The potential of renewable-based power plant development towards Bali green and independent electricity supply

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Abstract. This paper presents results of a study on the potential for renewable energy-based power plants development in Bali. The renewable energy-based power plants is developed in order to stop dependence of electricity supply from outside Bali and to increase the share of renewable energy in the power supply mix to achieve Bali green and independent electricity and for climate change mitigation. In this study, AIM-Enduse model was used to estimate the potential of renewable energy-based power plants and GHG emissions reduction from the deployment of renewables in Bali’s power supply mix. There were three scenarios for representing renewable energy-based power plants development in Bali, i.e. baseline (business as usual) and two scenarios (CM1 and CM2) of the deployment of renewables in the power supply mix. The CM1 described conservative scenario of the deployment of renewable in the energy supply mix of Bali’s power plants while CM2 represented optimistic scenario. Since the renewable is considered as carbon neutral, therefore these scenarios can also relate to the mitigation actions to reduce GHG emissions. Under the CM1, GHG emissions reduction potential from the deployment of renewable energy technology in Bali’s power plants and the conversion of coal to natural gas power plants is accounted to about 22% (1.5 MtCO\textsubscript{2}e) in 2030 and can be targeted up to 32% (4.0 MtCO\textsubscript{2}e) in 2050. The deployment of renewable energy under the CM1 is 0.96 GW in 2030 and 1.92 GW in 2050. Under the CM2, the GHG emissions reduction potential from the deployment of renewable energy technology in Bali’s power plants and the conversion of coal to natural gas power plants is accounted to about 23% (2.16 MtCO\textsubscript{2}e) in 2030 and targeted to achieve 27% (4.75 MtCO\textsubscript{2}e) in 2050. The deployment of renewable energy under the CM2 is more ambitious compared to those in CM2, i.e. 1.39 GW in 2030 and 2.36 GW in 2050.

1. Introduction
Bali is one of the renowned islands of tourism destination, domestically as well as internationally. This status has placed Bali with a regional GDP structure where the service industry is the main contributor to the regional GDP. This condition results in relatively high demand for electricity in Bali to meet energy consumption in the service/commercial sector. The electricity demand is currently supplied by small off-grid power plants (mostly diesel and renewables), IPPs (independent power producers) that are connected to the Jamali grid, and electricity from Jamali (Jawa Madura Bali) grid connected system where the grid is connected from Java to Bali through subsea cable network system. 2019, the electricity consumption is accounted for 5,032 GWh, in which the share of electricity supplied from sub-sea cable is accounted for 36.9% and the remaining of 63.1% is supplied from locally power generations [1].
The dependence on the supply of electricity from subsea cable will put Bali in a position with a high level of vulnerability due to power black-out. The power blackout could be caused by the broken cable due to an earthquake or other disaster. To secure the supply of electricity, Bali must be independent in supplying electricity. In addition, issues related to climate change and green energy will lead Bali to also consider renewable and green energy (less carbon emitting fuels) in their power supply mix plans. The National Electricity General Plan (Rencana Umum Ketenagalistrikan Nasional referred to RUKN)[1] stated that Bali will be independent in energy supply for the next future, in which the contribution of local power supply will increase to achieve 72.6% in 2038 and renewable will also to be included. The deployment of renewable energy and less carbon emitting fuels in Bali’s power supply mix can also be considered as mitigation measures that could be included into the commitment of Indonesia in reducing GHG emissions as written in the First NDC (nationally determine contribution) under the Paris Agreement[2].

The deployment of more renewable energy in the electricity supply mix that drives Bali to be independent in supplying high demand of electricity in the future is challenged. Several studies had been carried out by various institutions and/or researchers for assessing the power development plans of Bali, in which the deployment of renewables in power supply mix had been assessed. In the RUPTL (Electricity Generation Plan of PLN) for the period of 2019-2028[3], it is stated that electricity supply for Bali will account for 10,281 GWh in 2028, increases by 176% from 2019. While in the RUKN, it is estimated that the supply for Bali will account for 13,254 GWh in 2038. The forecast of the share of electricity supply from local generations and the contribution of renewable energy in 2050 must be made to assess whether Bali could achieve Green Energy and Independent Electricity Supply. In assessing the potential of energy resources in Bali, particularly renewable resources, the possibility to include biomass from Kalimantan in order to increase the share of renewable energy in the power supply mix.

Results study presented in this paper assessed the potential of renewable based and less carbon emitting power plants in the power supply mix in order to achieve Bali’s Green Energy and Independent Electricity in 2050. AIM-Enduse model was used for assessing those potentials using linear optimization approach, in which the type of power technologies was selected based on the least cost and the GHG emissions reduction potential.

2. Methods

2.1 AIM enduse model for power subsector
As mentioned previously, AIM-Enduse model was used in this study for assessing the potential of the deployment of renewable based and less carbon emitting power plants in the power supply mix to achieve Bali’s Green and Independent Electricity Supply Towards 2050. The model was developed by CREP-ITB (Indonesia), NIES (Japan), and Mizuho (Japan). It is a bottom-up model for the selection of power plant technology in the power generation system, in which GAMS (General Algebraic Modeling System) version 23.3 was used as a tool for modelling and solving linear optimization[4]. The optimization was performed using least cost approach under several constraints like satisfaction of service demands, availability of energy supply of each type of technology, technology characteristic and its performance (efficiency, penetration, cost of investments and operations, lifetime, and GHG emission reduction target). It simulated flows of energy and materials in an economy, from supply of primary energy and materials, through conversion and supply of secondary energy and materials, to satisfy the enduse services. The logic of thinking of AIM Enduse for power generation was structured such as in Figure 1.

It can be seen in Figure 1, the service demand (electricity) was first estimated to determine how much the electricity must be supplied, in which population, economic growth, lifestyle and electricity consumption per capita were the drivers of the electricity demand development. The power generation capacity of each selected technology was estimated to meet the service demand[4], which in turn will affect total energy consumption and the associated GHG emissions [5]. It should be noted that the model
was a recursive dynamic model that simulated the flow of energy, devices and services (see Figure 2) from the initial year to the target year with an economic and engineering approach. The output of the AIM-Enduse model can be interpreted in the form of a pivot diagram and further analysed in the form of energy mix, emission levels, service, stock, and installed technology.

The selected technology and its allocated capacity were then compiled into a road map for the power subsector development planning as a strategy to achieve specific GHG emission reduction targets[6] and could be included as component of sustainable low carbon development. Mitigation efforts from the power subsector will be part of national efforts to achieve the GHG emission reduction target in Indonesia's First NDC in order to fulfill the Paris Agreement commitment. In accordance to that, Bali electricity demand will be projected using 2010 as the base year and 2030 and 2050 as the target year.
Figure 1. Structure of the AIM-Enduse model in the power subsector

The model is a recursive dynamic model that simulates the flow of energy, devices and services (see...
Figure 2

Figure 2) from the initial year to the target year with an economic and engineering approach. The output of the AIM-Enduse model can be interpreted in the form of a pivot diagram and further analysed in the form of energy mix, emission levels, service, stock, and installed technology.

Figure 3

2.2. Scenarios and assumptions
Three scenarios were developed for the analysis of the potential of increasing GHG emission reduction efforts in the power generation subsector in order to achieve clean and green energy in Bali, namely the baseline and two mitigation scenarios (CM1 and CM2). The baseline scenario assumed that (a) there was no effort in increasing the energy efficiency of conventional technology, (b) no additional renewable power plants since the base year, and (c) the existing coal-fired power plant (PLTU-B) was maintained with no additional capacity, given the rejection of PLTU-B expansion in Bali, so that the additional electricity needs were met by the construction of gas-fired (PLTG/PLTGU) and oil-fueled (PLTD) power plants according to the power development planning for Bali.

Figure 3

For the mitigation scenario, it was assumed that the energy development was driven by the population and economy of Bali with the same growth rate as that of the baseline scenario. However, the mitigation scenario will include mitigation activities that lead to GHG emission reduction. The CM1 scenario included the conversion of coal-fired, oil-fueled and partially gas-fired power plants to renewables based power generations under the development plan of clean and low emitting energy. The mitigation activities in the CM2 scenario
were the same as in CM1, but at a higher level of renewables utilization. The assumptions used in each scenario are presented in Table 1 to

**Figure 4** Table 6. In Table 5, it can be seen preliminary assumptions in the energy mix to be optimized to determine the optimal energy mix (cost effective) in terms of GHG emission reduction.

**Table 1.** Assumptions for the projection scenarios

| Parameters                          | Baseline | CM1                  | CM2                  |
|-------------------------------------|----------|----------------------|----------------------|
| GDP growth                          | 2020-2025 (3%); 2025-2030 (5%); 2030-2035 (6%); 2035-2045 (5%); 2045-2050 (4.5%) |                       |                       |
| Economics structure                 | Economic structure in 2050 is still the same as that of 2010 | Following RUKN       | Following RUKN and more renewables |
| Electricity demand                  | Referring to the RUKN\(^1\) projection (2019-2038) which was corrected by the effect of the COVID-19 |                       |                       |
| Share of renewable energy in power  | Share of energy in 2050 is the same as that of 2010 | Following RUKN       | Following RUKN and more renewables |
| Renewable energy                    | No additions of renewable energy generation since 2010 | Biomass, hydro, solar, wind, biofuel, waste, sea current, and geothermal. | Biomass, hydro, solar, wind, biofuel, waste, sea current, and geothermal. |
| Coal power generation               | coal phase out (beyond 2035) |                       | coal phase out (beyond 2035) |

\(^1\)RUKN: general plans of national power generation issued by Ministry of Energy and Mineral Resources (MEMR)[1]

**Table 2.** The price of ‘actual energy’ and ‘projection energy’

| Energy type       | 2010   | 2018   | 2010   | 2018   | 2010   | 2018   | 2020   | 2025   | 2030   | 2040   | 2050   | Note | Ref. |
|-------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|------|
| Coal              | $73.04/ton | $56.62/ton | 116    | 90     | 80     | 86     | 97     | 120    | 152    |        |        | A     | [7], [8], [9] |
| Natural gas       | $4.52/MMBTU | $7.56/MMBTU | 180    | 301    | 301    | 301    | 324    | 324    | 324    |        |        | B     | [7], [8] |
| Oil               | $102.82/barrel | $87.10/barrel | 616    | 595    | 595    | 595    | 564    | 564    | 564    |        |        | C     | [7] |
| Biomass           | $106.85/ton | $106.85/ton | 293    | 293    | 293    | 293    | 293    | 293    | 293    |        |        | D     | [10] |
| MSW               | 76      | 76     | 76     | 76     | 76     | 76     | 76     | 76     | 76     | E     | F     | E,F   | [11] |
| Biofuel           | $1,240/ton | $720/ton | 1180   | 793    | 793    | 793    | 793    | 793    | 793    |        |        | F     | [12] |
| Geothermal        | $72.69/MWh | $54.31/MWh | 845    | 632    | 632    | 632    | 632    | 632    | 632    |        |        |       | [7] |

Note

A Coal calor value: 6322 kcal / kg (2018)
B The average price of fuel oil HSD, IDO, and MFO
C Domestic selling prices
D The average calor value of biomass is 3642.97 kcal / kg.
E Average calor value of MSW is 5668.53 kcal/kg.
F Assumption of stagnant price projections

**Table 3.** Calorific value, carbon content, and emission factors assigned to fuels used [13], [14]

| Fuel         | Calorific Value (TJ/Gg) | Carbon Content (%) | Emission Factor |
|--------------|-------------------------|--------------------|-----------------|
|              | (kgCO₂/TJ)              | (kgCH₅/TJ)         | (tN₂O/TJ)       | (tCO₂e/TJ)     |

Note
| Energy type       | Coal       | Oil         | Natural gas | Biofuel     | Biomass    | Municipal waste |
|------------------|------------|-------------|-------------|-------------|------------|-----------------|
|                  | 18.9       | 42.12       | 45.20       | 27.00       | 11.6       | n.a             |
|                  | 42.92-73.82| 85          | 71          | n.a         | n.a        | n.a             |
|                  | 99178      | 75200       | 57600       | 3           | 30         | 30              |
|                  | 1          | 3           | 3           | 0.6         | 4          | 4               |
|                  | 1.5        | 0.6         | 0.11        | 6           | 4          | 4               |
|                  | 99720.5    | 75203.6     | 57601       | 3.6         | 34         | 34              |

Table 4. Historical emission factors of electricity from JAMALI grid[15]–[18]

| Year | On Grid1, ton CO₂/MWh |
|------|-----------------------|
| 2010 | 0.738                 |
| 2011 | 0.778                 |
| 2012 | 0.823                 |
| 2013 | 0.855                 |
| 2014 | 0.845                 |
| 2015 | 0.903                 |
| 2016 | 0.877                 |
| 2017 | 0.89                 |
| 2018 | 0.89                 |

1emission factor was taken from the regional grid baseline emission factors of Bali province in 2010-2018, published by Directorate General of Electricity-MEMR.

Table 5. Share of electricity generation by the source of energy for the three scenarios

| Energy type | 2010 Base Year | 2030 Base Year | 2050 Base Year | 2010 CM1 | 2030 CM1 | 2050 CM1 | 2010 CM2 | 2030 CM2 | 2050 CM2 |
|-------------|----------------|----------------|----------------|----------|----------|----------|----------|----------|----------|
| Coal        | 45.9%          | 47.4%          | 32.0%          | 11.4%    | 0.0%     | 0.0%     |          |          |          |
| Oil         | 100%           | 8.7%           | 2.0%           | 2.0%     | 2.1%     | 0.5%     | 0.2%     | 0.2%     | 86.5%    | 73.7%    | 67.6%    |
| Natural Gas | 45.3%          | 1.1%           | 1.1%           | 0.2%     | 0.2%     | 0.2%     | 0.1%     | 0.1%     | 86.5%    | 73.7%    | 67.6%    |
| Hydro       | 6.3%           | 8.4%           | 8.5%           | 3.5%     | 3.8%     | 3.8%     | 4.3%     | 4.3%     |          |          |          |
| Solar       | 4.2%           | 3.5%           | 3.8%           | 10.9%    | 13.2%    |          |          |          |          |          |
| Wind        | 26.3%          | 2.0%           | 2.0%           | 2.67%    | 3.01%    |          |          |          |          |          |
| Biomass     | 8.7%           | 8.4%           | 8.5%           | 10.9%    | 13.2%    |          |          |          |          |          |
| Geothermal  | 0.35%          | 0.37%          | 0.10%          | 0.11%    | 0.03%    |          |          |          |          |          |
| Biofuel     | 0.10%          | 0.10%          | 0.07%          | 0.08%    | 0.10%    |          |          |          |          |          |
| Sea current | 0.9%           | 0.1%           | 0.3%           |          |          |          |          |          |          |
| Waste       | 0.9%           | 1.0%           | 0.3%           |          |          |          |          |          |          |

Table 6. Share of electricity generation by type of technology

| Technology                                      | 2010 Base Year | 2030 Base Year | 2050 Base Year | 2010 CM1 | 2030 CM1 | 2050 CM1 | 2010 CM2 | 2030 CM2 | 2050 CM2 |
|------------------------------------------------|----------------|----------------|----------------|----------|----------|----------|----------|----------|----------|
| Biomass BFB (Bubbling Fluidized Bed)           | 2.41%          | 2.99%          | 2.60%          | 3.15%    |          |          |          |          |          |
| Biomass CFB (Circulated Fluidized Bed)         | 3.21%          | 3.98%          | 3.47%          | 4.20%    |          |          |          |          |          |
| Biomass small                                   | 10.44%         | 12.94%         | 2.60%          | 3.15%    |          |          |          |          |          |
| Coal USC (Ultra Supercritical)                 | 27.99%         | 28.87%         | 19.48%         | 9.03%    |          |          |          |          |          |
| Geothermal large                               | 5.32%          | 6.39%          | 2.67%          | 3.01%    |          |          |          |          |          |
| Large hydro                                    | 0.35%          | 0.37%          | 0.10%          | 0.11%    |          |          |          |          |          |
| Medium hydro                                   | 0.10%          | 0.10%          | 0.07%          | 0.08%    |          |          |          |          |          |
| Mini hydro                                     | 20.10%         | 26.80%         |                |          |          |          |          |          |
| Natural gas combined cycle power plant (CCGT)  | 27.64%         | 0.12%          | 68.64%         | 38.36%   | 26.86%   |          |          |          |          |
| Natural gas open cycle gas turbine (OCGT)      | 27.64%         | 0.12%          | 68.64%         | 38.36%   | 26.86%   |          |          |          |          |
3. Results and Discussion

3.1. AIM-Enduse model results: power sector development scenario

In AIM-Enduse modelling, the service demand (electricity) was first estimated based on a rational projection of electricity demand from various sectors, which covered industry, public services (street lighting, city parks, places of worship, and others), commercial, household, and transportation sectors. The drivers of the electricity demand were economic growth, lifestyle and electricity consumption per capita. The projection of electricity demand refers to the electricity generation planning for the Province of Bali as stipulated in RUKN (2019-2038).

The projection value in RUKN still uses high economic growth, e.g. 6-7%, which has not considered the impact of COVID-19. Therefore, in this study, electricity demand was corrected to accommodate the impact of COVID-19 to the lower economic activity and growth in Bali. The corrected electricity demand projection is presented in Figure 3. As shown in Figure 3, electricity consumption per capita in 2050 was projected to become 4,661 kWh/capita or up to 4 times from 2010. Commercial sector will continue to dominate the overall electricity demand in Bali, considering that tourism is the main contribution of Bali’s economy. However, after 2030, transportation sector will take role in the demand electricity following the electric vehicles program.

![Figure 3. Projection of Bali’s electricity demand and intensity (corrected by COVID-19)](image-url)

Based on the review of existing electricity system in Bali, electricity supply in Bali were from JAMALI grid, fossil based (oil, gas and coal) power generations within the connected grid, and renewable energy generation (off-grid). Before 2030, the majority (62%) of electricity needs are still
supplied by power plants in Java which are transferred via submarine cables across the Bali Strait. However, this electricity corridor has a high risk of natural disasters such as earthquakes and tsunamis. The underwater centered earthquake could cause disruption to Bali's imported electricity supply. Therefore, beyond 2030, expansion of local power plants (especially renewable based power plants) will be carried out to meet Bali's electricity demand and at the same time to achieve energy security in Bali (see Figure 4).

**Figure 4.** Projection of electricity supply in Bali

The development of electricity production per type of fuel and technology in each of the baseline and mitigation scenarios can be seen in Figure 5 and Figure 6, respectively. In Figure 5, it can be seen that in the base year 2010, 100% of Bali's local supply was derived from oil-fired power plants. In the baseline scenario, the local electricity production in 2050 was projected to become 21,790 GWh, where is mostly dominated by gas-fired power plants, reaching 85.61% of local production, followed by coal-fired (11.38%) and oil fueled (2.11%). The projected electricity generation will be able to shift the share of electricity supply from highly dependent on imported electricity (supply from power plant/PP not in Bali) to locally generated, showed by significant decrease of imported electricity from 40.9% (2010) to 20.7% (2050).

**Figure 5.** Electricity generation in Bali power subsector for each type of energy
In the CM1 mitigation scenario, the electricity supply from renewable power plants in 2050 will increase to 25.8%, where the main portion (10.94%) comes from biomass power plants. This shows that biomass plays an important role to achieve green energy in Bali, considering the utilization of other renewable energy potentials have limitations, such as local wisdom that hinders development of geothermal energy in Bali. In order to meet the biomass mix target in 2030 to 2050, it apparently will require additional biomass supplies from other region. South Kalimantan's biomass resource potential is considered as imported biomass source for Bali in this study, since the region is regarded as main producer of biomass in Indonesia. In the CM2 scenario, the mitigation efforts carried out are the same as in the CM1 scenario but at a higher penetration rate. The electricity supply from renewable power plants will increase to 31.9% in 2050, where the portion of biomass generation is 13.2%, wind 7.2%, solar 4.3%, geothermal 3.8%, and remaining 3.45% is made up from hydro, sea-current, biofuel and MSW. Based on the results of the energy mix, it shows that there is an opportunity to make green energy possible as well as energy security achievable in Bali.

The implementation of low carbon technology in Bali power subsector in the mitigation scenario can be seen from the technology mix in 2030 and 2050 which has undergone drastic changes when compared to the baseline scenario (see Figure 6). In the CM2 scenario, USC (Ultra Super Critical) coal power plant will be replaced by renewable energy technology. In addition, open gas turbine technology in the CM2 scenario only has share 33.85% in 2050, decreased significantly from baseline (86.51%), meanwhile low carbon technologies such as combined cycle gas-fired generation and renewable energy technology increase to be 33.8% and 31.9%, respectively in local power technology share in the year 2050.
3.2. Projection of GHG emissions and its potential reduction

The profile of GHG emission levels from power generating in Bali depends on the level of electricity production, which determine the level of fuel consumption and the associated GHG emissions. In short, GHG emission level will depend on type of power technology, selected technology efficiency and type of fuel. It should be noted that GHG emissions resulted from local power generation is considered as direct emission and from imported electricity supply is calculated as indirect emission.

The GHG emissions projection under baseline, CM1, and CM2 scenarios and it’s intensity for 2010 to 2050 are presented in Figure 7. In 2040 to 2050, the GHG emissions will increase in all scenarios due to an increase in local electricity generation (see Figure 5). In 2030, the GHG emission reduction resulted from CM1 and CM2 scenarios are 22% and 32% respectively compared to the baseline scenario, meanwhile in 2050, the GHG emissions reduction in the mitigation scenario (CM1 and CM2) is 23% and 27%, respectively. Similar to emission reduction, emission intensity will be decreased significantly in 2030, however it tends to less sharply decrease in the following years (2040 and 2050).
Figure 7. GHG emissions and intensity of Bali’s power generation for various scenarios in 2010-2050

In both of mitigation scenarios (CM1 and CM2), the GHG emission reduction in 2050 is not too drastic compared to 2030 (see Figure 8), because of increase rate in electricity demand surpasses the implementation of mitigation potential. In addition, reduction potential of CM2 does not largely differ from CM1 due to similar reason that there is limitation in mitigation potential. The limitation of implementing mitigation potential is due to biomass utilization that is already maximum (high penetration). Starting 2030, in both mitigation scenarios, biomass utilization from local source will have been 100% of the resource potential and inevitably requires imported source (from South Kalimantan). Meanwhile, utilization of other renewables will have also been high (>50%). 50% is considered high since there are constraints in renewables utilization in Bali (local wisdom obstacle for geothermal, highly expensive off-shore wind technology is to be selected instead of on-shore as lands limited, etc). This condition indicates that towards 2050, achieving higher GHG emission reductions can only be possible if higher renewables penetration is implemented and operated with high efficient technology.

Figure 8. GHG emissions and reduction potential in the future Bali’s power subsector in various scenario
Figure 9 presents the GHG emission levels for each scenario: baseline, CM1 and CM2 in power generating subsector in Bali which is estimated based on the type of fuel used. In 2010, GHG emissions were dominated by oil-fueled power plant. Then, in 2015, GHG emissions shifted to coal combustion of PLTU-B Celukan Bawang which is still operating today and is expected to continue its production until 2030. After 2030, it is planned to increase the capacity of gas-fired power plants. The shift from coal to gas will have an impact on reducing GHG emission levels. In the period 2010 to 2030, the reduction in GHG emission levels does exist but not significant. GHG emission reductions will occur significantly only after 2030 and beyond. In addition, it can also be seen the high share of the local power supply. This future projection gives an overview that Bali has the potential towards independent in terms of electricity supply in the future.

Figure 9. GHG emission of Bali’s power generation under the baseline, CM1, CM2 scenarios up to 2050

3.3. Cost Analysis
In this study, the potential of the deployment of renewable based and less carbon emitting power plants in the power supply mix to achieve Bali’s Green and Independent Electricity Supply Towards 2050 was optimized using least cost approach, i.e. lowest additional cost and largest GHG emissions reduction. Figure 10 presents results analysis of additional cost under CM1 and CM2 scenarios compared to the baseline scenario using AIM-Enduse model. It can be seen in the figure that total emission reduction of CM2 scenario is higher than under scenario CM1. The total additional cost of selected technologies in CM2 scenario is negative (lower than CM1) in 2050, while in 2030 the cost is still expensive (higher than CM1). It can be seen that all technologies selected in CM2 scenario become cheaper although in the beginning the cost are still higher if they are compared to the baseline technology due to increasing GHG emissions reduction in 2050 compared to those in 2030.

Concerning the results of investment and maintenance and operational costs analysis of the selected technologies in CM1 and CM2 scenarios, Figure 11 presents the total cost and total initial investment of selected technologies for CM1 and CM2 scenarios while Figure 12 presents total annual investment cost and total operational and maintenance cost for CM1 and CM2 scenarios.
Figure 10. Additional cost of scenario CM1 and CM2 in 2030 and 2050

Figure 11. Total cost and Initial investment cost

Figure 12. Total annual investment cost and total operational and maintenance cost

4. Conclusions
From the results of this study, it can be concluded that the urgency of the development of new local power plants are important considering the rising of electricity demand, which increased by 252% in 2030 and 802% in 2050 compared to 2010. Up to recent (2019), 36.9% of the demand was still supplied by the power generation from outside of Bali within JAMALI grid. Independence in the electricity
supply will be achieved if the future electricity demand is able to be fully provided by local power plants in Bali. In 2030 and 2050, it is estimated that Bali's own power generation will be 61% and 79.3%, respectively. The potential use of renewable energy in local power plants in 2030 and 2050 is 25.8% and 31.9% respectively.

The predominant type of fuel used is biomass 13.2%, followed by wind 7.2%, solar 4.3%, geothermal 3.8% and the remaining 3.4% is made up from hydro (large, medium, mini and micro-hydro), sea-current, biofuel and MSW. With the replacement of coal to gas and the use of renewables, the potential of GHG emission reductions in 2030 in the CM1 and CM2 scenarios are 22% (1.5 MtCO$_2$e) and 32% (2.2 MtCO$_2$e), respectively, compared to the GHG emission in the baseline scenario. By 2050, the potential of GHG emission reductions in the CM1 and CM2 scenarios are 23% (4.0 MtCO$_2$e) and 27% (4.7 MtCO$_2$e), respectively.

It also can be concluded that the technologies selected in CM2 scenario become cheaper although in the beginning the cost are still higher if they are compared to the baseline technology. In addition, both CM1 and CM2 scenario could achieve higher GHG emissions reduction in 2050 compared to those in 2030. The result of this study gives an overview that Bali has the potential to be independent in terms of electricity supply in the future, however clean energy goals and higher GHG emission reductions can only be possible if higher renewables penetration is implemented and operated with high efficient technology.

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