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Environmental and Economic Performances of Different Technologies for Power Generation from Rice Husks

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This work compares the environmental impacts and economic performances of different technologies for rice husk-fuelled Combined Heat and Power (CHP) generation, in Thailand. A modified integrated model for efficient biomass and bioenergy network optimisation was used based on a previous work by Čuček et al. (2012). This model accounts for the evaluation of environmental footprints and economic performance within the framework of a Life Cycle Assessment (LCA). Rice husk is considered to be one of the main sources of biomass waste in Thailand. More recently, the Thai government has promoted the use of biomass for energy purposes as a substitute for fossil fuel consumption, and to reduce the environmental impacts caused by using fossil fuels. Consequently, rice husk is being widely used for electricity generation on a commercial scale.
This contribution assesses the environmental and economic profiles of different technologies for rice husk-fuelled CHP by employing a wider spectrum of technological options, including combustion, gasification, and pyrolysis systems. The indicators analysed are the key environmental footprints associated with biomass and fossil energy sources: carbon, nitrogen, and water footprints, and are supplemented by the costs. The results show that the best option from amongst the analysed options is pyrolysis, and the use of oil as a substitute for coal in the conventional coal power plants. The aggregated single measurement of sustainability regarding different technological options, the Sustainable Environmental Performance Indicator - SEPI (De Benedetto and Klemeš, 2009), was calculated, having the advantage that the subjective weighting of environmental footprints is unrequired. The results obtained from this work can be exploited by decision makers for selecting appropriate systems in terms of environmental and economic performances.

1. Introduction

Rice husk is one of the more promising biomass sources in Thailand, as this country is one of the larger rice producers in the world. Rice husk is generated during rice processing. In 2010 Thailand produced approximately 31 Mt of rice (Office of Agricultural Economics, 2011). About 23 percent by weight of paddy rice generates rice husk (Prasertsan and Sajjakulnukit, 2006). The Thai government has advanced the use of indigenous biomass as a substitute for fossil fuels, and to reduce the environmental impacts caused by using them. In order to comply with the Thai energy policy, local biomass such as rice husk is being utilised as an energy source across the country.
At present, rice husk is being widely used in Thailand on a commercial scale as a fuel during CHP production. The most common technology being used is combustion, although there are also other

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technologies available. Economic and environmental aspects should be considered, in order to arrive at decisions about the more sustainable technologies needed for rice husk-based CHP generation.
LCA is one of the better-known tools used in environmental management. It is used to ensure that all the possible impacts of the product or service under study are accounted for in all life cycle stages. Bergqvist et al. (2008) compared the technical and economic profiles of different technologies for rice husk-based CHP generation. Nonetheless, the scope of their study only focused on the technical performances of specific devices and technologies.
This paper compares the environmental and economic profiles over a wider spectrum of different technologies for rice husk-fuelled CHP production in Thailand, such as stoker-fired combustion, suspension-fired combustion, integrated gasification combined cycle, and pyrolysis, based on the framework of LCA. In this presented work, the technological options from Bergqvist et al. (2008) were extended, and additional assessments made regarding key environmental footprints relating to biomass usage. An Environmental Performance Strategy Map (EPSM) (De Benedetto and Klemeš, 2009) was created, where different technological alternatives were graphically represented. Furthermore, SEPI was calculated, thus providing an overall indicator of sustainability for each evaluated alternative.

2. Methodology

An integrated model for efficient biomass and bioenergy network optimisation, based on previous work by Čuček et al. (2012), was modified in order for use during this study. This model was constructed based on the framework of LCA. The modified model includes the transportation of products and the production processes, but excludes agricultural parts and pretreatment since rice husk is a waste product from the milling of rice. The model was used to calculate the environmental footprints and costs of different technologies for rice husk-fuelled CHP generation. The indicators to be analysed were the main related footprints: carbon, nitrogen, and water footprints, as well as the costs. In order to ease the comparisons between the options examined, these footprints and cost values were plotted in EPSM, based on the work of De Benedetto and Klemeš (2009 and 2010). In EPSM, the volume of the pyramid represents the overall environmental and financial impacts of the option being studied. Therefore, the smaller volumes indicate smaller environmental burdens and costs. This volume is the so-called "Sustainable Environmental Performance Indicator (SEPI)" (De Benedetto and Klemeš, 2009). The system's boundary for this study is shown in Figure 1.

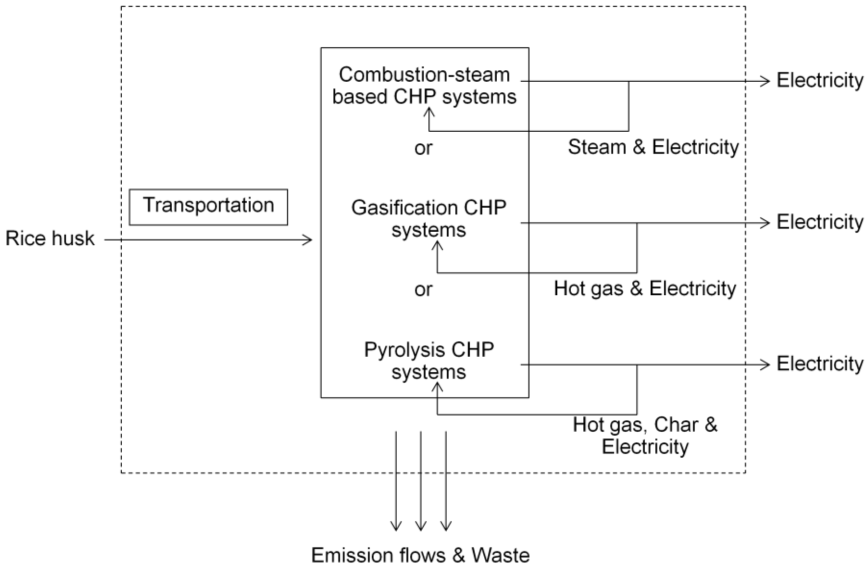

Figure 1: System boundary

The functional unit set for all the technological options examined during this study was the processing of 200,000 t/y rice husks. A functional unit was used as a basis for comparison across all the studied options.

3. Descriptions of Case Study

3.1 Combustion

Combustion technology is well-established and has been widely-used for CHP generation from biomass in Thailand. It is the most common technology used in the Thai rice husk-based power plants on a commercial scale (Energy Policy and Planning Office, 2011). It has been reported that stoker-fired boiler plants are the most common systems used to generate power from rice husk (Witchakorn and Bundit, 2004).

In the combustion system, rice husk is used as a fuel in the boiler furnace. Apart from the commonly used technology such as stoker-fired boilers, a newly-introduced technology such as suspension-fired boilers has also been established within Thai rice husk-based CHP production. These two technological options were taken into account for comparison.

3.2 Gasification

The combustible gas produced using a gasifier can be used within prime movers (gas engines, gas turbines, fuel cells) to generate electricity. One of the advantages of using gasification technology during power generation is that it has higher generation efficiency compared to combustion technology (Dinkelbach, 2000). In Thailand, gasification technology for CHP production from biomass exists. However, it is sparsely used amongst rice husk-based power plants, compared to direct combustion. At present, there are only a few small rice husk-based power plants using gasification technology, as it is still at the demonstration stage (Assanee and Boonwan, 2011). The integrated gasification combined cycle is an interesting option as it has higher efficiency. Hence, this option was chosen for the presented examination.

3.3 Pyrolysis

In Thailand, rice husk pyrolysis technology for CHP production is not yet established. Current research has found that fast pyrolysis technology has a potential for CHP production (BTG Biomass Technology Group, 2012). In fast pyrolysis processes, the main product is pyrolysis oil. The experimental results of Ji-lu (2007) showed that rice husk can produce up to 56 wt% of pyrolysis oil. The combustion of pyrolysis oil has been tested for heat production on a large scale, including co-firing in power plants. Tests for operating diesel engines and gas turbines using pyrolysis oil have been successful. Hovewer, its application for larger scale diesel engine systems is being developed (Chiaramonti et al., 2007). The gas produced has a medium heating value and can be used to provide heat during the pyrolysis process, or it can be extended to other applications such as feed-drying. Char can be sold or used to provide process heat (Bridgwater et al., 2002).

The distinguishable advantage of using pyrolysis technology during CHP generation is that the pyrolysis oil produced can be stored and transported to power-generating sites. However, as the pyrolysis technology is still at the development stage, it is currently less economically viable compared to other established technologies such as combustion and gasification (Bridgwater et al., 2002). Another interesting option is the context of using pyrolysis oil within existing conventional power plants. Therefore, this option was chosen for the presented study. The usage of pyrolysis oil as a substitute for coal in conventional coal power plants was chosen for examination, as these are the highest polluting power plants.

4. Results and discussion

4.1 Conversion factors for electricity generation

The final product was assumed to be electricity only, yet the co-products were also used during the processes to provide energy for power generation. The co-products generated from the studied systems were steam (combustion systems), hot gas (gasification and pyrolysis systems), and char (pyrolysis systems). The conversion factors for electricity generation regarding each option examined

are shown in Table 1. These factors were calculated based on data from different literature sources. These values were used to calculate the environmental footprints, and costs for each system. Specific literature sources used for each studied system are described in detail in section 4.2.
It can be seen that the conversion factors varied across the different technologies. This is the case because different technological options have different efficiencies. The integrated gasification combined cycle had the highest conversion factor because of having the highest generation efficiency compared to the other examined options.

Table 1: Conversion factors for electricity generation in MWh per t of rice husk (RH)

	Combustion		Gasification	Pyrolysis
Products	Stoker-fired	Suspension-fired	Integrated gasification combined cycle	Pyrolysis oil substitutes for coal
Electricity (MWh/ t RH)	0.847	0.919	1.587	0.904

4.2 Specific environmental footprints and costs for different systems

Specific environmental footprints were calculated based on data from different sources. Combustion systems' data were taken from Chungsangunsit et al. (2010) and Prasara-A (2010), gasification systems' from Henchobdee et al. (2011), and pyrolysis systems' from Fan et al. (2011) and Manyele (2007). As emission data for using pyrolysis oil produced from rice husk in CHP production were unavailable, data for oil produced from wood were used instead.
Costs consisted of transportation, raw materials, investment, and operating costs. The costs for all options were calculated based on data from different sources. The costs for the combustion and gasification systems were taken from Bergqvist et al. (2008), and for pyrolysis from Islam and Ani (2000). The costs of pyrolysis oil produced from rice husk, available from Islam and Ani (2000), varied depending on plant capacity. Hence, the most economically viable capacity, i.e. 1,000 kg (of rice husk fed)/h was selected for usage during the analyses. The rice husk costs were taken from the Energy for Environment Foundation (2011). The transportation costs was taken from Bhattacharya et al. (1999) and Bridgwater et al. (2002). The cost data from different sources were in different currencies, and from different years. In order to make them all comparable, all cost data were expressed as the year 2010 THB (Thai baht). 1 THB is equal to approximately 0.03 USD (July 2012). Specific environmental footprints and costs for the different systems studied are shown in Table 2.

Table 2: Specific environmental footprints and costs for different systems

Options	Carbon footprint (kg CO_2-eq/ (t RH))	Nitrogen footprint (kg N/ (t RH))	Water footprint (m^3/ (t RH))	Cost (year 2010 THB/ (t RH))
Combustion (stoker)	1,437	0.35	5.04	2,345
Combustion (suspension-fired)	1,369	0.58	5.47	2,384
Gasification (integrated gasification combined cycle)	896	0.172	12	3,843
Pyrolysis (Pyrolysis oil substitutes for coal)	94.12	0.0060	79.92	6,006

The values in Table 2 were inserted within the modified integrated model for efficient biomass and bioenergy network optimisation based on previous work of Čuček et al. (2012). The absolute indicator values for processing 200,000 t/y of rice husk in all the studied system options were obtained from the model. However, they were expressed in different units that were impossible for comparison. The absolute indicator values were therefore normalised into relative indicator values that were dimensionless, and therefore allowed comparisons between options. In order to simplify the comparisons, the relative indicator values were plotted in the EPSM, and SEPI was calculated for each option. The EPSM created from the results obtained from this study is shown in Figure 2. The volume of pyramids (SEPI) calculated for combustion (stoker-fired), combustion (suspension-fired), integrated gasification combined cycle and pyrolysis options were 0.12, 0.20, 0.09, and 0.04, respectively. It is clear that the pyrolysis option showed better performance over other options, as it has the lowest SEPI.

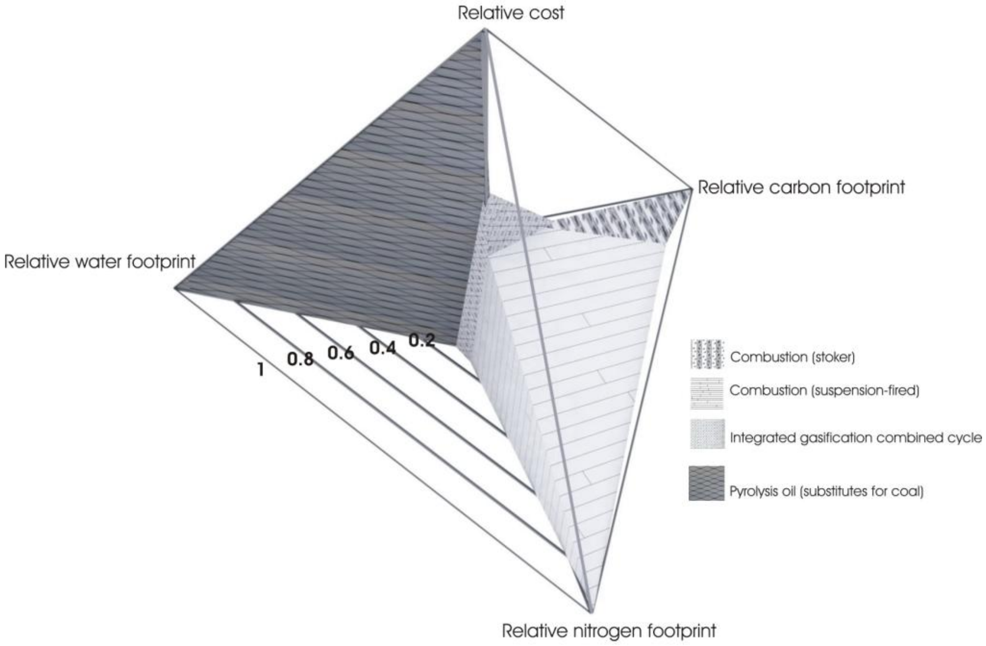

Figure 2: EPSM created from the results obtained from this study

5. Conclusions

An integrated model for efficient biomass and bioenergy network optimisation was modified in order to calculate the footprints and costs for different technologies regarding rice husk-fuelled CHP production. These absolute footprint and cost values were normalised into relative values, and then plotted in the EPSM. The results showed that the pyrolysis option was the best option from amongst all the options examined. The results can be used as supporting information for decision making about appropriate biomass technology. However, a weighting of the results has not yet been undertaken.

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References

Assanee, N., Boonwan, C., 2011, State of The Art of Biomass Gasification Power Plants in Thailand, Energy Procedia, 9, 299-305.

Bergqvist, M.M., Wardh, K.S., Das, A., Ahlgren, E.O., 2008, A techno-economic assessment of rice husk-based power generation in the Mekong River Delta of Vietnam, International Journal of Energy Research, 32(12), 1136-1150.

Bhattacharya, S.C., Arul Joe, M., Kandhekar, Z., Abdul Salam, P., Shrestha, R.M., 1999, Greenhouse-gas emission mitigation from the use of agricultural residues: the case of ricehusk, Energy, 24(1), 43-59.

Bridgwater, A.V., Toft, A.J., Brammer, J.G., 2002, A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion, Renewable and Sustainable Energy Reviews, 6(3), 181-246.

BTG Biomass Technology Group, 2012, Fast Pyrolysis <www.btgworld.com/index.php?id=22&rid=8&r=rd> accessed 4.01.2012

Chiaramonti, D., Oasmaa, A., Solantausta, Y., 2007, Power generation using fast pyrolysis liquids from biomass, Renewable and Sustainable Energy Reviews, 11(6), 1056-1086.

Chungsangunsit, T., Gheewala, S.H., Patumsawad, S., 2010, Emission Assessment of Rice Husk Combustion for Power Production, International Journal of Civil and Environmental Engineering, 2(4), 185-190.

Čuček, L., Varbanov, P., Klemeš, J., Kravanja, Z. 2012, Total Footprints-Based Multi-Criteria Optimisation of Regional Biomass Energy Supply Chains, Energy, doi: 10.1016/j.energy.2012.01.040.

De Benedetto, L., Klemeš, J., 2009, The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process, Journal of Cleaner Production, 17(10), 900-906.

De Benedetto, L., Klemeš, J., 2010, The Environmental Bill of Materials and Technology Routing: an integrated LCA approach. Clean Technology and Environmental Policy, 12(2), 191-196

Dinkelbach, L., 2000, Thermochemical Conversion of Willow from Short Rotation Forestry, Netherlands Energy Research Foundation.

Energy for Environment Foundation, 2011, Biomass Prices, Energy for Environment Foundation <www.efe.or.th/efe-book.php?task=25> accessed 12.02.2012

Energy Policy and Planning Office, 2011, Data on IPP, SPP, VSPP <www.eppo.go.th/power/data/index.html> accessed 13.01.2012

Fan, J., Kalnes, T.N., Alward, M., Klinger, J., Sadehvandi, A., Shonnard, D.R., 2011, Life cycle assessment of electricity generation using fast pyrolysis bio-oil, Renewable Energy, 36(2), 632-641.

Henchobdee, O., Kheawhom, S., Satayaprasert, C., 2011, Life Cycle Assessment of Biomass-based Intergrated Gasification Combined Cycle (IGCC) System from Agricultural Residues in Thailand, paper presented to the 4th Annual PSU Phuket Research Conference 2011, Prince of Songkla University, Phuket Campus, 16-18 November, <www.conference.phuket.psu.ac.th/PSU_OPEN_WEEK_2008/data/sci/1_27.pdf> accessed 10.01.2012 (in Thai).

Islam, M.N., Ani, F.N., 2000, Techno-economics of rice husk pyrolysis, conversion with catalytic treatment to produce liquid fuel, Bioresource Technology, 73, 67-75.

Ji-lu, Z., 2007, Bio-oil from fast pyrolysis of rice husk: Yields and related properties and improvement of the pyrolysis system, Journal of Analytical and Applied Pyrolysis, 80(1), 30-35.

Manyele, S.V., 2007, Life cycle assessment of biofuel production from wood pyrolysis technology, Educational Research and Review, 2(6), 141-150.

Office of Agricultural Economics, 2011, Agricultural Production <www.oae.go.th/ewt_news.php?nid=9749> accessed 28.02.2012

Prasara-A, J., 2010, Comparative Life Cycle Assessment of Rice Husk Utilization in Thailand, RMIT University, Melbourne, Australia, <researchbank.rmit.edu.au/eserv/rmit:6782/PrasaraA.pdf> accessed 24.07.2012

Prasertsan, S., Sajjakulnukit, B., 2006, Biomass and biogas energy in Thailand: Potential, opportunity and barriers, Renewable Energy, 31(5), 599-610.

Witchakorn, C., Bundit, E., 2004, Sizing and Location of Electricity Power Generation from Rice Husk in Thailand, paper presented to 19th World Energy Congress, Sydney, Australia, <www.worldenergy.org/documents/congresspapers/charusiriw0904.pdf> accessed 24.07.2012