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Woody biomass processing: Potential economic impacts on rural regions

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ABSTRACT

This paper estimates the economic and environmental impacts of introducing woody biomass processing (WBP) into a rural area in central Appalachia. WBP is among the most promising additions to energy generation portfolios for reducing import dependency while at the same time providing economic opportunity to stimulate regional economies, especially in rural regions where economic development options are often limited. We use an input-output framework to assess WBP under three different pathways, fast pyrolysis, ethanol and coal-biomass to liquids. We find that the proposed WBP will increase regional output by 0.5–1.3% of gross regional product; it will increase income by $17.32 to $51.31 million dollars each year, and regional employment by 218.1–1127.8 jobs, depending on the chosen pathway. Of these impacts, the direct portions are 63–77% of the total impact, depending on the chosen pathway. The economic analysis and the results from the accompanying environmental assessment show that only the ethanol pathway has both economic and environmental benefits. We conclude that because long-run economic development strategies in rural regions are limited and negative impacts do not alter dramatically the regional environmental profile, regional policymakers should include WBP among their development portfolio options.

1. Introduction

Energy use in the United States (U.S.) far exceeds the domestic energy supply, and according to the Energy Information Administration (EIA), imports accounted for 9.6% of the 97.528 quadrillion Btu used in 2015 (Energy Information Administration, 2017).[1] Woody biomass processing (WBP) is the transformation of cellulosic biomass (woody biomass) into bioenergy products such as biofuels (Liu, 2015). WBP has gained attention, and for some is among the most promising additions to energy generation portfolios for reducing energy import dependency while at the same time providing economic opportunity, especially in rural areas where other economic alternatives are limited (Lauri et al., 2014). Woody biomass is of particular interest because unlike many other potential biomass sources, woody biomass does not include crops that are used for energy and food, but instead comes from forest resources that are mostly unused in rural areas. Moreover, Perlack et al. (2005) argue that among the current renewable sources, biomass is the only renewable that can produce liquid transportation fuels. The International Energy Agency (IEA) estimates that only 10% of the world's primary energy supply comes from biofuels and waste, while 81.7% is still based on fossil fuels. Despite relatively abundant forest resources, wood and wood-derived fuels generate less than 2% of the energy consumed annually in the U.S. (International Energy Agency, 2014).

Although woody biomass constitutes only a small percentage of total energy use, its consumption still accounts for 27% of all renewable energy sources (White, 2010). As an available renewable energy source with little negative impact on food supply, WBP has the potential to be a much more substantial contributor to energy generation. In its 2011 report, the U.S. Department of Energy (DOE) estimates that by 2030, the U.S. potential forest and agriculture biomass, at $60 per dry ton under high-yield scenario assumptions (1374–1633 million dry tons), can offset at least 30% of U.S. petroleum consumption (U.S. Department of Energy, 2011).

Using wood as a source for heating is as old as mankind, but processing woody biomass to generate fuel and electricity is in its infancy. Regardless of the way woody biomass is used, biomass processing can directly support local economies and local job markets, which is especially advantageous to rural economies where other economic opportunities are often limited. The forest-related energy-source literature emphasizes that the potential impacts of WBP energy on local and national economies is substantial. This renewable resource can improve forest health, reduce the dependency on imported fossil fuels, enhance

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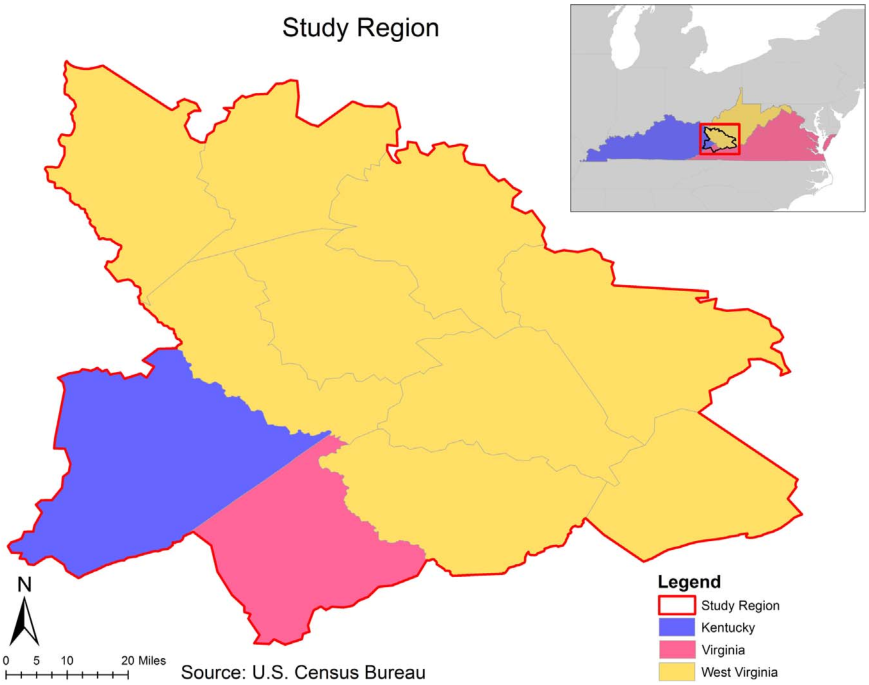

Fig. 1. Map of the study region.

sustainability, and potentially even reduce environmental impacts.

This study assesses the potential economic and environmental impacts of introducing WBP in an economically distressed rural region in central Appalachia. We compare three different WBP pathways, namely biomass to ethanol (WBP-ETH), biomass to biofuel via fast pyrolysis (WBP-FP), and coal-biomass to liquids (WBP-CBTL). The three biomass-to-liquids pathways include five logistic systems: biomass collection, transportation, storage, preprocessing, and conversion. Although the pathways have similar logistic systems, they can and do vary, especially as a result of differences in the composition of material inputs. Conversion systems most clearly differentiate the three pathways, as not only do output compositions differ, but so, too, does the nature of the underlying conversion processes, which is explained in greater detail in Section 5.1. The production parameters that we use for the WBP-FP conversion process are based on Jones et al. (2009), for WBP-ETH the process is based on Phillips et al. (2007), and the WBP-CBTL process is based on Jiang and Bhattacharyya (2014). Our direct source for conversion process data is Liu (2015), who, in conjunction with a project funded by the U.S. Department of Agriculture – National Institute of Food and Agriculture, provided us with data on input and output prices and quantities along with a unit-process technical requirements matrix based on a life cycle assessment (LCA). These data allow us to create three separate WBP production functions for embedding – each in turn – in a regional input-output (IO) table for our study region, depicted in Fig. 1, which is composed of nine counties in southern West Virginia and one county in Kentucky and Virginia.[2]

We use IO analysis to estimate the impacts of the wood-to-fuel industry on regional output, income, employment, and environment. The results provide useful information for policy makers assessing WBP as a sustainable regional economic development alternative.

2. Related literature

Woody biomass processing has experienced a rapid expansion in recent years because of a series of economic and environmental concerns. We can divide previous studies into three broad types: WBP as a renewable energy source, environmental issues in the utilization of woody biomass, and economy-wide impacts of WBP. We briefly canvas these topics below to situate our study in the related literature.

2.1. Woody biomass as a renewable

WBP has many benefits as a renewable energy source compared to fossil fuels. Numerous studies have assessed the potential contribution of a wood-based energy source as an inexhaustible, while sustainably harvested, alternative for energy generation on a regional, national, and worldwide level (Hall, 1997; McKendry, 2002; Parikka, 2004; Baxter, 2005; Hoogwijk et al., 2005; Prasertsan and Sajjakulnukit, 2006; Vries, 2007; Gokcol et al., 2009; Lauri et al., 2014; He et al., 2014). These studies focus on the competitiveness of WBP – as a non-food crop – with other indigenous energy alternatives. Further, while this literature tends to focus on woody biomass as a source of energy, only a few studies examine implications for specific regions. Exceptions include Hall (1997), He et al. (2014) and Prasertsan and Sajjakulnukit (2006) who study Austria, Denmark, Finland, Sweden and the U.S., the U.S. only, and Thailand, respectively. The consensus in the literature is that woody biomass is clearly a relatively low-cost, renewable and reliable source of energy. Lauri et al. (2014) notes, "Large unused woody biomass resources and an increasing need for climate change mitigation has awakened policymakers' interest in woody biomass energy potential" (p. 20). While finding new sources of natural gas in the U.S. will cover some portion of energy demand, scientists must still consider issues related to climate change and the environment related to the combustion of natural gas.

2.2. Woody biomass and the environment

One strand of WBP literature focuses on the correlation between fossil fuel consumption and damage to the regional environment in terms of pollutant concentration and human health (Klass, 1998; Martinsen et al., 2010; Popp et al., 2014; Herbert and Krishnan, 2016; Paiano and Lagioia, 2016; Sikarwar et al., 2016; Chang et al., 2017). The threat of global climate change can be partly attributed to the combustion of fossil fuels. With the new discoveries of oil and gas

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[2] The counties that compose our study region are: Boone, Lincoln, Logan, McDowell, Mercer, Mingo, Raleigh, Wayne, and Wyoming in West Virginia, Buchanan in Virginia and Pike in Kentucky.

reserves, energy security might be enhanced, but incentives to the adoption of greener technologies might well diminish. Therefore, due to climate change and other potential issues related to greenhouse gas (GHG) emissions, exploration of more environmentally friendly and sustainable energy sources like woody biomass should be encouraged. Keoleian and Volk (2005), Silalertruksa and Gheewala (2009), Zhang et al. (2009), Yu and Tao (2009), Saidur et al. (2011); and Wang et al. (2015) are examples of studies that try to capture the regional environmental impacts of WBP. To assess such impacts, these studies have used LCA, which we further combine with system-level IO analyses. The overall conclusion to date is that the use of WBP helps mitigate CO_2, NO_X, CH_4, and CO emissions. Hence, as long as woody biomass is converted to energy through an environmentally sustainable process, it can be considered a promising source of energy.

2.3. Woody biomass and the economy

Several studies have analyzed policies on international and national levels that support the use of woody biomass as energy generation source. These policies not only bring the environmental perspective, but also address the economic influence that WBP can have in the local and regional economy. Woody biomass has the potential to create direct and indirect local jobs in rural areas, and this characteristic can be key to attracting new business opportunities in rural forested economies. Because more jobs create more output, woody biomass – either as a subset of a larger and more general biomass sector or as a specifically independent category – is the focus of recent studies, most of which assessed WBP economic impacts using IO analysis (Madlener and Koller, 2007; Timmons et al., 2007; Gan and Smith, 2007; Perez-Verdin et al., 2008; Mehmood and Pelkki, 2009; Aksoy et al., 2011; Kebede et al., 2013). Other studies measured economic impacts by applying other methods such as partial equilibrium models and computable general equilibrium models (Tokgoz et al., 2007; Tyner and Taheripour, 2008; Hodges et al., 2010; Trink et al., 2010). Overall, these studies show some positive impacts in terms of output and employment in the study regions. WBP appears to represent an exceptional opportunity to stimulate regional economies, especially in forested rural areas.

3. Modeling alternatives

Impacts models can be partial or general equilibrium based. Partial equilibrium models that focus on one or a few sectors in isolation can be used to investigate the economic impacts of a new sector. However, a basic premise of partial equilibrium models is that sector impacts can be modeled independently. Therefore, they are often not the best choice for examining the effects of new industrial activities when increases in intersectoral flow of goods and services within an economy are expected. Instead, general equilibrium models that focus on all economic sectors and their interactions and interdependencies can be better alternatives. In this section, we provide examples of models that have been applied in similar impact analyses, and briefly discuss our modeling approach.

There are two types of general equilibrium methods that are commonly used for economic impacts estimation, namely IO (or its cousin, the social accounting matrix – SAM) analysis and computable general equilibrium (CGE) modeling. IO models seek equilibrium in goods markets only, while fully specified CGE models seek equilibria in all markets: goods, labor, capital, and land. CGE models can capture more accurately the impacts of economic shocks that are large enough to cause changes in wages, interest rates, or land rents, but they often provide less industry-specific detail, and they rely on an array of procedures (e.g., parameterization, calibration, and benchmarking), assumptions (e.g., functional forms and model closures), and additional data (e.g., substitution elasticities). If shocks are not expected to cause substantial changes in wages, interest rates, or rents, then IO and CGE modeling frameworks will often generate similar impacts estimate results.

IO analysis is often used to estimate the economy-wide effects from a specified exogenous change - a shock - in an economic activity. This shock can range from the increase in final demand from households through the introduction of a new industry in a local economy (Bess and Ambargis, 2011) to the response to new export markets. Hence, in the literature there are several papers that make use of IO to evaluate the impact of WBP in the economy. These have been regionally focused studies,relying on unique features and assumptions from the studied regions to derive their results.

Despite the specificities in their empirical work, we can build from these studies. Within the demand-driven IO modeling framework, the WBP analysis can take one of two forms: either the modification of an existing production structure (Gan and Smith, 2007; Lester et al., 2015) or the introduction of an entirely new (WBP) sector in the regional economy (Mehmood and Pelkki, 2009; English et al., 2013; Wicke et al., 2009; Aksoy et al., 2011). We opted to introduce the new WBP facility as a new industry in the production system, because no other industry in our study region produces liquid fuels. Also, because this study is part of a larger project (USDA Award 2012–67009-19660) we had access to highly precise estimates of regional costs, inputs and expected revenues.

Woody biomass research that uses IO models to analyze the impacts of forest related energy sectors generally identifies significant contributions to the local economy, especially in numbers of jobs generated. As noted, however, a weakness of IO lies in its fixed-price assumption. In contrast, one of CGE's main advantages lies in its endogenized price and substitution effects. Despite its own set of criticisms noted earlier, CGE models have been used in empirical analysis related to biomass and bioenergy issues, and they have often been effective in the evaluation of relevant policies (Steininger and Voraberger, 2003; Gan and Smith, 2007; Kretschmer et al., 2009; Elbehri et al., 2009; Trink et al., 2010; Evans, 2007; Huang et al., 2012; Allan, 2015). Of particular relevance to the research reported here, CGE models are rarely configured to assess increases in production to meet exogenous demands. Classical IO models, in contrast, are ideally suited to estimating production induced requirements to satisfy external demands. Both models, then, have strengths and weaknesses, and in the long run we will implement both methods. Because IO accounting frameworks are the foundation of social accounting matrices, which in turn form the bases of CGE models, we take the opportunity here to report the IO impacts assessment results, and leave the CGE assessment to follow-on research. IO models are often considered to result in upper-bound estimates. To minimize potential impacts overestimation, we make conservative analytical assumptions where possible.

4. Method and data

This section first reviews the IO method, then describes the data and their sources, and finally presents the procedural steps followed in generating the WBP production function.

4.1. IO Foundations

The IO framework as the general approach for our analysis is applied to assess the economic and environmental impacts of WBP for fuel generation in the region. The classical IO model can be shown in matrix form as:

$$Z + f \equiv x \tag{1}$$

where Z is a matrix of intermediate interindustry transactions, f is a vector of industry final demand,and x is a vector of total output. The technical coefficient a_{ij} is defined as the ratio of inputs from industry i to output in industry j, or Z_{ij}/x_j. Substituting $a_{ij}x_j$ for Z_{ij} in (1), we have:

$$Ax + f = x \tag{2}$$

or

$$(I - A)x = f \tag{3}$$

and solving for output,

$$x = (I - A)^{-1}f = (I + A + A^2 + A^3 + \ldots)f \tag{4}$$

Modern IO data are published in a commodity-by-industry accounting system, with *Use* (U) and *Make* matrices (V) that show commodity purchases by industry and primary and secondary commodity outputs by industry, respectively. Matrix U is analogous to the interindustry transaction matrix Z in conventional interindustry IO frameworks, but inputs are displayed by commodity rather than by industry. The modern accounting framework relies on additional math manipulations, but the fundamental principles and analytical form are consistent with the simpler format shown above.

To quantify the impact of WBP, we add a new industry and a new commodity to the U and V matrices. The initial n-industry, n-commodity system becomes a $(n+1)$-industry, $(n+1)$-commodity system. To simplify the analysis, we assume that except for a small amount of diesel and gasoline that it consumes in its own production process, the output from the newly introduced industry is sold to outside the region. We assume that WBP output is a regional export for two reasons. First, the most likely scenario is that WBP output would be sold to a wholesaler for subsequent distribution, and no such wholesalers are present in the study region. Second, attempting to identify specific local purchasers of the fuel produced by a new WBP facility would involve constructing a scenario that would require a number of additional and more or less arbitrary assumptions that, in turn, would embody a set of ad-hoc decisions on changes to be made to the production functions of other regional industries. Because such assumptions might or might not describe the eventual observed behaviors, they would add uncertainty to the scenario and might increase impacts assessment error. Therefore, the export assumption provides an explicit and transparent context against which to reference the results. It is possible, of course, that a wholesaling facility might be drawn to the region, representing an additional positive economic development impact. The assumption that this development impact would occur, however, would be difficult to defend.[3]

4.1.1. Multipliers

Among the key features of IO models is the ability to measure the total economic effects of a specified change in economic activity – an economic shock. Economic shocks are most commonly modeled as changes in final demand. IO multipliers derived from elements of the Leontief inverse matrix, defined as $(I - A)^{-1}$, are useful summary measures that are built on the relationships among the initial and total effects of a shock on variables of interest (Miller and Blair, 2009). The power series expansion of the multiplier matrix shown in Eq. (4) provides insight into the nature of IO multipliers in that the first term is the initial change in activity, the second term is the set of inputs needed to support the initial change, or the *first round of spending,* the third term represents inputs needed to support the first round of spending, the fourth term represents input requirements to support the second round of spending, and so on. The multiplier is the sum of all of these rounds of spending divided by the initial change. Multiplier comparisons can be used to identify in which industries initial changes of a given size will have the greatest total impacts. Regional policy makers frequently use multiplier analyses to provide information on expected returns to public capital investment by industry. Output and income multipliers measure total dollar impacts, while employment multipliers measure the total effects in terms of the number of jobs or full-time equivalents.

Although multipliers can be used to predict the impacts of a new or expanding industry, they are perhaps most useful for intersectoral comparisons. From a policy standpoint, the *significance* of regional economic impacts of a shock can be judged more intuitively by the number of new jobs that result and the amount of new income earned in the economy relative to their pre-shock regional totals. Absolute employment and income changes are immediately interpretable to any audience, hence they are often the most useful for policy discussions.

4.2. Data sources

Estimating the interdependence of the region's industries and economic impacts required several data inputs and sources. In this study we used three main data sources: IMPLAN,[4] the CEDA® Comprehensive Environmental Data Archive (Suh, 2011, 2005), and Liu (2015). We use IMPLAN as a source of the study region SAM. From this SAM we generated a regional IO table with 440 industries and commodities for the 2011 study year, selected for greatest compatibility with available data. To convert technical coefficients to regional trade coefficients for the purpose of within-region impacts, we follow the procedures developed in Jackson (1998).[5] Liu (2015) provided estimates for hourly employee compensation rates, number of employees per shift and number of shifts per day, along with the LCA data, which allow us to create a cost structure for each of three production pathways - fast pyrolysis (WBP-FP), ethanol (WBP-ETH) and Coal and Biomass to Liquid (WBP-CBTL). The $50 hourly compensation rate, according to Liu (2015) is in accordance with compensation rates in this industry. By comparison, 2011 median annual wages in biofuels engineering occupations was just more than $87k. This converts to $43 per hour in wages, which, in 2011 account for just under 70% of total compensation.[6]

We also used Liu (2015) as the source for information on production costs and revenues (See Table A1 for the main information on revenues and costs). To estimate total annual revenue, we combined daily commodity output in barrels for each pathway and commodity type with the annual number of days the facility would operate and the 2011 spot price of diesel, gasoline and ethanol in the U.S. Gulf Coast provided by EIA (Energy Information Administration, 2017) and USDA (U.S. Department of Agriculture, 2016). Lastly, we obtained the CO_2 equivalent emissions for all 430 U.S. industries from CEDA.[7] More details can be seen in the production functions presented in Table 1.

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[3] It is also unlikely that locally produced liquid fuel products would prompt other industries to engage in input substitution, per se. They would at most substitute local for imported product. The major behavioral differences would be that local product consumers would buy from a local wholesaler rather than one outside the region, and that the product might be shipped a shorter distance to the wholesaler. This would have an impact on the distribution logistics and accompanying emissions from the associated transport, but estimating these impacts in the absence of specific information on existing versus new wholesaler locations would add yet another layer of assumptions and complexity to the scenario. Further, making changes that would effectively modify shares of local demand met by local production would imply that the new shares of local demand produced locally would apply to future changes in economic activity levels, which would in turn imply production levels higher than those in the impacts scenario.

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

[5] Our implementation of Jackson's method implicitly assumes that the import proportions for industry inputs remain unchanged after the WBP activity is introduced. The alternative would imply that other industries' long-standing purchasing patterns would shift uniformly across all industries to slightly larger imports shares to accommodate the demands from local suppliers of the new WBP processor for these same inputs. It also would imply that industries would export slightly less because some of their previous exports might be reoriented to supply the new WBP facility. Our choice of implementation reflects a preference for any small error introduced by allowing other activities to continue prior behavior over the error that would be introduced by assuming that all regional activities would reorient their purchasing and sales activities due to the introduction of WBP.

[6] For biofuels wage data by occupational category, see https://www.bls.gov/green/biofuels/biofuels.htm. See https://www.bls.gov/web/ecec/ececqrtn.txt for data on wage and salary portions of total compensation. Both were last accessed October 7, 2017.

[7] The reported GHG are: CO_2, CH_4, N_2O, $HFCs$, $PFCs$, and SF_6. In the remainder of this paper, the terms CO_2 emissions and CO_2 equivalents are used interchangeably.

Table 1
Pathway production functions.

	Sector	Fast Pyrolysis	Ethanol	CBTL
1	Agriculture	0.000	0.000	0.000
2	Ag. Service	0.000	0.000	0.000
3	Logging	**0.104**	**0.148**	**0.005**
4	WBP	**0.005**	**0.001**	**0.003**
5	Mining	0.000	0.000	**0.259**
6	Construction	0.000	0.000	0.000
7	Other Manufacturing	**0.086**	**0.211**	**0.024**
8	Sawmill and Wood	**0.049**	**0.067**	**0.002**
9	Fabricated Metals	0.000	0.000	0.000
10	Machinery	0.000	0.000	0.000
11	Electrical Equip.	0.000	0.000	0.000
12	Wholesale	0.000	0.000	0.000
13	Retail	0.000	0.000	0.000
14	Transport	0.000	0.000	**0.009**
15	Truck Transport	**0.140**	**0.163**	**0.007**
16	Power Generation	**0.122**	0.000	0.000
17	Natural Gas	**0.148**	0.000	**0.000**
18	Water Sewage	**0.013**	**0.001**	**0.000**
19	FIRE	0.000	0.000	0.000
20	Professional Service	0.000	0.000	0.000
21	Misc. Service	0.000	0.000	0.000
22	Waste Management	**0.000**	**0.000**	**0.001**
23	Government	0.000	0.000	0.000
	Employment Compensation	**0.096**	**0.101**	**0.092**
	Other Value Added	**0.236**	**0.306**	**0.595**

Note: In bold the values that are different than zero in the LCA.

4.3. Data development

This subsection presents our approach to creating WBP production functions and for incorporating them into the existing regional IO table. To assess the impacts of a new industry on the regional economic system, we convert LCA process matrices to IO model production (cost) function format. The conversion requires careful delineation of system and subsystem boundaries to avoid double counting. Although WBP can be introduced as a new sector in the region, some aspects of the LCA process are already represented in the IO accounts. To deal with the potential for double counting, we follow the procedure presented in Cooper et al. (2013), which was designed specifically to address the system boundary issue. We use this method to generate the technical production functions for each WBP pathway, linking the micro level data (LCA) to macro data (IO). Because WBP is not explicitly incorporated in the current version of the IO accounts, we augmented the model to explicitly include the sector. LCA allows us to create the WBP input cost (production) function, and to determine the environmental impact of the WBP activity.

The LCA unit process matrix corresponds to the production of a single barrel – a unit – of WBP output. To calibrate the cost function, that is, the ratios of inputs used for each output unit, we use the prices of inputs from Liu (2015) and an accounting framework where costs equals revenue, which is consistent with the double-entry accounting framework of IO. Because costs also include value added (employee compensation, gross operating surplus and taxes) we calculated employee compensation per barrel from the WBP hourly compensation rates, and computed other value added costs as a residual.[8] This information allowed us to calculate standardized production functions for each pathway (see Table 1 below). It is important to stress that these production functions only include estimates for the most substantial inputs in the production process. For instance, the WBP-ETH and WBP-CBTL pathways report zero Power Generation values. According to Liu (2015) the former requires only insignificant amounts of energy in the conversion process, while the latter provides power for itself.[9]

Table 2
Key pathway process differences.

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
Coal and Biomass to Liquids - CBTL	Coal and Woody Biomass	Indirect Liquefaction	Diesel	47

Source: Liu (2015).

To complete the data preparation phase, the environmental (CO_2 equivalent) data[10] and the WBP sector input data were reclassified to conform to the same sectoral classification scheme and orders of magnitude as those in the base IO table data. To facilitate reporting, we present the results at a more aggregated level of industrial detail than used in the analysis while retaining as much detail as possible on WBP related industries. Table A2 provides the correspondence between the 440 sectors in the original table, the 430 sectors in the environmental data, and the 23 aggregated sectors we use for reporting.

5. The case study

5.1. Production pathways

The three WBP pathway processes differ qualitatively in several ways, and these differences give rise to the different production functions that explain the variation observed in their estimated economic and environmental impacts. Table 2 summarizes the salient characteristics of each production process. Whereas WBP-FP and WBP-ETH only use woody biomass as input, WBP-CBTL adds coal to the process. The woody biomass input used in our analysis consists predominantly of residual material from Logging and Sawmills. Therefore, we do not expect notable price changes due to the additional demand from WBP, as this is a demand for a resource that otherwise would not be consumed. While we also should expect an increase in producers' profit (or income) due to this new demand for residue that was not sold previously, increased profits do not drive additional impacts in IO models.

Likewise, the thermal conversion processes vary by pathway. WBP-FP relies on a heating process, WBP-ETH uses fermentation, and WBP-CBTL uses an indirect approach to gasify the feedstock. The output product mix also varies by pathway, with gasoline and diesel produced by WBP-FP, ethanol as the product of WBP-ETH, and diesel only as the product of WBP-CBTL. Thus, we can expect that each of these processes will have different direct and indirect regional economic and environmental impacts. For instance, according to Liu (2015), the direct CO_2 equivalent impact in the production of one barrel of output is 146 kg for WBP-FP, 11 kg for WBP-ETH and 47 kg for WBP-CBTL.

To simplify the comparison of impacts across pathways, we do not focus on the greenhouse gas impact of the use of these products once they have been produced. We assume that the amounts produced are small relative to the larger market, are sold as exports from the region,

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[8] Because this is an IO analysis, the portions of value added allocated to the other value added components do not enter into the IO computations.

[9] While it would have been ideal to have estimates for all inputs used in the production processes, Jensen and West (1980) and Jackson (1991) have shown that very small coefficients contribute very little to multipliers and impacts estimates, and that overall model sensitivity to errors in small IO coefficients is quite low.

[10] While we would like to expand the environmental analysis to include other pollutants, this was not possible given the LCA data provided by Liu (2015). The “environmental flows” in our LCA process contained GHG emission as CO_2 equivalent, Blue water consumption (BWC) and fossil energy consumption (FEC). The BWC is not a concern in our analysis since the study region has ample available water, according to Maupin et al. (2014). FEC are accounted for in our IO matrix. The interested reader can refer to Liu (2015) and Liu et al. (2017) for greater detail on the LCA, and the GHG components for each WBP system.

Table 3
2011 Study region socioeconomic characteristics.

County	State	Per Capita Income ($)	Labor Force*	Unemployment Rate* (%)	Poverty Rate (2009–2013)	Economic Status
Boone	WV	29,749	8680	8.1	21.1	At-Risk
Lincoln	WV	25,837	7678	10.7	26.5	Distressed
Logan	WV	33,201	12,913	8.9	19.6	At-Risk
McDowell	WV	26,990	6671	11.9	35.2	Distressed
Mercer	WV	32,247	23,732	8.6	21.8	Transitional
Mingo	WV	30,563	9201	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	8313	8.8	20.9	Distressed
Buchanan	VA	33,665	8475	8.6	24	At-Risk
Pike	KY	33,292	24,323	9.2	24.1	At-Risk

Source: Appalachian Regional Commission, BLS*.

and substitute for those amounts produced elsewhere in the economy by traditional methods. This implies that WBP product sourcing has no use-based environmental impact.

5.2. *The study region*

Our focus in this analysis is on an economic region composed of eleven rural counties in central Appalachia. The region was selected to be representative of predominantly rural regions with abundant woody biomass, where poverty rates are higher than the U.S. average, and where per capita income is much lower than the U.S. average. The study region shown in Fig. 1 includes Boone, Lincoln, Logan, McDowell, Mercer, Mingo, Raleigh, Wayne, and Wyoming counties in West Virginia, Buchanan and Pike counties in Virginia and Kentucky, respectively. Between 2009 and 2013, its poverty rate was 21.2% while the U.S poverty rate was 15.4%. Regional per capita income is $32,333, which is much lower than the U.S. value of $42,298. Table 3 shows the socioeconomic characteristics of the region.

Eight of the eleven counties in the study area do not have a city of 10,000 or more, accentuating the rural nature of the region. All of the region's counties have higher unemployment rates, higher poverty rates, and lower per capita incomes than the average U.S. county. The region's economy relies heavily on the coal industry, which has seen a downward spiral in recent years (Energy Information Administration, 2017). The combination of rural structure, economic distress, and limited economic opportunities poses huge challenges for regional economic development.

Revitalizing the economy of the region would require a substantial increase in the number of jobs, and biofuels production might have this kind of potential. Liu et al. (2017) reports that, “more than 80% of the total land area in WV is covered with forests, which makes it the third most heavily forested state in terms of forest coverage. The total forest area is 4.9 million hectares, of which 98% is timber land. The annual yield of woody residue is approximately 2.19 million dry tons …” (p. 77). With few alternatives, leveraging one of the region's few comparative advantages – its rich forest resources – might present a unique opportunity for creating long term and stable economic activity.

6. Application and results

For this impacts assessment, we report conventional IO output, employment, and income multipliers, economic impact levels, and environmental multipliers and impacts. Economies are more strongly linked to industries with larger multipliers, so demand shocks for those industries have larger impacts than for industries with smaller multipliers. Ongoing output, employment and income impact levels are measured for economic impacts of WBP operation and maintenance, and GHG are our metric for environmental impacts. We exclude construction impacts that, while not inconsequential, are nevertheless short-lived and not long-term economic development solutions. To establish comparability across the three pathways, we used WBP-FP production as the standard and set WBP-ETH and WBP-CBTL output at levels that would equalize daily energy production in megajoules (MJ) for the three pathways.

This section is divided into three subsections. We present the results and discuss IO multipliers, economic impacts, and the environmental impacts of each production pathway.

Table 4
Regional output multipliers for aggregated industries.

	Sector	Type I	Type II
1	Agriculture	1.18	1.46
2	Ag. Service	1.11	3.54
3	Logging	1.28	2.08
4	**WBP - FP**	**1.60**	**2.03**
	WBP - ETH	**1.57**	**2.00**
	WBP - CBTL	**1.30**	**1.57**
5	Mining	1.22	1.71
6	Construction	1.14	1.97
7	Other Manufacturing	1.16	1.44
8	Sawmill and Wood	1.38	1.83
9	Fabricated Metals	1.14	1.56
10	Machinery	1.14	1.61
11	Electrical Equip.	1.11	1.52
12	Wholesale	1.11	1.78
13	Retail	1.14	1.91
14	Transport	1.19	1.68
15	Truck Transport	1.20	1.83
16	Power Generation	1.18	1.47
17	Natural Gas	1.23	1.46
18	Water Sewage	1.26	1.90
19	FIRE	1.21	1.56
20	Professional Service	1.16	1.91
21	Misc. Service	1.16	1.93
22	Waste Management	1.26	1.83
23	Government	1.03	2.35
	Average FP	1.20	1.84
	Average ETH	1.20	1.84
	Average CBTL	1.19	1.82

Note: Because the only change between the three pathways analyzed are in the WBP production functions, the multipliers for the three pathways are the same for all industries but WBP. Therefore, we present them only once, differentiating the three WBP pathways, which are shown in bold.

6.1. *Multipliers*

Output multipliers are shown in Table 4, and employment and income multipliers are shown in Table 5. As described in Section 4.1, the multiplier analysis derives from the Leontief inverse and the employment and income coefficients, i.e., the ratios of total output,

Table 5
Employment and income multipliers for aggregated industries.

		Employment		Income	
	Sector	Type I	Type II	Type I	Type II
1	Agriculture	1.11	1.13	1.96	2.34
2	Ag. Service	1.02	1.13	1.02	1.22
3	Logging	1.41	1.53	1.30	1.55
4	**WBP - FP**	**5.62**	**7.18**	**2.56**	**3.05**
	WBP - ETH	**6.12**	**7.63**	**2.47**	**2.94**
	WBP - CBTL	**2.22**	**3.29**	**1.76**	**2.10**
5	Mining	1.42	2.03	1.25	1.49
6	Construction	1.12	1.42	1.10	1.31
7	Other Manufacturing	1.51	1.97	1.35	1.61
8	Sawmill and Wood	2.35	2.74	1.63	1.95
9	Fabricated Metals	1.29	1.61	1.24	1.48
10	Machinery	1.27	1.65	1.20	1.43
11	Electrical Equip.	1.28	1.75	1.18	1.40
12	Wholesale	1.20	1.59	1.12	1.34
13	Retail	1.08	1.26	1.11	1.33
14	Transport	1.60	2.22	1.29	1.54
15	Truck Transport	1.27	1.57	1.25	1.49
16	Power Generation	1.95	2.76	1.47	1.75
17	Natural Gas	1.88	2.61	1.72	2.05
18	Water Sewage	1.51	2.00	1.35	1.60
19	FIRE	1.29	1.52	1.34	1.60
20	Professional Service	1.18	1.47	1.15	1.36
21	Misc. Service	1.12	1.33	1.14	1.36
22	Waste Management	1.40	1.77	1.34	1.59
23	Government	1.02	1.39	1.02	1.21
	Average FP	1.59	2.01	1.36	1.62
	Average ETH	1.39	1.76	1.29	1.54
	Average CBTL	1.37	1.73	1.31	1.56

Note: Because the only change between the three pathways analyzed are in the WBP production functions, the multipliers for the three pathways are the same for all non-WBP industries. Therefore, we present them only once, differentiating the three WBP pathways, which are shown in bold.

Table 6
Regional sectoral output impacts of woody biomass processing (in U.S.$ million).

	Sector	Fast Pyrolysis	Ethanol	CBTL
1	Agriculture	1.3	1.4	0.0
2	Ag. Service	0.4	0.5	0.0
3	Logging	14.3	15.2	0.4
4	WBP	**208.9**	**156.0**	**106.9**
5	Mining	10.2	18.6	24.9
6	Construction	1.1	0.4	0.3
7	Other Manufacturing	7.6	12.1	0.7
8	Sawmill and Wood	7.4	7.5	0.2
9	Fabricated Metals	0.0	0.0	0.0
10	Machinery	0.0	0.0	0.0
11	Electrical Equip.	4.4	4.7	0.0
12	Wholesale	1.0	1.1	0.2
13	Retail	0.2	0.2	0.1
14	Transport	2.0	0.8	1.2
15	Truck Transport	22.6	19.8	0.9
16	Power Generation	22.3	0.4	0.3
17	Natural Gas	14.8	0.1	0.1
18	Water Sewage	0.5	0.0	0.0
19	FIRE	1.3	0.8	0.4
20	Professional Service	1.2	1.1	0.7
21	Misc. Service	3.8	3.0	0.5
22	Waste Management	0.1	0.1	0.2
23	Government	7.7	0.7	0.1
	Total	333.3	244.7	138.1

Table 7
Regional sectoral employment impacts of woody biomass processing (in numbers of jobs).

	Sector	Fast Pyrolysis	Ethanol	CBTL
1	Agriculture	69.4	73.8	2.0
2	Ag. Service	36.1	38.5	1.0
3	Logging	318.9	340.2	8.3
4	WBP	**201.6**	**157.8**	**98.7**
5	Mining	29.4	53.6	71.9
6	Construction	11.4	3.5	2.5
7	Other Manufacturing	16.4	26.3	1.5
8	Sawmill and Wood	30.8	31.4	0.8
9	Fabricated Metals	0.0	0.0	0.0
10	Machinery	0.1	0.1	0.0
11	Electrical Equip.	13.5	14.5	0.0
12	Wholesale	6.1	6.6	1.3
13	Retail	3.7	3.6	1.3
14	Transport	5.5	2.1	3.5
15	Truck Transport	169.0	147.8	6.9
16	Power Generation	28.7	0.6	0.3
17	Natural Gas	16.7	0.2	0.1
18	Water Sewage	2.3	0.2	0.0
19	FIRE	7.5	4.6	2.4
20	Professional Service	11.4	10.7	6.2
21	Misc. Service	50.5	39.8	6.9
22	Waste Management	0.7	0.5	0.9
23	Government	98.2	8.6	1.3
	Total	1127.8	965.0	218.1

employment, or income, to corresponding direct changes attributed to the specific WBP pathway. Because the WBP industry is assumed to sell all of its output as exports, there are no intraregional forward linkages, hence no pathway-specific causes of variation in other industries multipliers. This simplifies comparisons among pathways, and eliminates the need to estimate impacts from import substitution. There is variation only among WBP multipliers.

The output multiplier results include Type I and Type II multiplier values. Type I multipliers are for an open model and Type II are for a model closed with respect to households (HH). WBP-FP has the highest Type I and Type II multiplier values, at 1.60 and 2.03. This means that a $1 increase in (export) final demand would stimulate $0.60 in indirect production-related requirements and income-induced impacts add another $0.43 to the regional output impact total.

Although the output multiplier for WBP-FP is highest among the three possible pathways, the WBP-ETH pathway has the highest employment multiplier, with Type I and Type II multipliers of 6.1 and 7.6 jobs, respectively. This means that for every direct job generated in the ethanol production, there will be an additional 5.1 indirect jobs and an additional 1.5 jobs from induced income effects. The income results show the WBP-FP pathway as the one with highest multipliers, 2.56 and 3.05. Every dollar of income in this industry would result in 1.56 dollars of indirect income and an additional 49 cents of income-induced income impacts.

6.2. Economic impacts

Multiplier values are informative, but the actual magnitudes of estimates of regional output, jobs, and income generated from new activities are crucial for assessing the implications of these impacts for the regional economy. Tables 6–8 show these impacts for each sector due to the WBP shock.

Total regional output change by industry after introducing WBP can be calculated directly by pre-multiplying the three pathway final demand vectors by direct output (export final demand[11] changes for WBP-

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[11] The final demand changes are calculated using the information provided in Table A1. Because all the consumption comes from the export of its production, the final demand values are set to the energy-equalizing values of production from each WBP pathway.

Table 8
Regional sectoral income impacts of woody biomass processing (in U.S.$ million).

	Sector	Fast Pyrolysis	Ethanol	CBTL
1	Agriculture	0.108	0.115	0.003
2	Ag. Service	0.615	0.656	0.016
3	Logging	5.107	5.447	0.133
4	WBP	**20.160**	**15.776**	**9.873**
5	Mining	2.338	4.266	5.725
6	Construction	0.500	0.156	0.112
7	Other Manufacturing	0.914	1.468	0.085
8	Sawmill and Wood	1.202	1.222	0.033
9	Fabricated Metals	0.001	0.000	0.000
10	Machinery	0.003	0.004	0.001
11	Electrical Equip.	0.896	0.957	0.000
12	Wholesale	0.350	0.376	0.074
13	Retail	0.093	0.091	0.032
14	Transport	0.431	0.168	0.274
15	Truck Transport	6.669	5.835	0.273
16	Power Generation	2.602	0.052	0.031
17	Natural Gas	1.151	0.010	0.007
18	Water Sewage	0.136	0.012	0.003
19	FIRE	0.207	0.128	0.067
20	Professional Service	0.464	0.434	0.253
21	Misc. Service	1.506	1.188	0.207
22	Waste Management	0.032	0.025	0.041
23	Government	5.820	0.512	0.080
	Total	51.306	38.898	17.323

FP, WBP-ETH, and WBP-CBTL of \$208.9 M, \$156.0 M, and \$106.9 M) by the Leontief inverse matrix of multipliers for WBP for each associated pathway. We can then use the output impacts estimates by industry to compute employment and income impacts. Total output impacts range from a low of \$138.1 M for WBP-CBTL to a high of \$333.3 M for WBP-FP, employment impacts from 218.1 for WBP-CBTL to 1127.8 jobs for WBP-FP, and income from \$17.32 M for WBP-CBTL to \$51.30 M for WBP-FP. In terms of output impacts, the truck transportation, power generation, natural gas, and logging sectors are the most heavily impacted by the proposed WBP-FP. These results are similar to those calculated for the biomass resource assessment in Oregon (McNeil Technologies, I, 2003). For the WBP-ETH pathway, truck transportation, mining, logging, and other manufacturing sectors are more heavily influenced, while for WBP-CBTL, mining is the most heavily impacted sector.

Table 9
Woody biomass processing regional environmental multipliers.

	Sector	Type I	Type II
4	WBP - FP	1.380	1.393
	WBP - ETH	2.143	2.237
	WBP - CBTL	1.575	1.595

Note: Multipliers for other industries are available upon request.

The WBP-FP pathway would have the greatest employment impacts on logging, truck transportation, and government. WBP-ETH would increase employment in logging, truck transportation, and agriculture more than other sectors, and WBP-CBTL would impact mining substantially more than any other sector.

Like most such studies, the resulting income, employment, and output impacts *distributions* differ. For WBP-FP, truck transportation, government, and logging – in that order – would receive the most income. For WBP-ETH truck transportation, logging and mining income, respectively, would be most impacted, and for WBP-CBTL income, as with employment, the mining industry would see the largest gains.

Indirect and income induced impacts can be decomposed to correspond to “rounds of spending.” First round requirements are those needed by the WBP industry itself, second round requirements are those needed by WBP's suppliers, and so on. The power series representation in Eq. (4), makes the round-by-round effect evident. Fig. 2 shows

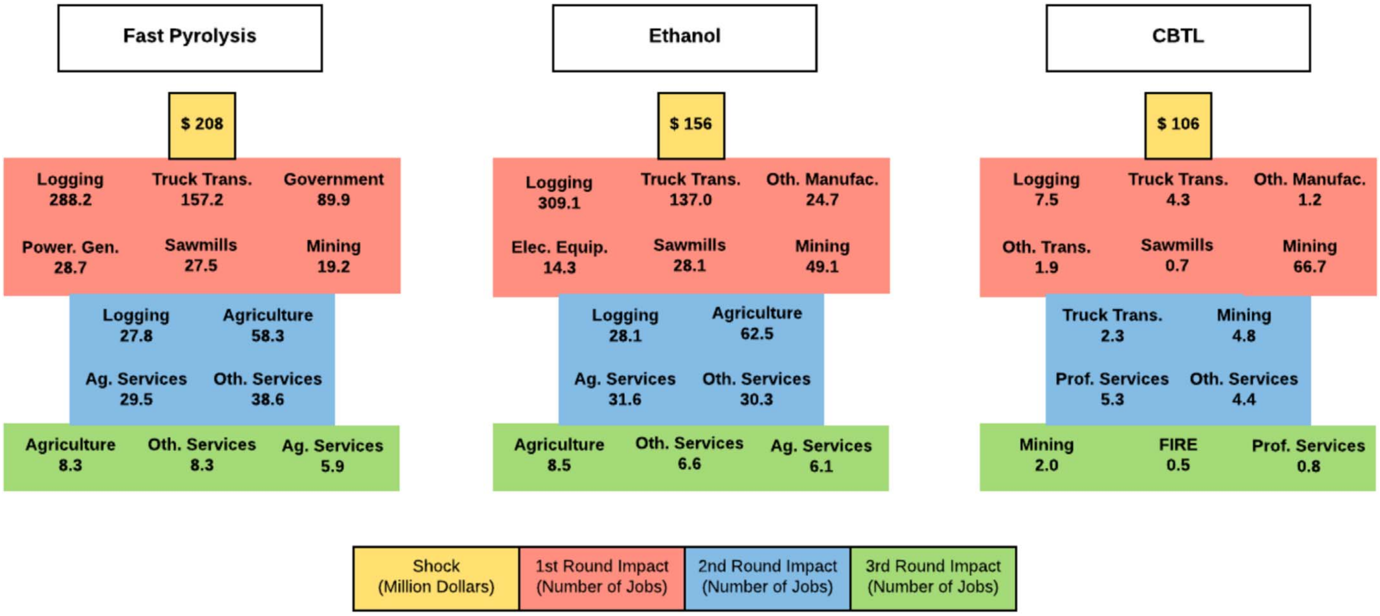

Fig. 2. Major employment impacts of woody biomass processing by spending round.

Table 10
Regional sectoral environmental impact of woody biomass processing (in tonnes).

	Sector	Fast Pyrolysis	Ethanol	CBTL
1	Agriculture	1339	1425	39
2	Ag. Service	122	130	3
3	Logging	1007	1074	26
4	WBP	**416,923**	**45,201**	**95,543**
5	Mining	21,024	38,359	51,483
6	Construction	135	42	30
7	Other Manufacturing	1655	2657	153
8	Sawmill and Wood	1010	1027	27
9	Fabricated Metals	0	0	0
10	Machinery	1	1	0
11	Electrical Equip.	186	199	0
12	Wholesale	27	29	6
13	Retail	7	7	2
14	Transport	1410	549	896
15	Truck Transport	3773	3301	154
16	Power Generation	109,793	2197	1323
17	Natural Gas	12,163	110	70
18	Water Sewage	349	31	6
19	FIRE	8	5	2
20	Professional Service	53	49	29
21	Misc. Service	163	128	22
22	Waste Management	197	154	253
23	Government	1370	121	19
	Total	572,714	96,796	150,090
	% Δ in Regional Emission	2.53	0.43	0.66
	Lower Bound CO_2 Cost (in U.S.$ million)	20.83	3.52	5.46
	Upper Bound CO_2 Cost (in U.S.$ million)	138.89	23.47	36.40

Note: Total Regional Emission pre WBP is 22,676,393 Tonne Lower and Upper bound costs are based on Moore and Diaz (2015) which are $33 and $220 per ton of CO_2.

Table 11
Traditional production vs. woody biomass processing CO_2 emissions (in thousands of tonnes).

	Model	Traditional production	WBP production	Percent difference
Fast Pyrolysis	Open model	156.0	630.8	304%
	Closed model	172.1	666.3	287%
Ethanol	Open model	279.7	102.0	−64%
	Closed model	307.1	128.1	−58%
CBTL	Open model	80.0	88.2	10%
	Closed model	88.2	201.2	128%

Table 12
WBP-to-traditional carbon-cost ratios, open model.

	Jobs	Income
Fast Pyrolysis	1.49	2.44
Ethanol	0.26	0.52
CBTL	0.73	0.83

Table 13
Pathway rankings.

Rank	Output (Highest)	Employment (Highest)	Income (Highest)	Emissions (Lowest)	Carbon-cost ratios (Lowest)
1st	FP	FP	FP	ETH	ETH
2nd	ETH	ETH	ETH	CBTL	CBTL
3rd	CBTL	CBTL	CBTL	FP	FP

graphically the employment impacts for the sectors most heavily affected by WBP in each round of impacts spending, to help visualize how the shock propagates in the economy in each pathway scenario. As expected, most of the impacted sectors are the same; however, there are some differences in the amount of the impact, especially in industries impacted in later rounds.

6.3. Environmental impacts

Among our research objectives is an assessment of WBP environmental impacts in terms of CO_2 equivalent emissions released by the region's industry in support of WBP production. To analyze environmental impacts, we use data from CEDA for all non-WBP industries, and use the LCA data provided by Liu (2015) for the WBP pathways. Tables 9 and 10 show the WBP emissions multipliers and emissions levels by industry. The WBP-ETH pathway has the highest multipliers, followed in order by WBP-CBTL and WBP-FP, yet WBP-ETH is the pathway with the lowest direct impact (Table 2). The total CO_2 equivalent emissions impact of WBP on the region is 572,714 tonne for WBP-FP, 96,796 tonne for WBP-ETH and 150,090 tonne for WBP-CBTL. These amounts would correspond to 2.53%, 0.43% and 0.66% increases in regional emissions.

Lastly, we can evaluate the existence of an economic–environmental tradeoff for these pathways, i.e., whether economic benefits come at the expense of environmental degradation. To do so, we compare the impacts of WBP to traditional production methods for corresponding WBP outputs. We use U.S. technical coefficients for this part of the analysis because we are concerned here with total system environmental impacts rather than the study-region only impacts. We know from the economic analysis that the region will gain jobs and income, but we do not know whether the environment also benefits on balance. Using estimates from Moore and Diaz (2015), however, we calculate and report in Table 10 the upper and lower bound estimates of the cost of CO_2 emissions. Combining these results with those in Table 8 reveals that the income benefits from the WBP-ETH pathway exceed the resulting environmental costs, while income from both WBP-FP and WBP-CBTL benefits lie between the estimated environmental cost lower and upper bounds.

Table 11 presents the environmental comparison results from both open and closed models. The results show that the environmental impact of WBP-FP is more than 280% higher than the traditional production of gas and diesel, and WBP-CBTL is more than 10% higher, which identifies the trade-off in terms of environmental degradation in return for economic benefit. In contrast, there is no trade-off for the WBP-ETH pathway, as both the economy and the environment benefit; total system CO_2 emission levels using this WBP pathway are 64% less than they are when produced using the traditional process. Table 12 presents the WBP-to-traditional jobs and income carbon cost ratios. WBP-FP generated nearly half again as much in CO_2 emissions per job as its traditional production counterpart, while WBP-ETH generates only about a quarter of the CO_2 emissions as in traditional production. For income, WBP-FP generates nearly 2.5 times as much CO_2 emission per income $, while WBP-ETH generates half the CO_2 emission per income $ as its traditional production counterpart. The values for WBP-CBTL are intermediate between the other two pathways, but generally more similar to WBP-ETH than to WBP-FP.

7. Implications and conclusions

This paper reports the results of an economic analysis using an IO model constructed to quantify the effects of the introduction of WBP to the economy of a distressed rural region in southern Appalachia. The hypothetical WBP facility was evaluated under three possible production pathways: fast pyrolysis (WBP-FP), ethanol (WBP-ETH) production, and coal and biomass to liquids (WBP-CBTL). In this concluding section, we discuss the implications of the results and contrast the three alternative WBP pathways.

The main economic results indicate that introducing WBP could add from $138.1 to $333.3 million dollars to the regional output per year, which, in the 2011 scenario year, would have been equal to 0.5–1.3% of total gross regional product. In terms of jobs and income, the jobs impact of introducing WBP would range from 218 to 1128, or from 0.1% to 0.7% of employment in the region; and the income gained by the labor force would range from $17.3 to $51.3 million dollars per year (0.13% to 0.37% of the income from labor force), depending on the pathway chosen. In terms of employment, WBP-FP and WBP-ETH impact the logging sector most, but the mining sector is the most heavily affected by the WBP-CBTL pathway.

Table 3 shows a pre-shock average per capita income at $32,333, and a regional unemployment rate of 8.6%. With the addition of a WBP-FP facility, there would be an increase of 1128 jobs representing 0.7% of the current participating labor force. The additional $51 M would increase per capita income by $120. For WBP-ETH, corresponding figures are 0.6% of the labor force and an extra $91 dollars per capita, while for WBP-CBTL the impacts are 0.1% of labor force and an additional $40 dollars per capita. These results rely on the simplifying and conservative assumption that all new jobs are filled by people within the region and that there is no migration shock.

One reason for the 2011 8.6% unemployment rate was the recent decline in coal industry employment. Idle coal industry workers would very likely have skills comparable to the higher-level skill requirements in a WBP facility, especially the WBP-CBTL pathway. Many other jobs would be filled by low- to medium-skilled occupations, such as maintenance and truck-driver. Hence, it is entirely possible that the locally unemployed could fill the vast majority of new worker demand.[12] Some in-migration would likely occur, of course, which would increase modestly the positive impacts on income and potentially on housing construction. Again, the goal of keeping the impacts estimates conservative supports the exclusion of migration in this analysis.

In addition to the economic impact, we measured the environmental impacts of the new sector in terms of CO_2 equivalent emissions. As a result of introducing WBP to the region, CO_2 emissions would increase by 96.8–572.7 thousand tonne, most of which would be attributed to direct WBP process emissions. These CO_2 contributions are greater than the traditional production process for the same products for WBP-FP and WBP-CBTL, but total system CO_2 from WBP-ETH is lower than traditional ethanol production on a per barrel basis.

Results from an IO analysis like this will always identify jobs and income benefits from introducing any of the three WBP pathways. Distressed rural areas like these often have few development alternatives, so such benefits cannot be discounted. Clear economic benefit, of course, should be considered in the context of negative environmental externalities (we have not attempted here to identify or assess potential externalities other than CO_2 that might be present, such as impacts on natural wildlife habitat). As shown in Section 6, there are environmental costs to all of the alternatives, but for WBP-ETH the CO_2 impact would be smaller than that from the same amount of ethanol produced via traditional production methods.

The results presented here are in line with other results in the literature, such as Aksoy et al. (2011), who report output multipliers between 1.35 and 1.43 and employment multipliers of 1.62–1.64. Whereas we omit the construction impact of the WBP facilities and focus instead on annually recurring operations impacts, others have reported impacts estimates for the construction phase of a liquid-to-biofuel facility. Lester et al. (2015), for example, find that constructing such a facility in Pitt County, North Carolina, would add 333 – 387 direct temporary jobs, with a labor income impact of $21 to $24 million and an output impact of $54 to $62 million. These estimates might be used to provide a rough indication of the associated short-run, one-time impacts for our study area.

Table 13 presents the three pathways ranked according to the five measures discussed in the paper; namely output, employment, income, CO_2 emissions, and carbon-cost ratios. These rankings suggest that WBP-CBTL is the least desired pathway as it generates less output, fewer jobs, less income, and the second highest emission levels. However, given the use of coal as one of the primary process inputs, CBTL might well be most effective in directly offsetting declines in the coal industry. WBP-FP generates more output, employment and income, but it also generates substantially more emissions and has the highest carbon-cost jobs and income ratios. If emissions can be discounted, either because environmental attainment is not an issue or because economic benefits take priority, WBP-FP is a viable alternative. But if environmental considerations dominate the decision, WBP-ETH would be the preferred pathway among the three alternatives as it is the least polluting, and generates the second highest levels of output, employment and income.

One final assessment presented here is the net contribution of each WBP pathway. How much is the new industry (WBP) contributing to the total supply of output (diesel and gasoline for WBP-FP, ethanol and diesel only for WBP-CBTL) net of its own use in the production process?[13] For every dollar worth of output, the WBP-FP pathway has a net contribution of 87 cents, while WBP-ETH has a net contribution of 75 cents and WBP-CBTL of 95 cents. This means that WBP-CBTL is the pathway that contributes the greatest portion of its product to the overall supply of output, because it uses less of its own output in its own production process.

There are two main policy implications from our results. First, while rural Appalachia is still connected to the coal industry, the decline in this industry produces an opportunity for the introduction of WBP in these regions. This is not only due to the logging and sawmills input availability, but also because the labor force that was idled by the coal industry has an appropriate skill set to fill the jobs created by WBP. This might be an opportunity to begin to break the dependency on coal in this lagging region. Second, although the economic benefits of introducing WBP may not be overwhelming, neither is the environmental cost, particularly for WBT-ETH, and especially if we assume that the product would be produced elsewhere were it not produced locally. Therefore, given the limited opportunities for economic development and the economic distress resulting from the decline of the coal industry, providing incentives for WBP in rural areas can be a viable economic option at little cost to society.

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[12] Drawing on unemployed labor for the new facility also impacts the region positively by moving some number of employees off of transfer and assistance payments and into the tax-paying, public service-supporting population. We have not attempted to capture these effects here, as modeling such changes typically lies beyond classical IO applications.

[13] This was calculated by subtracting the direct and indirect input requirement from the open Leontief inverse from 1.0.

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Appendix A

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Table A1
Economic information for each pathway.

Information	Fast Pyrolysis	Ethanol	CBTL
MJ/day (Benchmark)	14,737,370		
Days of activity	350		
Compensation per hour	50		
Hour per shift	8		
Shifts per day	3		
Barrel per day	5000	3931	2449
Price of Barrel of output	$119.38	$113.40	$124.74
Number of workers per shift	48	38	24

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

Table A2
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, 251, 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

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