CHEMICAL ENGINEERING TRANSACTIONS

VOL. 52, 2016

A publication of AIDIC

The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Peng-Yen Liew, Jun-Yow Yong, Jiří Jaromír Klemeš, Hon Loong Lam

ISBN 978-88-95608-42-6; **ISSN** 2283-9216

DOI: 10.3303/CET1652123

Input-output Based System Perturbation Analysis of the Environmental Implications of Rice Hull Utilization for Power Generation in the Philippines

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Agriculture dependent economies commonly produce low-value products relative to industrialized economies. Converting agricultural waste into electricity will increase the value of engaging such activities. However, climate change also contributes immensely to the shifts in seasons thereby effecting agricultural yield and biomass production. This study analyzes the impact of using rice hull waste into electricity generation to economic activities and carbon emissions using an input-output (I-O) approach. The I-O model is widely used for illustrating the interdependent relationship between various economic sectors. This study extends the traditional I-O model such that it links the I-O table to another table composed of further subsectors not found in the original database, providing a more detailed snapshot of activities. The Philippine case is considered, given that rice is the main staple crop. However, the volume of rice production is insufficient which causes the Philippines to import rice from neighboring countries. Despite the high level of demand for rice in the Philippines, farmers tend to shift their production to higher valued crops. Alternatively, the by-product of rice production, rice hull, is an underutilized crop residue available in large quantities which may be used for power generation. The potential electricity contribution of rice hull can either reduce the power shortage that has been going on for the last decade or displace fossil fuel based electricity, at the same time, increase the value of rice production. Hence, government can reduce rice imports and service the utility demand of its constituents.

1. Introduction

Climate change has influenced economic policies, as governments encourage electricity distributors to utilize renewable energy resources whenever possible. This has caused a shift from traditional to wind, hydro, solar and biomass as sources of energy. In the last United Nations Conference on Climate Change (COP21), the member countries committed to reducing global greenhouse gas emissions, particularly through adapting renewable energies and improving energy efficiency (COP21, 2016). With commitments made at an international level, countries have become more aggressive in adapting mitigation measures that will reduce their emission levels. The U.S. Energy Information Administration (2016) estimated a reduction in CO_2 emissions as they shifted towards renewable energy sources for the United States. Developed and developing countries have designed their feed-in tariff mechanisms to encourage the shift towards renewable energy. Couture and Gagnon (2010) provide a detailed analysis of the different models for feed-in tariffs. Hence,

Please cite this article as: Yu K. D. S., Aviso K. B., Eusebio R. C. P., Felix C. B., Mayol A. P., Promentilla M. A. B., Santos J. R., Ubando A. T., Tan R. R., 2016, Input-output based system perturbation analysis of the environmental implications of rice hull utilization for power generation in the philippines, Chemical Engineering Transactions, 52, 733-738 DOI:10.3303/CET1652123

electricity providers and households alike have began exploring the potentials of adapting such technologies. The choice of renewable energy to harness is also based on the resources available in a country. For example, agricultural economies may choose to use their agricultural waste for biomass energy. Prasara-A et al., (2012) explored the various technologies for rice husk- fuelled generators and found that some of the processes are indeed carbon neutral. In fact, all biomass derived power generation have lower carbon footprints compared to fossil energies (Čuček et al, 2012a).

Input-output (I-O) analysis has been used to measures the interindustry linkages between economic sectors based on a system of linear equations (Leontief, 1936). Given the linearity assumption, the model does not allow for substitution of inputs in producing output. It can also account for changes in the economy brought about by adapting new technology for producing goods and services in a given sector. In addition to I-O tables published by national statistical offices measure the monetary flows of goods and services in an economy, physical flows may also be considered as illustrated in Hubacek and Giljum (2003) and Suh (2004). It has been noted that physical tables include information on each sector's waste output (Dietzenbacher, 2005). While such models exist, there is a dearth in actual databases due to the difficult nature of standardizing processes as a consequence of their assumptions (Weisz and Duchin, 2006).

In addition, Life cycle assessment (LCA) is a tool for assessing the environmental impacts of goods and services (Heijungs, 1994). It summarizes the production streams into a system of linear equations which provides an inventory of inputs, outputs including emissions and wastes. It can account for the carbon emissions, nitrogen emission, and methane among others. While there are numerous indicators that can be measured, data has been a common bottleneck among researchers. Čuček et al. (2012b) proposes that through some environmental indicators are correlated up to a certain degree, hence, there is the possibility of reducing the dimensionality through multi-parametric optimization. Another method is to define composite footprints for assessing the multi-dimensional impacts (Čuček et al. 2012c). Hendrickson et al. (1997) compare economic input-output – life cycle assessment (EIO-LCA) and Ganzheitliche Bilanzierung – Integrated Assessment (GaBI), and were able to show that despite differences in foundational assumptions between the two models, the results are not too different from each other. EIO-LCA capitalizes on the existing I-O table published by the national statistical agencies and industry-specific environmental impacts to estimate direct and indirect impacts of each sector's activities (Lave et al., 1995). De Benedetto and Klemes (2009) incorporate environmental and financial indicators to produce a single measure for evaluating sustainability.

Previous studies have integrated I-O and LCA, however, this study provides a novel view such that it takes the waste from the I-O model and analyzes its commercialization through an LCA model before reintegrating it into the I-O framework to measure the changes in final demand and CO_2 emissions that may result from waste utilization.

2. Problem Statement

The formal problem statement is as follows:

- Given a system of linear equations that illustrates the interindustry linkages of economic sectors,
- Given that the economy produces agricultural waste that can be utilized as a feedstock,
- The problem is to estimate the impact of harnessing biomass feedstocks as an input for electricity generation to final demand and CO_2 emissions.

The mathematical and graphical representation of the model is provided in the next section.

3. Methodology

This study creates a hybrid model that extends the traditional I-O table and appends a sub-table that accounts for adapting new technology for producing an output of a specific sector. The I-O model is specified as:

$$\mathbf{x} = \mathbf{A}_{\mathbf{IO}}\,\mathbf{x} + \mathbf{y} \qquad (1)$$

where $\mathbf{x}$ is the total output vector, $\mathbf{A}_{\mathbf{IO}}$ is the technical coefficients matrix, and $\mathbf{y}$ is the final demand vector. The first term on the right hand side of Eq(1), $\mathbf{A}_{\mathbf{IO}}\,\mathbf{x}$, represents the intermediate demand in the economy. These are the transactions between each sector which are purchased for further processing. The second term $\mathbf{y}$ represents the transactions made for consumption of end-users such as households, firms, government and the rest of the world. The total output vector $\mathbf{x}$ takes the sum of both intermediate demand and final demand which shows the total production of the economy. Since Eq(1) presents the structure of a monetary I-O table, transactions that do not have monetary value are not in the system. Waste and emissions have not been accounted for. Thus, we propose a methodology of appending a submatrix that includes processes for converting non-valuable waste into a product for consumption of end-users.

The LCA model is used for measuring the impact of resource use and emissions generated through different processes used. We adapt the notations as discussed in Heijungs and Suh (2002). The model specification is in two parts. The first part measures the impact of production processes and is specified as:

$$\mathbf{A_{LCA}\,s = f} \tag{2}$$

where $\mathbf{A_{LCA}}$ is the technology matrix, **s** is the scaling vector and **f** is the final demand vector. It should be noted that the elements in the LCA model are denoted in physical values, such that values may be expressed in tons, kilograms among others. The technology matrix, $\mathbf{A_{LCA}}$**,** presents the required input and output produced by a given process. A negative value means that the entry is an input for production and a positive value means that it yields a certain level of output. The scaling vector, **s**, presents the values at which unit processes are scaled up or down depending on the level of final demand, **f.** The final demand vector, **f**, presents the level of goods or emissions produced as a result of each process.

The second part of the LCA model provides an inventory of emissions resulting from the production process in the first part. It is specified as:

$$\mathbf{B\,s = g} \tag{3}$$

where **B** is the intervention matrix, and **g** is the inventory vector. The intervention matrix, **B**, reflects the environmental interventions of that each process brings about. The inventory matrix, **g**, provides the physical unit of various types of emissions and waste from the different production processes.

Finally, the change in consumption of the identified sector will be factor back into the I-O model as the consumption of the good generated from waste displaces the same amount of the conventional good. As a result, it will reduce consumption of all other goods and services in the economy which is estimated as a result of rewriting Eq(1) as:

$$\mathbf{(I - A_{IO})^{-1}\,y = x} \tag{4}$$

Using carbon intensities of each sector, we can convert the reduction in consumption into reduction in CO_2 emissions.

4. Case Study

According to the World Bank (2016), 41.70 % of the Philippines land area is used for agricultural purposes. However, high population growth rates, as well as, rapid levels of industrialization have left the agricultural sector underdeveloped. Poverty incidence among households engaged in agricultural activities remains the highest in the country at 39.20 % (Philippine National Statistical Coordination Board (NSCB), 2014). This leads to the declining number of young people engaging in the agricultural industry. Siddiqi (2015) identifies that the average age of a Filipino farmer is 57, which yields issues of food security. Although rice is a staple food, the low returns of engaging in rice production has turned the country into a net rice importer in the past years. Several attempts to improve agricultural income have been made through legislation such as the Biofuels Act of 2006 and Renewable Energy Act of 2008, which are also aimed towards reduced import dependence. These policies have led to the development of the biomass industry wherein agricultural waste such as rice hull, coconut husk and bagasse that were initially a burden to dispose can now be used for power generation.

The 2000 Philippine I-O table published by the NSCB (2006) was aggregated to isolate the rice paddy, electricity and transportation sectors to show the impact on carbon emissions and power generation as a result of using rice hull as an input for power generation. Table 1 shows transactions matrix, final demand vector and total output vector for the 2000 Philippine economy.

According to the International Rice Research Institute’s (IRRI) Rice Knowledge Bank (2016), 20 % of total rice paddy output is rice hull. Prior to the emergence of biomass technologies, rice hull was disposed through burning and residue incorporation which contribute to air pollution and methane emissions (IRRI, 2016). Thus, rice hull is a potential biomass resource that can be harnessed as an alternative source of energy. As of the end of 2015, the Philippines has four rice husk-powered power plants with a total installed capacity of 47 MW, and six more under construction (Philippine Department of Energy, 2016). Based on these information, the current utilization rate of rice hull is 19.25 % or 476,992.36 tons for electricity generation. This serves as the initial input for the LCA in Table 2 which results to 15,200 tons CO_2 under the assumption that the farms where the rice hull is sourced is located 20 km away from the power plant on the average.

Table 1: 2,000 6-sector Philippine I-O Table in million pesos.

	Rice Paddy	Other Agriculture	Industrial	Services	Transport	Electricity	Final Demand (y)	Output (x)
Rice Paddy	4,428.60	114.40	94,777.82	3,454.57	-	-	2,334.13	105,109.52
Other Agriculture	3,502.58	42,866.45	441,179.44	36,467.40	-	13,283.70	82,123.42	619,422.98
Industrial	12,279.36	88,912.82	1,371,090.02	488,528.81	13,871.83	32,243.15	2,087,359.15	4,094,285.15
Services	2,298.43	23,367.36	376,282.54	264,015.54	3,547.33	6,101.46	1,821,173.33	2,496,785.99
Transport	-	41.10	17,742.14	12,742.70	-	109.83	6,815.67	37,451.45
Electricity	368.65	6,399.25	66,965.42	30,909.02	255.96	693.70	61,965.43	167,557.43
Total Input	105,109.52	619,422.98	4,094,285.15	2,496,785.99	37,451.45	167,557.43		
Carbon intensity in kg CO_2/PhP	0.0009	0.0085	0.0022	0.0013	0.3503	0.0530		

Table 2: LCA structure for rice hull electricity generation.

	Rice hull at farm	Rice hull at power plant	Electricity generated	Output	Units
Rice hull at farm	476,992.36	(476,992.36)	-	-	ton
Rice hull at power plant	-	476,992.36	(476,992.36)	-	Ton
Electricity generated	-	-	476,992,362.00	380,000,000.00	kWh
Services	-	19,079,694.48	-	15,200,000.00	kg CO2
Transport	476,992.36	(476,992.36)	-	-	Ton
Electricity	-	476,992.36	(476,992.36)	-	Ton
CO_2 emissions at average distance of 20 km	-	-	476,992,362.00	380,000,000.00	kWh

Table 3 presents the sensitivity analysis conducted for varying degrees of rice hull utilization and average distance from the farms to the power plant which is the main source of CO_2 emission for rice hull power generation since the net flux of emissions as a result of converting rice hull into electricity is zero (Vandana Vidhyut Limited, 2007). Based on a survey of existing power plants and their average distance to the farms, even if all the rice hull are sourced on an average of 140 km away, the carbon intensity of electricity sourced from rice hull is 0.0412 kg CO_2/ PhP compared to the conventional method which yields 0.3503 kg CO_2/ PhP. Given the carbon intensities as computed from the Philippine Department of Energy statistics, and operationalizing Eq(4) using the values in Table 1, we are able to compare the reduction in CO_2 emissions resulting from adapting rice hull as an input for electricity generation. A sensitivity analysis based on the utilization rate of rice hull stock is provided in Figure 2. It shows that even if there is a decrease in consumption of electricity, the reduction in carbon emissions may not be as high.

Table 3: Carbon emissions in kg CO_2 for each utilization rate and average distance from farm to power plant

Average Distance (km)	Utilisation Rate (%)					Carbon Intensity
	19.25	30.00	50.00	75.00	100.00	
20	15,200,000.00	23,688,311.79	39,480,519.65	59,220,779.47	78,961,039.29	0.0059
40	30,400,000.00	47,376,623.58	78,961,039.29	118,441,558.94	157,922,078.58	0.0118
60	45,600,000.00	71,064,935.36	118,441,558.94	177,662,338.41	236,883,117.88	0.0176
80	60,800,000.00	94,753,247.15	157,922,078.58	236,883,117.88	315,844,157.17	0.0235
100	76,000,000.00	118,441,558.94	197,402,598.23	296,103,897.35	394,805,196.46	0.0294
120	91,200,000.00	142,129,870.73	236,883,117.88	355,324,676.81	473,766,235.75	0.0353
140	106,400,000.00	165,818,182.51	276,363,637.52	414,545,456.28	552,727,275.04	0.0412

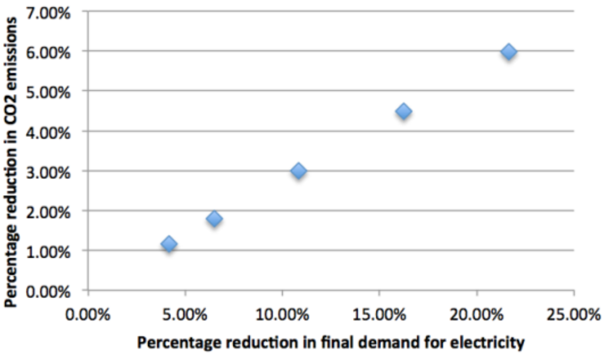

Figure 2: Percentage reduction in final demand for electricity vis-à-vis percentage reduction in CO_2 emissions.

5. Conclusions

This study was able to show that IO and LCA can be integrated to show the benefits of using waste as an input for displacing conventionally produced goods and services to reduce the emissions of an economy. This hybrid methodology allows us to compare the reduction in economic value of electricity as well as the reduction in CO_2 emissions. Using the case of the Philippines, we can infer that although reduction in consumption of electricity is high, it does not necessarily translate to high ripple effects on the reduction of CO_2 emissions each sector have varying degrees of carbon intensity. However, utilizing waste as an alternative source shows an improvement in emission levels which can contribute towards a country's commitment in agreements such as COP21. Future work may explore the application of such modelling technique to other sectors that may need agricultural waste such as transportation among others.

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