Greening the grid: The implication of aggressive emission target on Indonesian electricity generation

Krisna Gupta

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Motivation, objective, method, results, implications.

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1 Introduction

The importance to ramp up efforts to decarbonize Indonesian energy sector just reached a new height.The Indonesian government joined the global bandwagon of committing to a more emission reduction target. Just before the 27^th session of the Conference of the PRties (COP27), The Indonesian government comitted to a more aggresive reduction of greenhouse gas (GHG) emission by 31.90% by 2030, or by 43.20% with the help of other countries (Resosudarmo, Rezki, and Effendi 2023).

For the energy sector, the Indonesian government pledged to reduce the emission from energy sector by 12.5% or by 15.5% with the global help. Energy sector remains an important emitter of GHG in Indonesia. While the target is not as aggresive as the forestry and land use sector, the energy sector is going to account for 58.17% of the total emission in 2030 under the business as usual (BAU) projection (Resosudarmo, Rezki, and Effendi 2023).

In the energy sector, electricity generation will play an even greater role going forward. The latest data suggests the Indonesian electricity sector to provide around 20% of the Indonesian total energy needs (Wahyuni 2022; MoEF 2021). This share, however, will increase as the Indonesia nudge toward electrification of cooking and transportation (Resosudarmo, Rezki, and Effendi 2023). Greening the Indonesian grid, therefore, become one of the most important challenge the Indonesian government must met to achieve the emission target (Burke et al. 2019; Resosudarmo, Rezki, and Effendi 2023).

This paper aims to discuss the cost of the Indonesian electricity transition toward renewable under the government's aggressive emission target. Linear optimization assume perfect substitution with constraints is chosen as the preferred method to project the cost of electricity. Linear optimization is suitable for a perfect substitution grid (Cowell 2006; Sargent and Stachurski, n.d.). Moreover, the method is simple enough to replicate and provides a useful to make projection and plans given a proper parameterization and constraints.

findings and its implications

The next section discusses the literature around the new emission target and Indonesia's electricity sector. Section 3 explains the method of choice. Section 4 discusses the results and its implications toward greening the grid, and section 5 concludes.

2 Indonesia electricity outlook

Just prior the COP27, Indonesia submitted an optimistic document describing its updated nationally determined contributions (NDCs) (Resosudarmo, Rezki, and Effendi 2023). Indonesia pledged to reduce total emission by 31.9% under CM1 and 43.2% under CM2[1]. Meanwhile, the energy sector is pledged to reduce emission by 12.5% and 15.5% under CM1 and CM2 respectively.

Looking at a roadmap by The National Energy Council (DEN) of Indonesia, the strategy to achieve this target relies heavily on electrification of energy. According to the Indonesian government's roadmap, Indonesia would supply 25% of the total energy from renewables by 2030 (Resosudarmo, Rezki, and Effendi 2023). On the demand side, it projects a 5.5 million of electric cars, 8.5 million of electric motorcycles, and 5 million households with induction cookers in in 2030 (Resosudarmo, Rezki, and Effendi 2023). Indeed, electrification is an important part of the Indonesian effort to fulfill its NDCs.

Indonesians are among a relatively smaller consumers of electricity, and its use is concentrated mostly in Java island (Burke and Kurniawati 2018). The electricity market is dominated by the state-owned firm, *Perusahaan Listrik Negara* (PLN), in both distribution and generation (Resosudarmo, Rezki, and Effendi 2023). While an Independent Power Producer (IPP) is allowed to generate electricity, they must sell it to PLN as the sole distributor of electricity.

Electricity pricing is highly regulated by the government (Burke and Kurniawati 2018). The electricity tariff schedule is layered and differentiated between consumers. The tariff schedule is separated by households, business, and industry. For each group, tariff is discriminated further by its maximum volt-ampere. Moreover, households are often the highest receiver of subsidy and consequently pay the lowest on electricity compared to businesses and industries (Burke and Kurniawati 2018).

PLN is central to Indonesia's electrification strategy. Renewable is projected to be the source of 52% of PLN's electricity generation (MEMR 2020a). However, the road toward greening

[1] CM1 = Counter Measure 1 (without international support), while CM2 = counter measure 2 (with international support).

the greed seems slow. According to PLN (2021) statistics, the percentage of renewables generated by PLN in 2021 is only 8% (see Table 1). A large majority of the renewable electricity is sourced by hydropower and geothermal. Additionally, the growth of renewable electricity since 1998 (31.2%) is dwarfed by PLN's total capacity growth (144.08%). Indeed, the majority of PLN's capacity growth is from coal, defying the global trend (Lolla and Yang 2021; Burke and Kurniawati 2018).

Table 1: The amount of renewable electricity by PLN (GWh)

source	1998 (GWh)	2021 (GWh)
Hydro	9,649.00	11,869.30
Geothermal	2,616.80	4,216.17
Solar	-	5.63
Wind	-	-

The slow growth of renewables stem from the Indonesian's reliance on coal (Resosudarmo, Rezki, and Effendi 2023; Burke et al. 2019). Coal is cheap, abundant, and reliable, reducing the incentives to look for alternative. Moreover, PLN's pricing is highly regulated by the government. Meaning, already relatively low, Indonesian electricity price cannot be raised by PLN when it is needed. The Indonesian government also would like to limit subsidy, leading to further reliance on coal (Resosudarmo, Rezki, and Effendi 2023).

Indonesia's renewables are coming mostly from hydropower and geothermal. Unfortunately, the two sources are growing very slowly, mainly due to a slow land acquisition, especially geothermal (Burke et al. 2019). Indonesia's wind potential is not promising, leaving solar Photovoltaic (solar PV) as the best soource of renewable growth (Burke et al. 2019). Indonesia has a good potential for solar energy and may utilize floating solar panels above waters (Blakers and Silalahi 2023). The ecological impact of blocking the sun on water may still need studies.

While the PLN's renewable accounts for only 8% of total PLN generation, renewable accounts for 17% of total general electricity generation (Lolla and Yang 2021). This majority of the discrepancy may come from IPPs. In 2021, around 36.79% of the Indonesian electricity is generated by IPPs, which is only accounting for 3.78% of total generation in 1998. Moreover, it is projected that IPP would provide 64$ of electricity in 2030 (MEMR 2020a). This shows the importance of IPPs for improving the Indonesian renewable electricity capacity.

The popularity of IPP rises in 2013 when the government announced reverse auction for solar panel (Burke et al. 2019). However, a limitation imposed on foreign involvement in both investment and product components as well as low administrative capacity slow down the growth (Burke et al. 2019). Moreover, some projects are too expensive for PLN. Since it does not control price, it cannot impose a premium pricing for some expensive IPP projects. Lastly, an overcapacity of coal electricity leads PLN to slow down its third-party purchases of renewables. Direct competition with PLN's own asset is also a known problem in supporting renewable electricity (Burke et al. 2019).

In short, financial capacity needs to be improved. PLN's lack of pricing prower and subsidies limit its capacity to invest and absorb energy invested by third party generators. It may need to early-retire a large number of coal powerplant. The government also need to improve grid infrastructure and general project infrastructure to lower the cost of building new renewable generators and its transmission. According to MEMR (2020b), Indonesia needs Rp 3,500 trillion ($0.23 trillion) to achieve its NDCs targets.

Internal financing is constrained considering the limitation of Indonesia's domestic saving and fiscal capacity (Gupta 2021; Resosudarmo, Rezki, and Effendi 2023). One way to improve this situation is to find alternative source of funds like the carbon tax. The Indonesian government issued a for implementing an emission trading system (ETS) in 2021 (Resosudarmo, Rezki, and Effendi 2023). A pilot project in 2021 results an average carbon price of $2 per tonne of carbon dioxide and a proposed a 30 IDR/kgCO2 carbon tax [Putri (2022).

3 Simulation

This paper proposes a linear optimization method to simulate the state of Indonesian electricity given a changes in carbon quota and prices. The strength of linear optimization method lies in its simplicity in execution and in explaining the resulting output (Sargent and Stachurski, n.d.). A fully linear system also warrant a solution, and can be adjusted easily by parameterization or additional equations.

A fully linear system may not represent well the industry's electricity supply in general. However, if direct competition among different supplier as in (Burke et al. 2019) is indeed holds back renewable adoptions, it is likely the perfect substitution be feasible. In the presence of additional contraints, we can poses a restrictions on the parameters.

This section focuses on building the system, parameterization, and scenarion descriptions.

3.1 The linear system

Let Q be a quantity produced by the Indonesian economy which is nested with a leontief production function with energy. That is, $Q = \min(F(.), G(\omega))$, where F is a combination of factors such as capital and labour. Let Ω be the total energy required to produce Q in one period. The economy produces ω with a fully substitute sources:

$$\omega = w_a + w_b + w_g$$

where w_a is the amount of clean energy used, while w_b and w_g are coal and gas respectively. if p is a vector of prices of the three sources of energy and $w \in \{w_a, w_b, w_g\}$, producers in the economy are faced with a cost minimization problem to produce Q, and by extension, ω.

$$\min_{w} p \cdot w$$
$$\text{subject to } \omega = w_a + w_b + w_g$$

In this setting, ω is taken as exogenous as the consequence of the Leontief production nest. That is, factor of production is the driver of Q and consequently ω. This assumption allows the use of the cost minimization technique and observe the cost impact of idiosyncratic shock to prices or ω (and Q by extension) if one needs to change the total output (Cowell 2006).

We improve this setting by adding emission constraints. We limit total emission coming from the use of each source of energy. Next, we limit how much the total combination of emissions from these sources is allowed. This variable, then, can be set exogenously to reflect the government's preference of emission.

Let a, b, g be parameters which reflect emission generated per megawatt hour by w_a, w_b, w_g respectively. Let ε be the total emission generated by the Indonesian electricity sector, Then the total emission generated by these sources is:

$$aw_a + bw_b + gw_g = \varepsilon$$

With the above emission constraint, we have a complete linear system as follows:

$$\begin{aligned} \min_{W} \; & p \cdot w \\ \text{subject to } \; & w_a + w_b + w_g \geq \omega \\ & aw_a + bw_b + gw_g \leq \varepsilon \\ & w_a, w_b, w_g \geq 0 \end{aligned}$$

The shock of the model can come from two exogenous variables p which reflects a carbon tax, or ε which reflects how much carbon quota is given in the economy as a whole.

3.2 parameterization

The next step is to find a representative parameter. PLN (2021) is the main source of ω and $p \cdot w$. Perusahaan Listrk Negara (PLN) statistics is reliable since it is the sole distributor of electricity in Indonesia. According to PLN (2021), Indonesia generates 289,470.57 Gigawatt hour (GWh) in 2021. From those, around 60% are produced using coal as its main source and around 23% by some mixes of fossil fuels. Only 17% is generated by renewables, mostly hydroelectric (Lolla and Yang 2021; PLN 2021).

PLN (2021) also contains data on prices per Kilowatt hour (KWh) of electricity based on sources. The prices per KWh of solar is used for p_a since solar PV has the most promising renewable growth at the moment. The price for coal-based electricity p_b is half as expensive as p_a accodring to PLN (2021). Meanwhile, other fossil fuel is priced exactly in between p_a and p_b.

Lastly, emission factor a, b, g are calibrated from Febijanto (2010) and Steen (2001). The number of emission factor varies between countries and in different reports, and emission factor in this paper tries to balance those differences[2]. The emission factor is set to be very low (from procuring the photovoltaic panels). The emission factor for coal is ten times from the renewable, while other fossil fuels is set to be 70% of coal. Total emission generated by the electricity sector is calculated based on the emission factor and how much energy source is used by the sector.

3.3 Scenarios

Various scenarios can be tested on this model, but 7 scenarios stand out. Case 1 is the status quo. That is, the source is restricted to fit the current share of electricity by source according to Lolla and Yang (2021). That is, 17% renewables, 60% coal and 23% from other fossil fuels. This scenario serves as parameterization for total emission emitted by the electricity sector given emission factor. This exercise also provides a baseline cost of the status quo generation.

Case 2 is the cost optimization given the same electricity generated and the same total emission from case 1. This scenario shows what the model would tell us how much share of electricity would be if the sector is fully substitute with no switching cost. One can argue the case for long-run generation if there is no emission targeting in place. That is, the country adjust the electricity generation solely for accessibility. Looking at how the coal progresses in Indonesia, this scenario would likely shows us a total coal domination if it is not restricted.

The carbon tax scenario is the case 3. The 50 IDR/kgCO2 is imposed as a carbon tax. This tax is extremely low, however, which translates to 0.6 IDR/KWh. Since the price of electricity in 2023 is around 1,400 IDR/KWh, the proposed carbon tax is extremely trivial. It may poses no change compared to the case 2.

Case 4 and 5 poses restrictions on the total emission generated. The goal from CM1 and CM2 in the NDCs is implemented on the model. That is, case 4 and 5 imposes a restriction on total emission to be 12.5% and 15.5% lower than case 2 respectively. The goal of these exercise is to show how much more expensive electricity is under these scenarios, on top of the cost to make the switch in the first place.

Lastly, we would like to know how much the cost and emission generated under the government's plan for the PLN. 2 plans are tested. Case 6 tests the scenario where 25% of electricity generation is by renewable source as in Resosudarmo, Rezki, and Effendi (2023). There is a new plan, however, which pose a more aggressive 52% electricity from renewable resources (MEMR 2020a), which will be the case 7.

[2]See appendix for a more complete codes and parameterisation used in this paper.

All of these cases are summarized in Table 2. These 7 cases are exercised as a benchmark for possible emission and cost of the Indonesian electricity generation. Moreover, these 7 cases also show the flexibility of the model in projecting cases by altering different exogenous variables. These exercises provides a good comparative static which will be discussed in the next section.

Table 2: scenario descriptions

case	description	model setting
1	status quo	restricting the current share of generation.
2	current emission, optimized	case 1 without source restriction.
3	carbon tax	Same emission limit but with a carbon tax
4	CM1	same prices but a 12.5% emission reduction
5	CM2	same prices but a 15.5% emission reduction
6	Old RUPTL	case 2 with 25% renewables
7	New RUPTL	case 2 with 52% renewables

4 Results

The 7 cases is shown below.

Case 1: status quo

```
The total cost is 262.29 trillion IDR or 906.11 IDR/KWh
The total emission is 225,208,103,460.00 kgCO2
Total electricity by renewables is 49,209,996.90 MWh (17.00 %)
Total electricity by coal is 173,682,342.00 MWh (60.00 %)
Total electricity by other fossil fuels is 66,578,231.10 MWh (23.00 %)
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case 2: minimized cost, same emission (no target)

```
The total cost is 237.36 trillion IDR or 819.96 IDR/KWh
The total emission is 225,208,103,460.00 kgCO2
Total electricity by renewables is 71,402,740.60 MWh (24.67 %)
Total electricity by coal is 218,067,829.40 MWh (75.33 %)
Total electricity by other fossil fuels is 0.00 MWh (0.00 %)
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case 3: carbon tax

```
The total cost is 237.49 trillion IDR or 820.42 IDR/KWh
The total emission is 225,208,103,460.00 kgCO2
Total electricity by renewables is 71,402,740.60 MWh (24.67 %)
Total electricity by coal is 218,067,829.40 MWh (75.33 %)
Total electricity by other fossil fuels is 0.00 MWh (0.00 %)
```

case 4: CM1

```
The total cost is 261.29 trillion IDR or 902.63 IDR/KWh
The total emission is 190,277,276,630.00 kgCO2
Total electricity by renewables is 110,214,770.41 MWh (38.07 %)
Total electricity by coal is 179,255,799.59 MWh (61.93 %)
Total electricity by other fossil fuels is 0.00 MWh (0.00 %)
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case 5: CM2

```
The total cost is 265.75 trillion IDR or 918.07 IDR/KWh
The total emission is 183,753,484,288.40 kgCO2
Total electricity by renewables is 117,463,428.57 MWh (40.58 %)
Total electricity by coal is 172,007,141.43 MWh (59.42 %)
Total electricity by other fossil fuels is 0.00 MWh (0.00 %)
```

case 6: old RUPTL

```
The total cost is 237.95 trillion IDR or 822.02 IDR/KWh
The total emission is 224,339,691,750.00 kgCO2
Total electricity by renewables is 72,367,642.50 MWh (25.00 %)
Total electricity by coal is 217,102,927.50 MWh (75.00 %)
Total electricity by other fossil fuels is 0.00 MWh (0.00 %)
```

case 7: new RUPTL

```
The total cost is 286.14 trillion IDR or 988.49 IDR/KWh
The total emission is 153,998,343,240.00 kgCO2
Total electricity by renewables is 150,524,696.40 MWh (52.00 %)
Total electricity by coal is 138,945,873.60 MWh (48.00 %)
Total electricity by other fossil fuels is 0.00 MWh (0.00 %)
```

In general, there are several key feature from this model, mainly due to parameter choices. Firstly, it is clear that coal is the main choice for cost reduction. The high price relative to emission for other fossil fuels does not justify using it at all in the optimization process. The cost-emission trade-off is basically a choice between coal and renewable sources.

Secondly, the perfect substitution assumption, without proper constraints to w, shows a typical corner solutions. That is, the cost-minimized combination of w is to put everything to the cheapest w, both in terms of cost and emission. This is actually a good proxy of the long run possibility, which explains why Indonesia are investing more on coal power plant, defying the tremd of most countries.

5 Challenges

on PV and wind Burke et al. (2019)

Calculation for cost will likely changes when renewables increases so much. Investment cost can be internalized in a Levelized Cost of Energy (LCOE) [need citation]. However, non-monetary cost like land rights can be a constraint as well. Securing land rights has already become a problem for geothermal (Burke and Kurniawati 2018). If solar PV and wind has reached a certain level, securing land rights will be a bottleneck. While cost per KWh of LCOE has been an important indicator for planning electricity generation, the government must also consider how much area needed per KWh.

Possible violation from perfect substitution and linear cost. Perfect substitution can be changed with either real input factor, while linear cost is possible if the cost faces variable returns to scale. Fix cost, load, land.

cap-n-trade Some shit from Sabzevar et al. (2017) and He, Dou, and Zhang (2017) on calculation of cap n trade.

6 Conclusion

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