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

Krisna Gupta

November 5, 2023

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 $27^t h$ 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 (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 reenwables 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).

Indonesians are among a relatively smaller consumers of electricity, and its use is concentrated mostly in Java island (Burke and Kurniawati 2018). The market is dominated by the state-owned firm, *Perusahaan Listrik Negara* (PLN), in both distribution and generation (Resosudarmo, Rezki, and Effendi 2023). While third-party firms 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).

The road toward greening 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).

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

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).

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 third party generation. In 2021, around 36.79% of the Indonesian electricity is generated by third party, which is only 3.78% in 1998. This shows the importance of third party generators for improving the Indonesian renewable electricity capacity. But the growth of third-party generators is also hindered.

The rise of third party generator for renewables 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 electricity. 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 (2020), Indonesia needs Rp 3,500 trillion ($0.23 trillion) to achieve its NDCs targets.

Some of the money will come from the newly set carbon market.

3 Simulation

3.1 Method

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.

$$\begin{aligned} &\min_{w} \; p \cdot w \\ \text{subject to} \;\; &\omega = w_a + w_b + w_g \end{aligned}$$

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.

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.

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 279,511.24 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 of electricity based on sources. Total emission generated by the electricity sector is calculated based on the emission factor and how much energy source is used by the sector. Lastly, emission factor a, b, g are calibrated from Febijanto (2010) and Steen (2021). The number of emission factor varies between countries and in different reports, and emission factor in this paper tries to balance those differences[2].

Also cekidot https://www.cnbcindonesia.com/news/20220119103739-4-308598/pajak-karbon-pltu-berlaku-april-2022-picu-tarif-listrik-naik

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3.2 Results

The linear setting in the previous section is trivial enough to be solved by linear programming method in Scipy (Sargent and Stachurski, n.d.). Four different cases are considered in this paper.

case	description	model setting
1	status quo	current share of energy use
2	current emission, optimized	current total emission, optimized
3	carbon tax	current share but carbon is taxed
4	long-run with aggresive target	like case 2 but with emission reduced by 27%
5	long-run with renewable constraint	case 4 with renewable contraint

Case 1: status quo

[2]The Indonesian electricity generation grows by 271,58% between 1998-2021. The largest growth comes from third-party grows from 2,938.76 GWh in 1998 to 106,496.69 GWh in 2021.

```
The total cost of electricity generation is 262.29 trillion IDR or 906.11 IDR/KWh
The total emission is 225,208,103,460.00 kgCO2
Total electricity generated from renewables is 49,209,996.90 MWh (17.00 %)
Total electricity generated from coal is 173,682,342.00 MWh (60.00 %)
Total electricity generated from other fossil fuels is 66,578,231.10 MWh (23.00 %)
```

case 2: minimized cost, same emission (no target)

```
The total cost of electricity generation is 237.36 trillion IDR or 819.96 IDR/KWh
The total emission is 225,208,103,460.00 kgCO2
Total electricity generated from renewables is 71,402,740.60 MWh (24.67 %)
Total electricity generated from coal is 218,067,829.40 MWh (75.33 %)
Total electricity generated from other fossil fuels is 0.00 MWh (0.00 %)
```

case 3: carbon tax

```
The total cost of electricity generation is 266.48 trillion IDR or 920.59 IDR/KWh
The total emission is 225,208,103,460.00 kgCO2
Total electricity generated from renewables is 71,402,740.60 MWh (24.67 %)
Total electricity generated from coal is 218,067,829.40 MWh (75.33 %)
Total electricity generated from other fossil fuels is 0.00 MWh (0.00 %)
```

case 4: aggresive carbon cap

```
The total cost of electricity generation is 282.89 trillion IDR or 977.26 IDR/KWh
The total emission is 158,745,613,645.60 kgCO2
Total electricity generated from renewables is 145,249,951.50 MWh (50.18 %)
Total electricity generated from coal is 144,220,618.50 MWh (49.82 %)
Total electricity generated from other fossil fuels is 0.00 MWh (0.00 %)
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case 5: non-aggresive transition

```
The total cost of electricity generation is 351.87 trillion IDR or 1,215.57 IDR/KWh
The total emission is 158,745,613,645.60 kgCO2
Total electricity generated from renewables is 83,853,372.00 MWh (28.97 %)
Total electricity generated from coal is 21,427,459.49 MWh (7.40 %)
Total electricity generated from other fossil fuels is 184,189,738.51 MWh (63.63 %)
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4 Challenges

on PV and wind Burke et al. (2019)

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

5 Conclusion

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