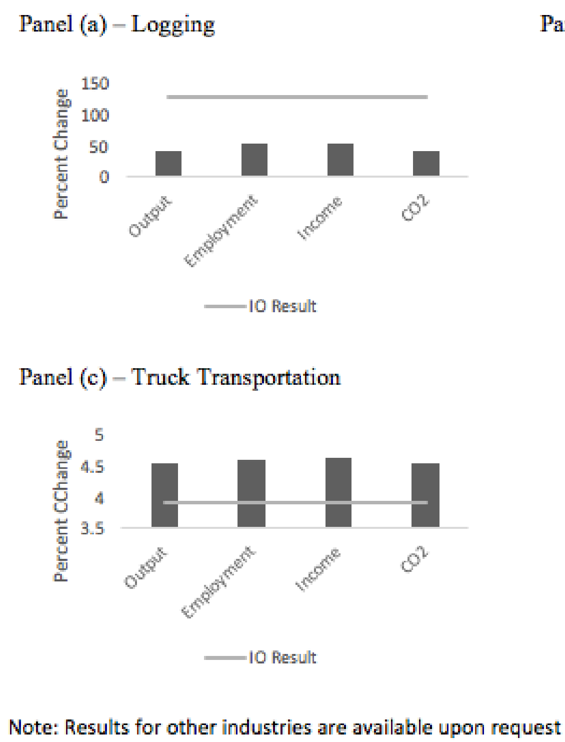
For the ETH pathway (Figure 4), most impacts from the CGE model are very small or negative. The three industries that have higher impacts are Logging (panel-a), Sawmill and Wood (panel-b) and Truck Transportation (panel-c). The results for the most heavily impacted sectors are similar to those from the FP scenario, in levels and in which industries shocks are

Figure 3: Regional impacts of WBP-FP in CGE vs. IO for selected industries



Note: Results for other industries are available upon request

Figure 4: Regional impacts of WBP-Ethanol in CGE vs. IO for selected industries



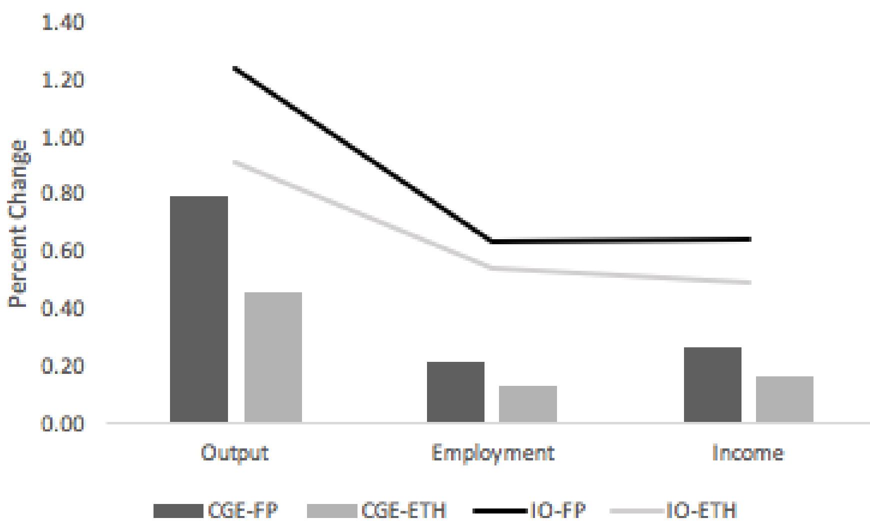
reinforced or offset.

Figure 5 shows the total percentage impacts summed over all sectors. Consistent with expectations, the IO impacts are uniformly larger for the total economy. The overestimation is stronger for the ETH scenario than for the FP scenario, and is most pronounced for the ETH employment estimate, which for IO is more than four times that for CGE, and least pronounced for FP output, where the IO impact estimate is 56% higher than the CGE estimate.

4 Summary and Conclusion

In this study, using a CGE analysis as the primary tool, we quantified the potential economic and CO2 impacts of introducing a woody biomass pro-

Figure 5: Total regional impacts of WBP-Ethanol in CGE vs. IO



cessing industry to a distressed rural region of southern Appalachia, rich in forest resources. We assessed two production pathways: fast pyrolysis, and ethanol production. The main economic results are that FP and ETH both would increase the output, employment, income and CO2 levels, but neither would contribute very substantially in percentage terms. The economic impacts all range from 0.13% to 0.79%. A new FP facility would have a greater positive impact on the region than would a new ETH facility. A new WBP facility would increase regional output levels by between 0.45% to 0.78%, employment between 0.13% to 0.2%. Income gained by the labor force would increase by 0.16% to 0.26%, and CO2 levels would increase by 0.05 for ETH and 4.73% for a FP facility.

In both WBP-FP and WBP-Ethanol pathways, the logging industry is the most heavily affected sector, while the second and the third most affected industries depend on which pathway was chosen. The differences are due primarily to the nature of the biomass conversion process, which is the application of heat for pyrolysis and fermentation for ethanol production. This difference also accounts for the differences in CO2 emissions. Both pathways would increase the CO2 emissions, but compared to the WBP-FP, WBP-Ethanol is a much more environmentally friendly production pathway.

While both pathways have the potential to absorb some of the workforce due to a declining coal sector, the substantial positive emissions contribution from fast pyrolysis makes clear the tradeoff, in this instance, between economy and environment.

Lastly, our comparison of CGE to IO model impacts estimates confirms the conventional wisdom that IO modeling results in higher impacts for most industry sectors. In other words, allowing substitution of production factors and changes in commodity prices decreases the size of impacts. Whether this is difference in model outcomes reflects real-world behaviors depends at least in part on the extent to which the introduction of a facility into a region of this size – both economically and geographically, will result in the price changes and behavioral effects that the CGE model produces. Modifying the CGE model to reflect non-binding logging supply constraints would also bring the results of the two frameworks closer into alignment. Given these considerations, it might be reasonable to expect that the actual impacts would fall somewhere between the IO and CGE impacts presented here.

In the context of regional development policy, introducing WBP into an economically distressed region that has abundant forest resources might well represent one of few viable options for sustaining the rural regional economy. While there is an environmental cost, it may be small enough – especially if the ethanol pathway is chosen – to be acceptable. Whether a nearly 5% increase in regional CO2 emissions would be justified by the creation of so few jobs, however, is much less clear.

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Appendix

Appendix 1: Economic information for each pathway

Information	Fast Pyrolysis	Ethanol
Days of activity	350	
Wages per hour	50	
Hour per shift	8	
Shifts per day	3	
Barrel per day	5,000	3931
Price of Barrel of output	\$119.38	\$113.40
Number of workers per shift	48	38

Note: Number of workers are converted to full-time equivalent

Appendix 2 – Aggregation Schemes

Sector Number	Sector Name	Abbreviation	IMPLAN codes	CEDA codes
1	Agriculture	AGRI	1-14, 17, 18	1-14, 17,18
2	Ag Service	AGRIS	19	19
3	Logging	LOGG	15, 16	15, 16
4	WBP	WBP	LCA	LCA
5	Mining	MINI	20-30	20-30
6	Construction	CONS	34, 35, 36, 39, 40	34, 35, 36, 39, 40
7	Other Manufacturing	OMAN	41-94, 96-185, 187, 190-206, 208-220, 224-231, 234-242, 246-250, 252-265, 274- 318	41-94, 96-185, 187, 190-208, 210-220, 224-230, 232, 234-242, 245, 246, 248-250, 252- 265, 274- 319
8	Sawmill and Wood	SAWW	95	95
9	Fabricated Metals	FABM	186, 188, 189	186, 188, 189
10	Machinery	MACH	207, 221-223, 232, 233,	209, 221-223, 231, 233
11	Electrical Equip	ELEC	243-245, 251, 266-273	243, 244, 247, 2 51, 266-273
12	Wholesale	WHOL	319	320
13	Retail	RETA	320-331	331
14	Transport	TRAN	332-334, 336, 337	321-323, 325, 326,
15	Truck Transport	TRUC	335	324
16	Power Generation	PGEN	31	31
17	Natural Gas	NATG	32	32
18	Water Sewage	WATS	33	33
19	FIRE	FIRE	354-361	346-352, 429
20	Professional Service	PSER	37,38- 367-370, 374-376, 381	37,38, 358-361, 365-367, 372
21	Misc. Service	MSER	338-353, 362-366, 371-373, 382-389, 391- 426	327, 329, 330, 332-345, 353-357, 362-364, 368- -371, 373-380, 382- 417
22	Waste management	WMAN	390	381
23	Government	GOVE	427-440	328, 418- 428, 430