Jurnal Pendidikan Teknologi Kejuruan, Vol. 6, No. 1, pp. 48-55, February 2023
e-ISSN 2621-1548; p-ISSN 2621-3273

Design analysis configuration and capacity of off-grid with implementation of photovoltaic (PV) and battery energy storage system (BESS) as power supply for shipping activities at ports

Fiqi Mutiah* and Budi Sudiarto

Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, **Indonesia**

*Corresponding Author: fiqi.mutiah@ui.ac.id

Received 12th Jan 2023; 1st Revision 20th Jan 2023; 2nd Revision 14th Feb 2023; Accepted 26th Feb 2023

Cite this https://doi.org/10.24036/jptk.v6i1.31623

Abstract: The government of Indonesia developing mitigation for climate change and achieving decarbonization in the sea transportation sector by encouraging increased use of onshore power supply for ships when berthing at ports. Off-Grid is one of the green transition technologies that provide great benefits to ports for the mitigation of environmental. To ensure optimal system operation, determining the proper configuration and component sizes is an important decision at the design stage. One of the important activities at the port is the transportation of mining products, B3 waste, and others by using ships operated with diesel engines which are known to be expensive and not environmentally friendly. The configuration consists of a photovoltaic system and an energy storage system as well as land electricity support at the port then optimized by considering solar radiation, temperature, and data component specifications to supply power to the ship so that do not use diesel generators on board. From the calculation results it is known that when the ship is anchored it requires 3,310.34 kWh/day of electrical energy. To meet electricity needs, 3,200 units of PV modules are designed with a power output of 1,216 kW peak and a BESS capacity of 4,064 kWh

Keywords: Photovoltaic (PV); Battery Energy Storage System (BESS); Off-Grid; Port; Ship

1. Introduction

The area of Indonesia is 1,916,906.77 km2 with 16,766 islands in it (Badan Pusat Statistik, 2022). Inter-island connectivity in Indonesia, one of which is supported by the availability of ports. Apart from being a place for ships to dock, the port is also a place that supports industrial, mining, and trading activities that require a place to lean on for sea transportation to carry out commodity goods, loading and unloading of mining products, B3 waste and others without having to take into account the distance between islands as an obstacle.

In Indonesia, sea transportation or ship is powered by diesel generators using fossil fuels, which are known to be expensive and not environmentally friendly. On the other hand, the Government of Indonesia has committed to participate in the Paris Agreement to hold global temperature rise below 2oC and work to limit it to a maximum of 1.5oC. This commitment is realized through the publication of the Nationally Defined Contribution (NDC) which states that Indonesia will reduce 29% of greenhouse gas emissions from business as usual (BAU), which is detailed as a reduction in CO2 emissions of 314–398 Tons from the energy sector in 2030 (Outlook Energi, 2021). In 2025 Indonesia targets a renewable energy mix of 23% of primary energy and in 2050 the mix exceeds 31% of primary energy (Pemerintah Indonesia, 2014; Peraturan Presiden, 2017).

From 2000-2019, the greenhouse gas inventory reported that the largest contributors to emissions resulted from industrial, mining, and transportation activities in the use of energy in the form of fuels which are still dominated by fossil energy fuels. Transportation produces 27% of CO2 emissions in Indonesia and is the second contributor to emissions in 2019 (KLHK, 2020). And for the world scope that 2.5% of carbon emissions come from sea transportation (Boksman Asia, 2022). The government continues to strive to reduce carbon emissions, including in the transportation sector, by optimizing the use of renewable energy and starting to use electricity as a substitute for fossil fuels in transportation. Passenger and goods transportation needs to be decarbonized so that temperature increases remain within the limit of 1.5°C (IESR, 2021).

The Indonesian government has prepared steps to achieve the Nationally Defined Contribution (NDC) target in mitigating greenhouse gas emissions, including in the maritime transportation subsector (Peraturan Presiden, 2021). Achievement of the contribution of the marine transportation subsector target in 2050 in reducing annual greenhouse gases from shipping by 50% and reducing carbon intensity from shipping by 70%. One of the efforts is the use of onshore power supply (OPS) from ports for ships when berthing (Kemenhub, 2022).

For this reason, it can be advantageous to use onshore electricity especially by implementing renewable energy and Battery Energy Storage Systems (BESS) in ports. Besides being able to reduce CO2 emissions to meet the NDC target, increasing the penetration of renewable energy is also expected to reduce energy costs, including saving operational and maintenance costs for ship engines. However, these benefits can only be obtained through proper planning because the implementation of BESS from renewable energy in ports requires a sizable investment.

The application of a renewable energy system combined with energy storage has benefits, firstly, it can increase the renewable energy mix, and secondly, it can reduce energy generation costs when a suitable design is implemented. Sumatra Province in Indonesia was taken as a case study, including in 2021, in research entitled "Optimal Hybrid Renewable Energy System Design for Generation Cost Reduction and Increased Electrification in Isolated Grid in Indonesia" and the results show that: 1) optimal design avoids the possibility of adding more diesel generators to meet demand; 2) Optimal HRES can cut generation costs by up to 50% (Jufri et al., 2021).

Recently, Battery Energy Storage Systems or BESS can be considered a good alternative to diesel fuel. Apart from that, the supply to recharge BESS using one of the renewable energies that are being widely applied in many countries is solar energy through photovoltaic (PV) systems, including in Indonesia. This study, answers problems in the electrification system of ships that have expensive fuel prices and greenhouse gas emissions by implementing BESS to supply electricity to shipping activities while docked at the port. The purpose of this research is to determine the optimal BESS capacity in shipping activities at the port as energy arbitrage.

2. Methods

This study is a technical analysis in the context of implementing a Photovoltaic (PV) and Battery Energy Storage Systems (BESS) as a ground power supply for ship activities at the Port by reviewing the technical requirements. The study was carried out by carrying out a calculation study with a literature study to determine the conditions and needs of the ship's electricity supply while it is docked at Indonesian ports. In the study of the implementation of PV and Battery Energy Storage Systems (BESS) on ship activities at the port, the following steps are carried out:

1. Determining the length of solar irradiation or Peak Sun Hours (PSH) is the length of time in hours at 1,000 W/m2 radiation level needed to produce energy equivalent to the total energy in one day, the amount of which depends on Global Irradiance. Based on the

criteria proposed by (Oladeji & Akorede, 2019), if the PSH is greater than 3, it implies that the proposed site is suitable for PV installation and PSH in Indonesia is 4.

2. Calculated the total daily module energy requirements for ships while docking at the port requires system loss-loss value parameters including PV modules, inverters, cabling, and BESS. So that the total energy requirement can be calculated by equation (1) with a system loss value of 27.5% with details in table 3 (Energising development, 2018).

$$E_T = \frac{E}{100\% - Total\ Estimated\ Loss(\%)} \quad (1)$$

3. Determined the sizing of the Photovoltaic (PV) capacity by taking into account the capacity of the PV inverter in advance, taking into account the demand for electricity per day and the availability of solar energy given PSH and assumptions of system efficiency. Equation (2) is used to calculate the capacity of a stand-alone PV system (Al Riza & Gilani, 2014; Bhatia, 2018).

$$P_{Inverter\ PV} = \frac{E_T}{PSH\ x\ \eta_{system}} \quad (2)$$

$P_{inverter}$ PV is the capacity of the PV inverter in kW. ET is the total energy demand for one day in kWh, PSH is the peak sun hour or length of solar radiation and η_{system} is the overall system efficiency with a value of 0.9 (Latasya et al., 2019). So that the PV capacity can be calculated by equation (3) where the value of the DC/AC ratio is assumed to be 1.3 (Gumintang et al., 2020). PPV is the capacity of PV modules in kWp.

$$P_{PV} = P_{Inverter\ PV}\ x\ Rasio\ DC/AC \quad (3)$$

4. Calculating the capacity of the Battery Energy Storage System (BESS) as an energy source whose amount depends on daily energy consumption, DoD, efficiency, and time of use or days of autonomy in use. The calculation is done manually by first making a system configuration consisting of PV and BESS. Therefore, the battery capacity can be obtained as follows (Kim et al., 2018):

$$BESS\ Capacity = \frac{Power\ required\ x\ Duration\ required}{Depth\ of\ discharge\ \ x\ Battery\ efficiency} \quad (3)$$

It should be noted that BESS Capacity in units of MWh is the battery capacity, the power required is the power in MW units, duration required is the autonomy time in units of h, depth of discharge (DOD) is the maximum depth for battery discharge (%), and battery efficiency is the efficiency BESS. Furthermore, the required amount of BESS can be calculated using. n is the number of BESS (units) obtained by dividing the BESS capacity (MWh) by the BESS energy capacity from the manufacturer.

$$n_{BESS} = \frac{BESS\ Capacity}{BESS\ Capacity\ from\ fabrication} \quad (4)$$

5. Calculated the area of the solar module to be built can use the following equation:

$$PV\ Area = \frac{E_T}{GHI\ x\ TCF\ x\ \eta_{PV}\ x\ \eta_{out}} \quad (5)$$

$$TCF = \frac{P_{max}\ saat\ T_{max}}{P_{max}} \quad (6)$$

$$P_{max}\ when\ T_{max} = P_{max} - P_{max}\ \ when\ T_{>STC} \quad (7)$$

$$P_{max}\ when\ T_{>STC} = 0{,}5\%\ x\ P_{max}\ x\ (T_{max} - T_{STC}) \quad (8)$$

PV Area is The area of PV modules to be built (m^2), ET is Total energy demand per day (kWh), GHI (Global Horizontal Irradiation) in ($kWh/m^2/day$), TCF (Temperature Coefficient Factor) in (%), ηpv modul is Solar module efficiency (%), ηout is Output efficiency (%) assumption 0.9, Pmax when Tmax is Maximum power of the PV module when the ambient temperature is max, Pmax is Maximum power of the PV module P_{max} when $T_{>STC}$ is Maximum power of the PV module when the ambient temperature is higher than 25℃ (STC temperature), T_{max} is Maximum ambient temperature (℃)

6. The on shore power supply system is carried out at a port in Indonesia. The location of this research is in a port with a power source still using a diesel generator with fossil fuels. The consideration in designing this system concerns the sustainability of BESS. This system configuration can be seen in Figure 1.

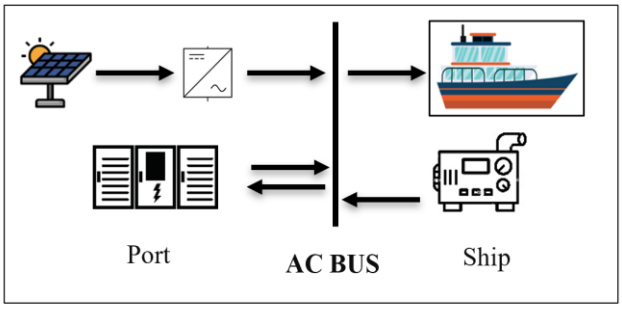

Figure 1. Designing the implementation of PV-BESS on ship activities at the Port

Information data regarding ships anchored at the port with power 100 kW and operation 24 hours when berth. In addition, for parameters in determining the number of PV modules, the number of PV module series and the number of strings and the number of inverters for each component can be seen in Table 1.

Table 1. Component specification

Deskription		Specification
PV ST72M380 (Sky Energy, 2018)	Peak power (Pmax)	380 Wp
	Power tolerance	± 3 %
	Rated voltage (V_{MPP})	40.61 V
	Rated current (I_{MPP})	9.36 A
	Open circuit voltage (V_{OC})	47.27 V
	Short circuit current (I_{SC})	10.22 A
	Efficiency (%)	19.14 %
Inverter	Voltage PV Input Max. ($V_{PV\text{-}max}$)	1100 V
	Voltage PV Input Min. ($V_{PV\text{-}min}$)	585 V
	Voltage Start-up Input ($V_{PV\text{-}start}$)	250 V
	MPP Voltage range ($V_{PV\text{-}range}$)	550-850 V
	Number input MPP (N_{mppt})	9
	Max. number PV string per MPPT ($N_{stringmppt}$)	2
	Current PV Input Max. ($I_{PV\text{-}max}$)	26 x 9 A
	Current DC Short circuit Max. ($I_{SCPV\text{-}max}$)	40 x 9 A
	Power inverter ($P_{inverter}$)	100 kW
BESS LUNA2000-1.0MWH-1H1 (Huawei, 2022)	Nominal energy capacity	1,016 kWh
	Cell type	Li-ion
	Depth of Discharge (DoD)	80 %
	Efficiency battery	80 %
	Round Trip Efficiency (RTE)	95 %

All electrical data PV are measured under standard testing conditions : 1000W/m², AM1.5, 25⁰C

7. Design initial of series and parallel arrangement of PV modules. In the construction of PLTS, solar modules are connected in series to get the desired voltage and connected in parallel to get the desired current. In determining the number of solar modules arranged in series and parallel, the rating of the grid inverter used and the PV rating must be considered. The number of PV modules in series is determined by the lower limit and upper limit by equation (9)(10),

$$Min.N_{seri} = \frac{V_{PV-min}}{V_{mpp}} = \frac{V_{PV-start}}{V_{mpp}} = \frac{Min.V_{PV-range}}{V_{mpp}} \tag{9}$$

$$Max.N_{seri} = \frac{V_{PV-max}}{V_{oc}} = \frac{Max.V_{PV-range}}{V_{mpp}} \tag{10}$$

To calculated the number of strings per inverter, use equation (11) by calculating the upper limit as follows. And to get the number of inverters can be calculated by equation (12),

$$Max.N_{string/inverter} = \frac{I_{PV-max}}{I_{mpp}} \tag{10}$$

$$N_{inverter-PV} = \frac{P_{inverter-PV}}{P_{inverter}} \tag{11}$$

Then determined the number of solar modules preferably in multiples of 16/18/20 to facilitate design with the following equation (12) and number of PV strings with equation (13).

$$N_{PV} = \frac{P_{PV}}{P_{max}} \tag{12}$$

$$N_{string} = \frac{N_{PV}}{N_{seri}} \tag{13}$$

8. Analyze according to market availability.

3. Results and discussion

The implementation of PV and Battery Energy Storage System (BESS) used is on shore power supply by providing electricity supply from land to supply electricity for ships while docked at the port. Table 1 shows the input data needed to calculate the ship's load requirements while leaning at the port. With the ship's power at berth is 100 kW, in one day the electrical energy needed is 2400 kWh/day. To anticipate system losses, it is assumed to be 27.5% of daily electricity with details of the losses listed in table 2.

Table 2. Total losses of PV-BESS system

Cause of loss	Modul PV	Charge controller	Inverter	Cable	Battery Li-Ion	Total
Estimated loss (%)	11.5	3	6	2	5	27.5

So according to equation (2), the total need for electrical energy for the ship while leaning on the port is 3310.34 kWh.

The PV-BESS system, which is used to supply electricity to ships while docked at this port, uses a stand-alone or off-grid PLTS design in the form of an AC coupling. The designs designed for this system can be seen in Tables 1 and 2. From the calculations for the PV-BESS system that have been carried out, the calculation results are presented in Table 3.

Table 3. Calculation results of the PV-BESS system ship activities at the port

Parameter		Value	Unit
PV and Inverter	PSH	4	Hour/day
	E_T	3310.34	kWh
	$P_{inverter-PV}$	919.54	kW
	P_{PV}	1195.40	kWp
	P_{max} when $T_{>STC}$	7.22	W
	P_{max} when T_{max}	372.78	W
	TCF	0.98	-
	PV Area	4897.33	m^2
	Range N_{seri}	14-24	Modul/string
	N_{seri}	16	Modul/string
	Max.$N_{string/inverter}$	25	String/inv.
	$N_{string/inverter}$	20	String/inv.
	$N_{inverter-PV}$	10	Inverter
	N_{PV}	3200	modul
	N_{string}	200	string
BESS	Demand Capacity of BESS	3333.34	kWh
	n_{BESS}	4	Unit
	Autonomy day	1	day

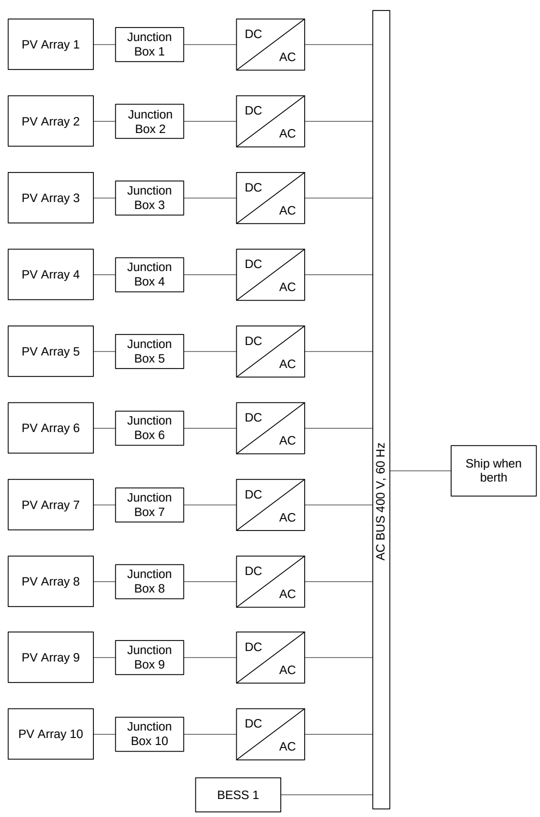

Figure 2. Configuration of implementation PV-BESS for ship activities at the port

BESS includes battery, charger controller and inverter capacity. So to charge or charge BESS from PV using an inverter that is inside BESS when the PV is over-supply by changing AC to DC which will enter BESS. And when PV does not generate electricity, the ship's electricity needs are supplied from BESS by converting DC to AC. The following is the configuration of the components in the form of a one-line diagram.

From the results of the research that has been done, it is known that the configuration for implementing PV-BESS in supplying ship electricity while leaning at the port is to use a stand-alone/Off-Grid AC Coupling configuration with an energy storage system in the form of BESS can be seen in Figure 2. The benefits of the AC coupling system configuration allow PV to be hybridized with other renewable energy generators. And the energy storage system in BESS is used to supply electricity to ships when the PV lacks power to supply or even does not generate electricity at all, such as during rainy and cloudy weather.

In the results of research that has been done, it is known that to supply electricity while the ship is docked at the port, an inverter capacity of 1000 kW is needed with a PV capacity of 1216 kWp and BESS 4064 kWh which can work for 1 day when the PLTS does not produce electricity. Based on the calculation results in Table 3 the recapitulation of the capacity of the PV-BESS component for ship activities at the port is shown in Table 4 and Table 5.

Table 4. Summary of PV-BESS system calculations on ship activities at the port

Parameter		Value	Unit
PV	Number of PV module	3,200	Unit
	Capacity of PV module	1,216	kWp
	String configuration	200	String
	Number of PV module series per string	16	module/string
	Number of string per inverter	20	String/inverter
	Number of PV Array	10	Array
Inverter	Capacity of inverter PV	1000	kW
	Capacity of inverter choosed	100	kW
	Number of Inverter	10	Unit
BESS	Demand capacity of BESS	4,064	kWh
	Number of BESS 1,106 kWh	4	Unit

Table 5. Differences in calculation and market suitability for the PV-BESS system on ship activities in ports

Component		Calculation result	Market availability
PV and Inverter	$P_{inverter\text{-}PV}$ (kW)	919.54	1,000
	P_{PV} (kWp)	1,195.4	1,216
BESS	Demand Capacity of BESS (kWh)	3,333.34	4,064

4. Conclusion

This research was conducted to design the potential use of Off Grid PLTS with Battery Energy Storage System (BESS) with optimal configuration and minimize the use of diesel generators to replace ship diesel generators while docking at the port. With an estimated total daily electrical energy requirement for ships while leaning on the port of 3310.34 kWh per day. The results show that the generated PLTS power is 1216 kWp with 10 PV array circuits, so the number of solar panels is 3200 units and 10 inverters, with a configuration of 200 PV strings and 16 modules in series per string.

In addition to PLTS to optimize the supply of electricity to ships, BESS is also provided in this design. With 1 day of autonomy, a BESS capacity of 4472 kWh is required with a BESS size of 2236 kWh of 2 units. So that the implementation of PLTS and Battery Energy Storage System

(BESS) as a supply of electricity for shipping activities while leaning at the port is optimal to be applied as an electrification alternative for shipping at the port.

References

Al Riza, D. F., & Gilani, S. I. U. H. (2014). Standalone photovoltaic system sizing using peak sun hour method and evaluation by TRNSYS simulation. International Journal of Renewable Energy Research, 4(1), 109–114.

Badan Pusat Statistik. (2022). Statistik Indonesia. In Badan Pusat Statistik (Vol. 1101001). https://www.bps.go.id/publication/2020/04/29/e9011b3155d45d70823c141f/statistik-indonesia-2020.html

Bhatia, A. (2018). Design and Sizing of Solar Photovoltaic Systems. Continuing Education and Development, Inc, 877, 2–125.

Boksman Asia. (2022). Kapal Listrik Baterai untuk Ekspedisi Kontainer, Kurangi Emisi Karbon. Boksman.Com. https://boksman.com/blog/ekspedisi-kontainer-dengan-kapal-listrik-baterai-kurangi-emisi-karbon

Energising development. (2018). Instalasi Pembangkit Listrik tenaga Surya Dos & Don'ts (ing. B. Ramadhani (ed.)). Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Energising Development (EnDev) Indonesia.

Gumintang, M., Sofyan, M., & Sulaeman, I. (2020). Design and Control of PV Hybrid System in Practice. In Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, atas nama Kementerian Federal Jerman untuk Kerja sama Ekonomi dan Pembangunan. www.giz.de

Huawei. (2022). Fision Solar Smart Micro-grid Solution. Solar Huawei, 1–39. Solar.huawei.com

IESR. (2021). Climate Transparency Report. In IESR. https://iesr.or.id/en/pustaka/climate-transparency-report-2021

Jufri, F. H., Sudiarto, B., & Garniwa, I. (2021). Optimal Hybrid Renewable Energy System Design for Generation Cost Reduction and Increased Electrification in Isolated Grid in Indonesia. 2021 IEEE 4th International Conference on Power and Energy Applications, ICPEA 2021, 147–152. https://doi.org/10.1109/ICPEA52760.2021.9639295

Kemenhub. (2022). Surat Edaran Nomor SE-DJPL 22 Tahun 2022 Tentang Penggunaan Fasilitas Listrik Darat (Onshore Power Supply (OPS)) di Pelabuhan bagi Kapal yang Berlayar di Perairan Indonesia.

Kim, D. K., Yoneoka, S., Banatwala, A. Z., Kim, Y.-T., & Nam, K.-Y. (2018). Handbook on Battery Energy Storage System. In Asian Development Bank (Issue December). https://www.adb.org/publications/battery-energy-storage-system-handbook

KLHK. (2020). Laporan Inventarisasi GRK 2020 dan Monitoring, Pelaporan, Verifikasi (MPV). In Kementerian Lingkungan Hidup dan Kehutanan.

Latasya, Z., Sara, I. D., & Syahrizal, S. (2019). Analisis Rancangan Pembangkit Listrik Tenaga Surya (Plts) Off-Grid Terpusat Dusun Ketubong Tunong Kecamatan Seunagan Timur Kabupaten Nagan Raya. Jurnal Komputer, Informasi Teknologi, Dan Elektro, 4(2), 1–14. http://www.jurnal.unsyiah.ac.id/kitektro/article/view/12951

Oladeji, A. S., & Akorede, M. F. (2019). Assessment of Solar and Hydropower Energy Potentials of Three Rural Communities in Nigeria. IEEE PES/IAS PowerAfrica Conference: Power Economics and Energy Innovation in Africa, PowerAfrica 2019, 187–192. https://doi.org/10.1109/PowerAfrica.2019.8928929

Outlook Energi, B. (2021). OUTLOOK ENERGI INDONESIA 2021 Perspektif Teknologi Energi Indonesia: Tenaga Surya untuk Penyediaan Energi Charging Station. In Pusat Pengkajian Industri Proses dan Energi (PPIPE) Badan Pengkajian dan Penerapan Teknologi (BPPT).

Pemerintah Indonesia. (2014). Peraturan Pemerintah Republik Indonesia Nomor 79 Tahun 2014 Tentang Kebijakan Energi Nasional.

Peraturan Presiden. (2017). Peraturan Presiden Republik Indonesia Nomor 22 Tahun 2017 tentang Rencana Umum Energi Nasional.

Peraturan Presiden. (2021). Peraturan Presiden Republik Indonesia Nomor 98 Tahun 2021 Tentang Penyelenggaraan Nilai Ekonomi Karbon untuk Pencapaian Target Konstribusi yang ditetapkan Secara Nasional dan Pengendalian Emisi Gas Rumah Kaca dalam Pembangunan Nasional.

Sky Energy. (2018). Smart Power Live Better Our Product Catalogue. Dutch Lady Milk Industries Bhd.