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Powering electric cars in Malaysia with green electricity produced from oil palm biomass

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Abstract. Generation of electricity and transportation in Malaysia are largely dominated by fossil fuel sources. These non-renewable fossil fuel sources generate approximately 0.77 kgCO2eq for every kWh of electricity generated and 2.31 kgCO2eq per liter of petrol for every kilometer traveled by a typical car contributing adversely to global warming. A possible solution to promote green electricity generation and reduce fossil fuel utilization is to use oil palm biomass to generate electricity to power electric vehicles (EVs) in Malaysia. With 454 palm oil mills (POMs) processing a total capacity of 112,187,800 tons of oil palm fresh fruit bunches (FFB) per year, there is ample source of oil palm biomass available in Malaysia. Each ton of FFB produces biomass waste of 7% palm kernel shell (PKS), 14% palm mesocarp fiber (MF) and 23% empty fruit bunch (EFB). By storing and transporting this excess electricity in a mobile energy storage system to power EVs in Malaysia, CO2 emission reduction of 0.9 tCO2eq per EV per year can be realised, and may be a cheaper alternative to fuelling up with gasoline by 2030.

1. Introduction

In Malaysia, there is an abundance of biomass generated from POMs and harnessing this energy to generate green electricity could be the answer to reducing CO2 emission. As of December 2017, there are 454 POMs in Malaysia with a total processing capacity of 112,187,800 tons of oil palm fresh fruit bunches (FFB) per year [1]. In general, 1 ton of FFB contains 21% crude palm oil (CPO), 6% palm kernel cake (PKC), 7% palm kernel shell (PKS), 14% palm mesocarp fiber (MF) and 23% empty fruit bunch (EFB) [2].

Actual case studies done in Malaysia have shown that POMs with processing capacities of 30 tons FFB per hour can generate adequate biomass amounts to produce power up to 5 MW per month [3]. With 454 POMs across the country with similar or higher FFB processing capacities, there is great potential for oil palm biomass to generate large amounts of electricity for the nation.

1.1. Barriers harnessing electricity directly from POMs

Despite numerous policies and incentives introduced by the government to encourage uptake in generating electricity from renewable energy (RE) sources, this great biomass potential has largely gone untapped. The main reasons are many POMs are located far away from the main grid system and installation cost of new electricity distribution inter-connection cost USD 312,500 per kilometre [4].

A study done by Umar et al. [5], showed that 63% of 170 POMs surveyed across Malaysia were located more than 10km from the nearest grid connection point. The construction of transmission lines to connect remote POMs to the main grid would require huge infrastructure investment by the POM license holders hence increasing cost of generating electricity from oil palm biomass.

1.2. Barriers to the uptake of EVs in Malaysia

Malaysia's idea on reducing CO2 emission from the transport sector began in 2009 with the launching of the National Automotive Policy (NAP) and the National Green Technology Policy to promote the usage of EVs in the country. Despite these efforts, the uptake of EVs in Malaysia is still very poor compared to other countries such as China, US and Norway. To date, there are only a few hundred EVs on Malaysian roads and these EVs are mainly owned by government departments and large corporate companies.

The reasons for this slow uptake of EVs among Malaysians are due to a few factors. The price of EVs is still higher than conventional internal combustion engine vehicles (ICEVs), making it less affordable for many low and middle-income families in Malaysia. The unavailability of EV charging stations in non-urban areas and along highways is a great inconvenience factor deterring many Malaysians from owning an EV. For urban dwellers, the inconvenience of having to spend close to an hour to charge an EV is another inconvenience factor contributing to the slow uptake of EVs in Malaysia. Better EV fast charging stations (EVFCSs) are required to overcome this barrier.

2. Methodology & Assumptions

The assumptions taken in this proposal is based on a POM with a capacity of processing 30 tons FFB per hour, operating for a total of 4380 hours per year. This POM capacity was used because majority of POMs in Malaysia operate at 30 tons FFB per hour or more. The combined heat and power (CHP) system in the POM is based on existing technology without any additional modifications. EVs mentioned in this proposal are battery electric vehicles, and have an average battery capacity of 30kWh with mileage efficiencies of 21kWh per 100km. Feasibility analysis and CO2 calculations are based on utilization of the POMBatt at EVFCSs at strategic locations along Malaysian highways and do not account for urban locations.

2.1. Literature Study and Verification of Excess Electricity Availability at POMs

Detail literature study was conducted on the potential of producing energy from oil palm biomass in Malaysia. One such study conducted by Wu et al. [6] simulated optimized energy generation based on a conventional CHP plant using different oil palm biomass combinations showed that all combinations produced enough electrical power and heat to meet the energy demand for POM downstream processes, with potential extra energy of 8 GWh annually. Another study conducted by Suzuki et al. [7] found that oil palm biomass alone could contribute 3.8 times of total electricity supply for Sabah in 2010. A study done at the BELL-KSL Lorong Sua Manggis POM showed potential surplus electricity amounting to 17 GWh annually when MF, EFB and PKS was utilized as fuel in the CHP system [3].

Aspen Plus V8.8 was used to verify the calculated excess electricity generated by the selected oil palm biomass in this proposal.

2.2. Oil Palm Biomass Selection

For every ton of FFB processed in a POM, the ratio of MF, PKS and EFB produced are 0.13, 0.06 and 0.23 respectively [2]. Majority of POMs in Malaysia use 70% of MF and 30% of PKS in their CHP system. This trend is seeing a shift towards utilizing more EFB since PKS is being increasely exported to Japan and Korea as biomass fuel for power plants at these countries. EFB is also widely sold-off to biomass pellet producers and used as mulching agents at oil palm plantations. For this proposal, all of the MF and 50% EFB produced in the POMs downstream processes is assumed to be consumed as biomass fuel in the POMs CHP system. The reason for not utilizing all if the EFB produced is to compensate for EFB having other income generating use for POM owners.

2.3. Battery Type Selection for the POMBatt
Lead Acid and Lithium-ion (Li-ion) batteries are the two leading battery types used for energy storage. Levelized cost of electricity (LCOE) for both these batteries was analyzed in this proposal. Listed below were the assumptions used for LCOE calculations:

- LCOE was calculated for 3000 charge cycles
- Current price of batteries (2018) were used [8]
- Lead Acid capacity rating factor (Cf) for 12 hours = 0.889 [9]
- Li-ion capacity rating factor (Cf) for 12 hours = 1 [9]
- Number of usable cycles for Lead Acid is taken as 750 with depth of discharge (DoD) of 80%
- Currency conversion rates: 1USD = RM3.623 (Average conversion rate based on conversion values from 2010-2018) [10]
- Multiplication Factor (Mf) = (1/DoD) x (1/Cf) x Number of batteries to get 3000 Cycles
- Total Cost = Cost/kWh x Mf
- LCOE = Total Cost / 3000 cycles

3. Results & Discussion

3.1. Availability of Excess Electricity from POMs
Based on optimized simulations done in Aspen Plus V8.8, a POM with a capacity of processing 30 tons of FFB per hour, utilizing all MF and 50% of EFB produced from POM downstream processes, can generate an excess electricity of 295 kWh. This result is comparable with analysis done by Nasution et al. [11], where 300 kWh was obtained for the same type of biomass feedstock. With an assumption that the POM operates 12 hours per day, 3540 kWh of total gross excess electricity is available per day. By considering up to 10% fluctuations in FFB yield on a yearly basis and 5% losses in the AC to DC converter to charge the POMBatt, the net available excess electricity to charge the POMBatt is 3000kWh per day.

3.2. POMBatt Battery Type and Capacity
The LCOE per battery charge cycle calculated for Lead Acid and Li-ion batteries are RM0.82 and RM0.25 respectively. Li-ion batteries are selected for the POMBatt due to its higher energy density, longer charge cycles, lower maintenance requirements, smaller size and lower LCOE.

In EVs, it is recommended to have a State Of Charge (SOC) of 70% for fast charging Li-ion batteries [12], making maximum charge requirement for each EV to be 21 kWh. Assuming each EV owner takes a total of 30 minutes (actual charge time is 24 minutes with 50kW fast charger) from entering to exiting the EVFCS, an EVFCS operating for 12 hours per day can service a maximum of 24 cars, requiring a POMBatt that can deliver a net of 504 kWh per day. The POMBatt is also needed to supply energy for display panels and lighting needs at the charging points in the EVFCS. This is estimated to be 20kWh per day per fast charging point.

With recommended 80% DoD for Li-ion batteries [13], each POMBatt is sized at 750 kWh to comfortably fast charge 24 EVs each day. Based on available net excess energy of 3000 kWh at the POM, the optimized POMBatt design will consist of 4 battery packs with each pack having a power rating of 150 kW and energy rating of 750 kWh. This allows for each pack to be connected to a charging point at the EVFCS allowing 4 EVs to fast charge independently at the same time without adding additional burden to the other battery packs. Currently in Malaysia, fast chargers are rated at 22 kW [14]. The rating of most fast chargers in US, China, Japan and Europe is currently 50 kW [15] and expected to move up to fast chargers with ratings of 150 kW by 2020 [16]. Taking this into consideration, each POMBatt is rated at 150 kW to allow for future fast chargers to be used with it. At maximum (100%) utilization of the EVFCS, a total of 96 EVs can be charged per day.

Designing the POMBatt as one large unit (3000 kWh) will pose problems in terms of increased charging time per EV. With a power rating of 150 kW, energy batteries like the POMBatt are designed to last longer by releasing energy at the rated power for long periods of time. If 4 EVs simultaneously utilized one large POMBatt, the battery compromises its power by reducing the amount of energy it releases to each car, hence lengthening charging time. Utilizing a 150 kW fast charger, it will take a 30 kWh rated EV battery 10 minutes to charge, but this increases to 35 minutes when there are 4 EVs charging simultaneously from one large POMBatt.

For mobility purposes the POMBatt will be permanently mounted on a Class 7 (weight limit: 11800-15000kg) EV truck used to transport the POMBatt's between the POM (charge) and EVFCS (discharge). This will reduce the amount of handling of the POMBatt and make transportation of the POMBatt more efficient and safe.

3.3. POMBatt Feasibility Analysis

The price of Li-ion batteries is the major cost driver for the POMBatt. The average price of Li-ion batteries is currently at USD 203/kWh and is expected to fall below USD 100/kWh by 2025 as shown in Figure 1 below. The overall cost to own and operate the POMBatt and EVFCS is expected to drop by 9% in 2020 and 46% in 2030 from current overall cost of RM3.98M in 2018.

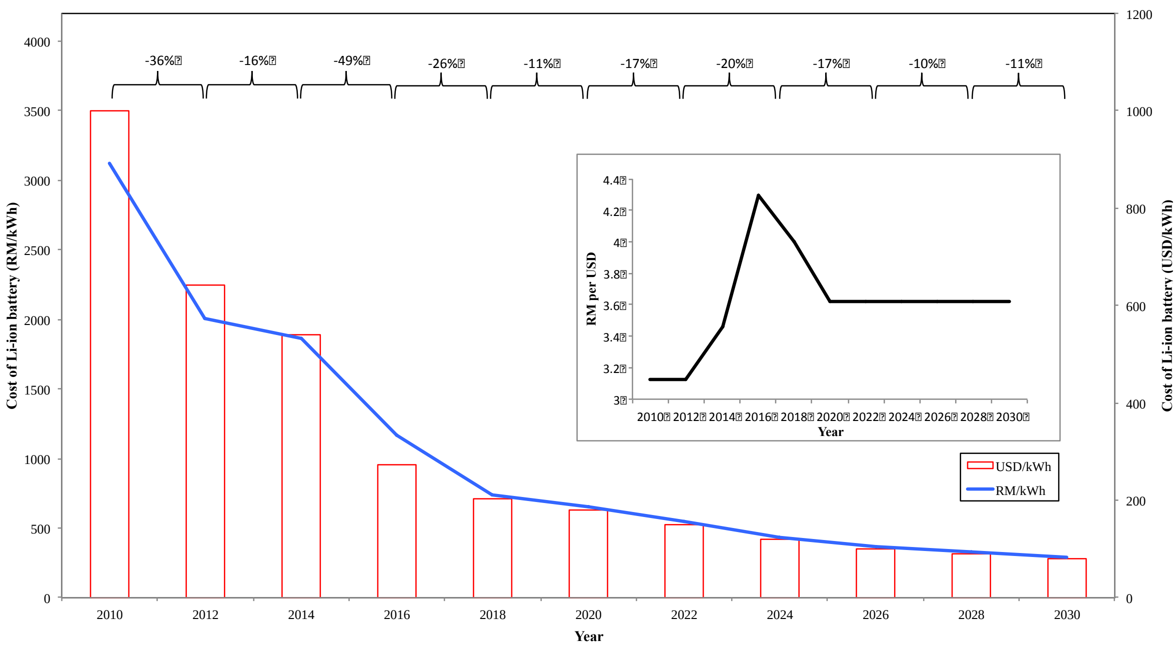

Figure 1. Price trend of Li-ion battery from 2010-2030 [8] with inset of currency conversion rates used

The lifetime of the POMBatt in this proposal is assumed to be 8 years (3000 charge cycles) based on current Li-ion battery technology. A detail analysis was done to determine price per kWh to charge EV owners to achieve a PBT of less than 4 years along with positive NPV and IRR of more than 15%, taking into account EVFCS utilization frequency and the 2 different scenarios.

The minimum price per kWh to ensure the feasibility of the POMBatt and EVFCS in 2020 and 2030 is shown in Table 1.

Table 1. Minimum price per kWh (RM/kWh) at EVFCS for 2020 and 2030

EVFCS Utilization frequencies	Scenario 1: Minimum price RM/kWh		Scenario 2: Minimum price RM/kWh	
	2020	2030	2020	2030
40% - 38 EVs per day	3.00	1.80	3.30	2.10
60% - 57 EVs per day	2.00	1.20	2.30	1.50
80% - 76 EVs per day	1.50	0.90	1.80	1.20
100% - 96 EVs per day	1.20	0.70	1.50	1.00

Based on potential EVFCS utilization frequencies and expected 90% increase in gasoline price by 2030 [17], it will be cheaper to charge an EV at a POMBatt-EVFCS compared to fuelling up with gasoline for ICEVs earliest by 2025 (Scenario 1 + 80% EVFCS utilization) and latest by 2034 (Scenario 2 + 40% EVFCS utilization) as shown in Figure 2 below. The price of gasoline in Figure 2 is inclusive of government subsidy of RM0.40/liter.

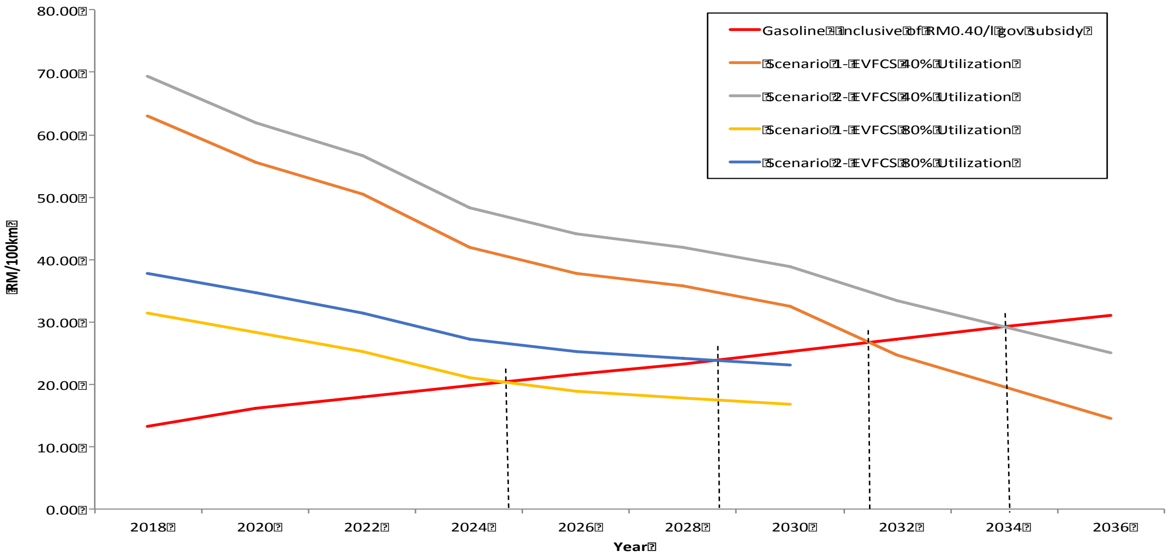

Figure 2. Price trends for fuelling with gasoline vs. charging at the POMBatt-EVFCS

With the possibility of reduced or removal of government subsidies, the price of gasoline could be expected to increase further and the timeline for cheaper charging at the POMBatt-EVFCS compared to fuelling with gasoline may be achieved even earlier than 2025.

3.4. CO_2 Emission Reduction

Malaysia's pledge in the 2015 United Nations Framework Convention on Climate Change's (UNFCCC) 21st Conference, COP21 held in Paris is to lower CO_2 emission to 260 $MtCO_2eq$ from 310 $MtCO_2eq$ projected total CO_2 emission by 2030 [18].

Malaysia currently has a total of 454 POMs [1]. If 50% of these POMs can contribute 3000 kWh each to charge 4 POMBatts per day, a total of 198 GWh of electricity is contributed to EVFCSs along highways, which can be used to charge a total of 205,000 EVs annually. The total amount of CO_2 reduced is 0.9 tCO_2eq per EV each year bringing it to a total reduction of 0.2 $MtCO_2eq$ per year. This amount contributes 0.4% reduction annually and cumulative reduction of 4% (10 years) to the nations 45% GHG emission reduction goal by 2030 relative to 2005 levels.

A study by Kasipillai et al. [19], indicate that growing GDP and income in Malaysia will lead to an increase in demand for transport services. Another study done in Malaysia based on data from 1990-2013 showed that the growth in number of vehicles (8.6% per annum) was faster than the growth in the population of 2.5% per annum [20]. With more than 80% of vehicles still running on petroleum based fuels, the increase in the number of vehicles annually will lead to significant increase in CO_2 emission. Promoting the uptake of EVs in Malaysia will aid in the reduction of CO_2 emission from road transport, but will increase the CO_2 emission from the energy sector since more fossil fuels such as coal and natural gas will need to be burned to produce more electricity to support EV charging across the nation.

The POMBatt eliminates this problem entirely by providing electricity from a biomass source that has zero carbon emission. Table 2 shows the potential of further CO_2 reduction to contribute to Malaysia's goal of 50 $MtCO_2eq$ reduction by 2030. For each case study, it is assumed that all other factors remain the same and POMBatt capacity is increased accordingly to the additional excess electricity generated from the POMs.

Table 2. Further Potential for CO_2 emission reduction per year

Case Study	Excess electricity generated (kWh per day)	Total No. of EVs charged per year	CO_2 reduction (Mtons per year)	CO_2 reduction (% per year)
POM operating 18 hours per day	5200	355,000	0.3	0.7
POM capacity increased to 60 tons FFB per hour	7000	470,000	0.4	0.9

4. Conclusion

The availability of POMBatt-EVFCSs along Malaysia's highways can reduce charging anxiety and encourage the uptake of EVs among Malaysians. Malaysia's plan to introduce 100,000 EVs by 2020 via GreenTech's Electric Mobility Flagship program, will lead to an increase in energy demand of up to 97 GWh per year based on total long distance mileage of 4620 km per year per EV. Each POMBatt (750 kWh, 80% DoD) can contribute a maximum of 219 MWh per year and if 115 POMs across the nation can contribute 3000 kWh to charge 4 POMBatts per day, 100% of this annual additional electricity demand on Malaysia's highways can be met using the POMBatt-EVFCS combination. Leveraging excess electricity generated from oil palm biomass in POMBatts to power EVs can generate CO_2 reduction of 0.9 tCO_2eq per EV per year. With early intervention from the Malaysian government in terms of financial support, subsidies and tax incentives, implementing the POMBatt at 50% (227) of POMs in Malaysia by 2020 will enable fast charging of 205,000 EVs along Malaysia's highways every year, reducing annual CO_2 emission by 0.4% from a total reduction plan of 50 $MtCO_2eq$ by 2030. A cumulative reduction of 2 $MtCO_2eq$ can be realized within 10 years, contributing a total of 4% CO_2 reduction to Malaysia's goal of 45% GHG emission reduction by 2030 based on 2005 levels.

Continuous technology improvement and decreasing price of Li-ion batteries combined with strong government support for green electricity generation from POMs across the nation will make the POMBatt a sustainable solution to decarbonizing electricity generation to power EVs in Malaysia.

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