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Carbon Capture Utilization Potential in Malaysia

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Abstract. Under the Paris agreement, Malaysia has set its target of reducing greenhouse gas emissions by 45% by 2030 (35% of which is on an unconditional basis), having 2005 as the base year. Carbon capture and utilization, together with an increased use of renewable energy sources, will be one of the main pillars of the national policy towards achieving this goal. Malaysia produces on an annual basis more than 100 million tons of biomass and is the second largest palm oil producer in the world. Thus, the focus of this study is the biogenic sources of carbon dioxide, and more specifically biomass power plants and palm oil mill effluent-based biogas power plants, operating at different scales across the country. Our objective is to map the existing carbon sources as well as the potential carbon receivers as many as possible (in both regions, East and West Malaysia), estimate the annual amount of produced carbon dioxide and identify the most economically viable business models for the development of symbiotic schemes based on the capture and reuse of carbon dioxide.

Keywords: Industrial Symbiosis, Carbon Capture Utilization, Malaysia, Biogenic Sources

1. Introduction

Carbon Capture, Utilization (CCU) and Storage (CCS) have been rapidly developing worldwide, as strategies to reduce the carbon dioxide emissions at a global scale. Both approaches are based on capturing carbon dioxide (CO_2) from industrial sources and then transporting it to an endpoint. In the case of CCS, CO_2 is stored an underground geological formation, whereas in CCU the potential receivers are using CO_2 (either directly or as supplementary resource) to produce several commodities.

Global warming represents a significant environmental issue for Southeast Asia, including Malaysia, where annual CO_2 emissions have increased from 57.8MtCO_2 in 1990 to 248MtCO_2 in 2019, with major contributor from energy industries with more than 55% of the total emissions (Othman et al., 2009). The per capita emissions in the same period increased from 3.11 to 7.67 tCO_2 (MNREM, 2015).

Based on the Intended Nationally Determined Contribution of the Government of Malaysia, the country needs to reduce by 2030 the carbon emissions intensity to 45% relative to that of 2005. The implementation of CCS in Malaysia is not extensive although a series of surveys have been conducted to assess the potential at national level (Muhd Nor, et al., 2016). There are currently two existing commercial-scale CCS-related projects:

- The K5 Strategic Technology Project, implemented to tackle the concerns associated with the CO2 emission of petroleum extraction in shallow waters off Sarawak.
- The TNB Jana Manjung Project, which captures approximately 8.5-9.5 MtCO2 per annum, from a coal-fired power station in Perak and then compressed and transported to offshore Terengganu for geological storage.

The CCS implementation is in line with the goal of Transformasi Nasional 2050 (TN50) in positioning Malaysia as one of the top 20 biggest economies at a global scale, and a model state for management issues related to climate change by providing affordable and clean energy by 2050 (Jorat, et al., 2018).

At the same time, CCU has not been extensively studied, although it could potentially complement the CCS activities towards mitigating the effects of CO_2 emissions. The objective of our study is to apply a three-step top-down methodological approach, developed by Patricio et al. (2017), to assess the CCU potential in Malaysia.

In the first step, the qualitative and quantitative characteristics of the regional carbon sources are collected, focusing on the type of the industry, the amount of the carbon emission and their expected purity. The list of relevant plants by industry in the selected region are mapped according to their coordinates. In the second step, the matrix of potential CO_2 receiving industries is developed. Such industries are characterized by the annual maximum CO_2 uptake, the required purity and their availability in the selected region. The maximum uptake is estimated based on the conversion factors proposed by Patricio et al. (2017), whereas the purity for each process assessed is retrieved based on Pieri (2018). The final step involves matching of CO_2 sources with their potential receivers on a case by case basis. The factors that are included, are mainly focused on the economical and geographical parameters.

2. Biogenic CO_2 Sources

This study focuses on the biogenic carbon sources in Malaysia, and more specifically the power generation sector. The CO_2 sources are defined as the industrial sites that use biomass-related materials as fuel and produce CO_2 during the combustion process. The typical composition of the flue gases from such process is nitrogen, carbon dioxide, carbon monoxide, hydrogen halides, nitrogen oxides, sulfur, and hydrogen sulfide. The industrial sites are classified according to the type of feedstock used as fuel. The categories of the feedstocks that are assessed in this study are presented in Table 1.

Table 1 Feedstock Categories

Category	Waste type	Feedstock
Biomass	Agricultural waste	Empty Fruit Bunch (EFB)
	Industrial waste	Wood chips
	Livestock farming	Chicken manure
Biogas	POME	POME biogas

The amount of CO_2 emitted can be either retrieved from online databases or estimated using emission factors. In this study, the second option has been selected. Through literature review, it was concluded that that there were limited comprehensive studies on the emission factors of Malaysian biomass-based power plants.

Table 2 Feedstock Emission Factors

Category	Feedstock	EF_e (tCO_2/MWh)
Biomass	EFB	1.111
	Wood chips	1.302
	Chicken manure	0.760
Biogas	POME biogas	1.466

Thus, these have been estimated for the purposes of our study for biomass and biogas feedstock (Table 2), based on the nature of the local feedstock and previously published studies (Olisa & Kontigo (2014), EPA (2018), de Graaff, Odegard, & Nusselder, (2017) and Cuellar & Webber (2008)).

3. Mapping Industrial Activity

Malaysia is separated by the South China Sea into two regions, Peninsular Malaysia, and Borneo's East Malaysia. Both regions have been examined in this study, but the proposed business models are examined for each island separately, as it is not economically viable to transport CO_2 via ship for such a short distance.

East Malaysia comprises of Sabah, Sarawak, and Labuan. Sabah and Sarawak together consist of 20.6% of the country's total population. Both states are in the process of shifting from primary commodity economy to industry-based economy. Labuan is a small industrial island located off the coast of Sabah. A total of 81 biomass-related industrial sites have been identified in East Malaysia (Figure 1). Among these industrial sites, 22 are EFB-based power plants and 53 are POME-based biogas plants. Four wood waste biomass power plants and a chicken manure biomass power plant existed. Based on the proposed emission factors, it was estimated that approximately 3.5 $MtCO_2$ is produced from these plants each year. There are also 6 potential CO_2 receivers in the region. 3 of which are methanol production facilities, 2 are urea production facilities, and an algae cultivation facility.

Western or (Peninsular) Malaysia consists of 11 out of the 13 states, including the capital city, Kuala Lumpur. It is more densely populated compared to East Malaysia, since it covers 40% of the total country area but its population reaches 80% of the total population. A total of 144 biomass-related industrial sites have been identified in the region (Figure 1). Among these industrial sites, 32 are EFB-based power plants and 104 are POME-based biogas plants. Three wood waste biomass power plants and five landfill gas power plants are also mapped. Based on the proposed emission factors, it was estimated that approximately 3.4 $MtCO_2$ was produced from these plants each year. There are also 6 potential CO_2 receivers in the region, involving sugar and urea production facilities.

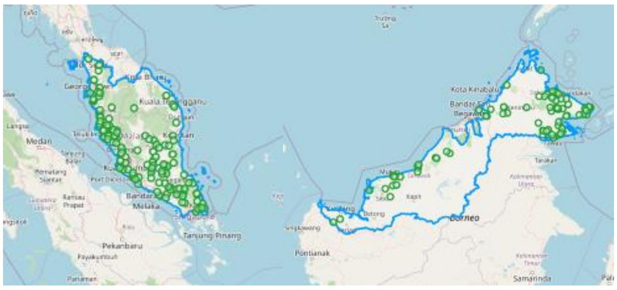

Figure 1 Mapping biogenic CO_2 Sources in Malaysia

4. Proposed Business Models

In East Malaysia, the majority of the CO_2 sources are located in a higher density on the east coast of Sabah, This could be due to the thriving palm oil industry in the region.

However, the six potential receivers are in the west coast of the region. Based on the economic feasibility analysis, the most promising symbiotic opportunity is between the Sipitang (Sabah Forest) Biomass Plant and the neighboring receivers (ammonia, urea or methanol plants). There are industries which are in less that 5km of the source, making a pipeline connection possible. The proposed link if implemented could result in a reduction of CO2 emissions by 0.8MtCO_2 per annum, which corresponds to more than 20% of the annual emissions of East Malaysia.

The propose symbiotic schemes follow a different model in West Malaysia. In this case, there is not a dominant source which can supply various receivers. However, there are various smaller sources, which are in proximity between themselves and could potentially develop a regional CCU hub, which can collect all the streams and distribute them appropriately inland or ship them. The total amount of emissions that could be captured and reused does not exceed 0.3 MtCO_2, at this first instance. However, based on the location of the CCU hub, more feasible capture schemes might arise due to reduced distance and cost. The nature of the potential symbiotic schemes in this region (smaller in size and scattered) creates a greater uncertainty in terms of the future development of CCU in this region but also offers more flexibility towards the selection of the best scheme.

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References

Cuellar, A. D., & Webber, M. E. (2008). Cow power: the energy and emissions benefits of converting manure to biogas. *Environmental Research Letters*, 3(3). https://doi.org/10.1088/1748-9326/3/3/034002

de Graaff, L., Odegard, I., & Nusselder, S. (2017). LCA of thermal conversion of poultry litter at BMC Moerdijk. Delft: Netherlands

EPA. (2018, March 9). Emission Factors for Greenhouse Gas Inventories. Retrieved March 12, 2020, from United States Environmental Protection Agency (EPA): https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf

Jorat, M., A. Aziz, M., Marto, A., Zaini, N., Jusoh, S., & Manning, D. A. (2018, December). Sequestering Atmospheric CO2 Inorganically: A Solution for Malaysia's CO_2 Emission. *Geosciences*, 1-14. https://doi.org/10.3390/geosciences8120483

Olisa, Y. P., & Kontigo, K. W. (2014). Utilization of Palm Empty Fruit Bunch (PEFB) as Solid Fuel for Steam Boiler. European *Journal of Engineering and Technology*, 2(2)

Othman, M.; Zakaria, R.; Fernando, W. (2009) Strategic Planning on Carbon Capture from Coal Fired Plants in Malaysia and Indonesia: A Review. *Energy Policy*, 37, 1718–1735.

Ministry of Natural Resources and Environment Malaysia. Malaysian Biennial Update Report to the UNFCCC. 2015. Available online: https://unfccc.int/files/national_reports/non-annex_i_parties/biennial_update_reports/application/pdf/malbur1.pdf (accessed on 13 November 2018).

Muhd Nor, N., Selamat, S., Abd Rashid, M., Ahmad, M., Jamian, S., Sia, C., Yokoyama, S. (2016). Carbon Sequestration and Carbon Capture and Storage (CCS) in Southeast Asia. *Journal of Physics.* https://doi.org/10.1088/1742-6596/725/1/012010

Patricio, J., Angelis-Dimakis, A., Castillo-Castillo, A., Kalmykova, Y., & Rosado, L. (2017). Region prioritization for the development of carbon capture and utilization technologies. *Journal of CO2 Utilization*, 50-59. https://doi.org/10.1016/j.jcou.2016.10.002

Pieri T, Nikitas A, Castillo-Castillo A, Angelis-Dimakis A. Holistic Assessment of Carbon Capture and Utilization Value Chains. *Environments.* 2018; 5(10):108. https://doi.org/10.3390/environments5100108