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OPTIMIZATION OF THE ELECTRICITY ECONOMICS SYSTEM (EES) IN SUPPORTING NATIONAL ENERGY POLICY USING A TRI-LEVEL PROGRAMMING APPROACH

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ABSTRACT
High electricity subsidies in the national budget (APBN) pose a challenge to national fiscal sustainability. This research aims to formulate an optimization model for the Electricity Economics System (EES) that hierarchically balances the interests of the government, consumers, and producers. The methodology employs a Tri-Level Programming approach with a nested optimization strategy. Simulation results demonstrate that the model reached a stable convergence point at the 41st iteration with a zero relative change value. The national subsidy allocation was significantly reduced from IDR 68.64 trillion to IDR 24.03 trillion. Thus, this model serves as a strategic decision-making instrument that effectively represents hierarchical interactions between energy actors to produce more efficient fiscal policy solutions and support the sustainability of the national power system.
Keywords : Optimization, Electricity Economics System, Tri-level Programming

I. INTRODUCTION

Electricity is a crucial element in supporting economic and social activities in the modern era [1]. In Indonesia, the management of the electricity sector faces a significant challenge in the form of an increasing subsidy burden in the National Budget (APBN). In 2023, the electricity subsidy allocation reached IDR 68.6 trillion, reflecting an imbalance between the cost of providing electricity and the tariffs affordable to the public [2]. This condition demands a national energy policy framework that can balance economic efficiency with national fiscal availability to ensure long-term energy sustainability [3].

The issues within the Electricity Economics System (EES) involve dynamic interactions between three main entities arranged hierarchically [4]. The government acts as the supreme regulator (upper level) determining tariff and subsidy policies [5], consumers are at the intermediate level (middle level) responding to tariffs by optimizing consumption volumes [6], and producers are at the foundational level (lower level) tasked with meeting electricity demand at the most efficient operational generation costs [7]. Consumers not only determine electricity consumption levels but also consider the trade-off between cost savings and comfort levels (discomfort cost) [8]. These three actors form a decision chain where the leader's policy triggers sequential adaptive responses from the followers below [9].

Recent studies on electricity system optimization have primarily focused on improving tariff design, demand response, generation scheduling, and energy market efficiency using mathematical optimization approaches such as linear programming, mixed-integer programming, stochastic optimization, and bilevel programming. These approaches have demonstrated significant potential in enhancing operational performance and reducing electricity costs. However, most existing models consider interactions between only two decision-making levels. For example, Grimm et al. (2021) investigated the relationship between electricity tariffs and consumer responses [10], whereas Guo and Weeks (2022) focused on electricity demand response mechanisms [11]. However, neither study simultaneously incorporated government fiscal policy, consumer behaviour, and producer generation decisions within a unified optimization framework.

To address this research gap, this study proposes a tri-level programming model because the EES inherently involves three sequential and interdependent decision-makers, namely the government, consumers, and producers. The hierarchical interactions among these actors require an optimization framework capable of capturing sequential leader–follower decision-making, which cannot be adequately represented by conventional single-level or bi-level optimization models. Recent studies have demonstrated the capability of tri-level programming in modelling hierarchical decision-making processes in electricity-related applications. Research by Kim et al. (2021) developed a tri-level programming model to examine the interactions between regulators, utility companies, and wholesale electricity markets, leading to more efficient tariff and incentive structures [12]. Similarly, Sohet et al.

(2021) demonstrated that applying tri-level programming to electric vehicle charging systems effectively reduced network costs and enhanced price stability [13]. These studies demonstrate that tri-level programming is well suited for modelling sequential decision-making in complex electricity systems.

Building upon these advances, the present study extends its application to the Electricity Economics System by integrating government tariff and subsidy decisions, consumer demand responses, and producer generation scheduling into a unified optimization framework. To realize this hierarchical optimization framework, the proposed model is implemented using a nested optimization strategy. The tri-level programming model operates via a nested optimization strategy [14], where upper-level government policies are cascaded to middle-level consumers, whose responses subsequently define the target load for lower-level producers [15].

Given the inherent complexities of the Electricity Economics System, the Nelder–Mead algorithm is employed as the solution method for the proposed tri-level programming model [16]. The EES involves nonlinear interactions among government tariff policies, adaptive consumer demand responses, and producer generation scheduling, resulting in a multidimensional and non-convex solution space. In addition, the nested structure of the tri-level model makes the analytical derivation of first-order gradients difficult because the objective function at each level depends on the optimal responses of the lower levels. The Nelder–Mead algorithm is particularly suitable for this type of problem because it is a derivative-free optimization method that does not require explicit gradient information. Instead, it iteratively searches for improved solutions using simplex transformations, making it effective for handling nonlinear, hierarchical, and computationally complex optimization problems.

This study aims to formulate an EES optimization model utilizing a tri-Level Programming approach to support the achievement of national energy policy objectives. The findings are expected to serve as a strategic decision-making instrument for relevant authorities in designing electricity policy frameworks that are more efficient and sustainable within the Indonesian context.

II. METHODS

This research employs a quantitative approach through the mathematical modeling of hierarchical systems [17]. The study follows a systematic procedure ranging from data collection and the development of an optimization theoretical framework to the execution of numerical simulations using Python. Its primary objective is to formulate an optimal electricity subsidy allocation strategy by balancing the economic interests of three distinct hierarchical decision-making tiers.

Within the developed tri-level programming model, each hierarchy is defined by distinct decision variables and specific optimization objectives [18]: (1) at the upper level, the government acts as the primary decision-maker (leader), setting electricity tariffs (x_i) as the decision variable with the aim of minimizing the total national subsidy burden subject to national budgetary constraints; (2) at the middle level, consumers serve as the first followers, determining electricity consumption volumes (y_i) in response to government-mandated tariffs, with the objective of minimizing total economic costs which encompass real billing expenditures and utility discomfort costs; and (3) at the lower level, producers act as the final followers, determining the optimal production mix across various generation technologies (z_j) to minimize internal operational costs while satisfying the aggregate load demand mandated by the consumer level. Figure 1 illustrates the conceptual framework of the tri-level programming optimization model for the electricity economics system:

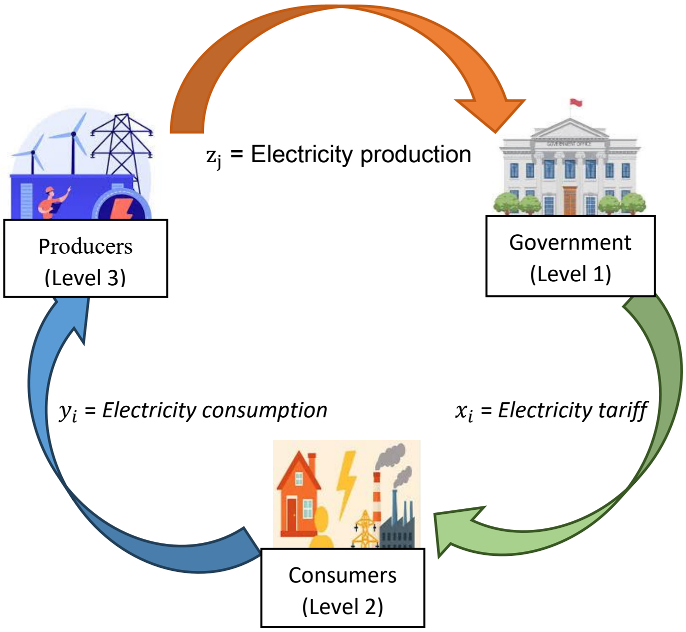

Figure 1: Optimization of the EES(EES)

This research is grounded in secondary data sourced from the 2023 PLN Statistical Report and pertinent academic literature to solidify its theoretical and methodological foundations. The data encompass various critical parameters, including tariff policy limits, demand flexibility, power generation operational costs, production capacities, and consumer sensitivity coefficients. Furthermore, the model integrates invariant system operational parameters, which remain fixed relative to independent unit operational decisions to guarantee the highest level of accuracy in national subsidy calculations.

Tri-level programming is a hierarchical optimization framework employed to resolve decision-making problems involving three distinct tiers of actors that interact within a hierarchical structure [19]. The general formulation of tri-level programming can be expressed as follows [15]:

Level 1 (Upper Level):

$$\min_{x \in X} F_1(x, y, z) \quad (1)$$

$$\text{s.t } G_1(x, y, z) \leq 0 \quad (2)$$

where y, z are the solutions to Level 2 (Middle Level):

$$\min_{y \in Y} F_2(x, y, z) \quad (3)$$

$$\text{s.t } G_2(x, y, z) \leq 0 \quad (4)$$

where z are the solutions to Level 3 (Lower Level):

$$\min_{z \in Z} F_3(x, y, z) \quad (5)$$

$$\text{s.t } G_3(x, y, z) \leq 0 \quad (6)$$

The fundamental characteristic of this model is its nested structure [20], implying that the optimal solution at the upper level (leader) is determined only after accounting for the optimal responses from the two successive follower levels [21].

This study develops an optimization model using a tri-level programming approach to capture the interactions between stakeholders within the national electricity sector. Specifically, index i represents six consumer sectors ($i = 1, \ldots, 6$) encompassing households, industry, business, social, government buildings, and street lighting. Meanwhile, index j denotes seven types of power generation technologies ($j = 1, \ldots, 7$) consisting of Hydro, Coal-fired, Geothermal, Gas, Combined Cycle, Diesel, and Solar power plants. Table 1 summarizes the index notations employed in the model formulation:

Table 1: Model indices

Index	Description	
$\boldsymbol{i}$	Consumer type $-i$ ($i = 1,2,3,4,5,6$)	1 = Household 2 = Industry 3 = Business 4 = Social 5 = Government buildings 6 = Street lighting
$\boldsymbol{j}$	Power generation type $-j$ ($j = 1,2,3,4,5,6,7$)	1 = Hydroelectric Power Plant (HPP) 2 = Coal-fired Steam Power Plant (CSPP) 3 = Geothermal Power Plant (GPP) 4 = Gas Turbine Power Plant (GTPP) 5 = Combined Cycle Gas Turbine (CCGT) 6 = Diesel Power Plant (DPP) 7 = Solar Photovoltaic Power Plant (Solar PV)

The decision variables in this model encapsulate the strategic choices made by each actor within the EES. At the upper level, the decision variable is the electricity tariff defined for each consumer category (x_i), At the middle level, it corresponds to the energy consumption volume per sector (y_i) while at the lower level, the optimized decision variable is the energy production output for each generation technology (z_j). Table 2 presents the decision variables utilized in the model:

Table 2: Decision variables in the model

Variable	Description	Units
$\boldsymbol{x_i}$	Electricity tariff for consumer category i	Billion IDR /GWh
$\boldsymbol{y_i}$	Electricity consumption for consumer sector i	GWh
$\boldsymbol{z_j}$	Electricity production for generation type j	GWh

The parameters in this model constitute fixed values that define the technical, economic, and social characteristics of the power system. These encompass tariff bounds ($x_{i_{min}}, x_{i_{max}}$), ideal consumption targets ($D_{i_{max}}$), consumer sensitivity coefficients (β_i), unit production costs (C_j), generation capacities (K_j), and the invariant system burden (E). Table 3 details the parameters utilized in this study:

Tabel 3: Parameters in the model

Parameters	Description		Value	Units
$\boldsymbol{x_{i_{min}}}$	Lower bound of electricity tariff for consumer category i	1 = Household	0,92492	Billion IDR /GWh
		2 = Industry	0,86426	Billion IDR /GWh
		3 = Business	1,00852	Billion IDR /GWh
		4 = Social	0,66558	Billion IDR /GWh
		5 = Government buildings	1,27034	Billion IDR /GWh
		6 = Street lighting	1,36734	Billion IDR /GWh
$\boldsymbol{x_{i_{max}}}$	Upper bound of electricity tariff for consumer category i	1 = Household	1,38738	Billion IDR /GWh
		2 = Industry	1,29638	Billion IDR /GWh
		3 = Business	1,51278	Billion IDR /GWh
		4 = Social	0,99838	Billion IDR /GWh
		5 = Government buildings	1,90550	Billion IDR /GWh
		6 = Street lighting	2,05102	Billion IDR /GWh
$\boldsymbol{D_{i_{max}}}$	Maximum electricity consumption for consumer category i	1 = Household	146.807,63	GWh
		2 = Industry	106.305,22	GWh
		3 = Business	68.534,40	GWh
		4 = Social	13.795,32	GWh
		5 = Government buildings	6.342,14	GWh

		6 = Street lighting	4.338,23	GWh
$\boldsymbol{\beta_i}$	Consumer sensitivity coefficient for category i	1 = Household	0,00026034	Billion IDR /GWh
		2 = Industry	0,00002084	Billion IDR /GWh
		3 = Business	0,00006307	Billion IDR /GWh
		4 = Social	0,00072370	Billion IDR /GWh
		5 = Government buildings	0,00120180	Billion IDR /GWh
		6 = Street lighting	0,02363891	Billion IDR /GWh
$\boldsymbol{C_j}$	Production cost for generation type j	1 = HPP	0,00026034	Billion IDR /GWh
		2 = CSPP	0,00002084	Billion IDR /GWh
		3 = GPP	0,00006307	Billion IDR /GWh
		4 = GTPP	0,00072370	Billion IDR /GWh
		5 = CCGT	0,00120180	Billion IDR /GWh
		6 = DPP	0,02363891	Billion IDR /GWh
		7 = Solar PV	0,00026034	Billion IDR /GWh
$\boldsymbol{E}$	System operational burden		160.053,211	Billion IDR /GWh
$\boldsymbol{K_j}$	Maximum available capacity for generation type j	1 = HPP	31.510,77	GWh
		2 = CSPP	179.053,52	GWh
		3 = GPP	5.074,32	GWh
		4 = GTPP	24.212,38	GWh
		5 = CCGT	105.900,52	GWh
		6 = DPP	48.990,48	GWh
		7 = Solar PV	283,21	GWh

The objective function serves as the central component of the optimization model, defining the targets to be achieved. At Level 1, the government aims to minimize the national subsidy burden Z_1 which is calculated as the difference between total operating costs and the revenue generated from all consumer sectors. This subsidy minimization process is strictly governed by tariff bound constraints, requiring the tariff decision variable (x_i) to remain within the specified range of the lower bound ($x_{i_{min}}$) and the upper bound ($x_{i_{max}}$). The formulation of the Level 1 objective function is presented below:

$$\min Z_1 = \underbrace{\sum_{j=1}^{J} C_j \cdot z_j^* + E}_{\text{Total cost of supply}} - \underbrace{\sum_{i=1}^{I} x_i \cdot y_i^*}_{\text{Electricity sales revenue}} \tag{7}$$

s.t. $x_{i_{min}} \leq x_i \leq x_{i_{max}},\ \forall_i \in I$ (8)

At Level 2, consumers aim to minimize the total consumer economic cost burden often referred to as the generalized cost which integrates real financial billing expenditures with utility discomfort costs. The determination of optimal consumption (y_i) at this level is subject to sectoral maximum consumption capacity constraints (D_{imax}) as well as system power availability constraints, thereby ensuring that the requested demand volume remains within the corridor of rational requirements. The objective function formulation for Level 2 is presented as follows:

$$min\ Z_2 = \underbrace{\sum_{i=1}^{I}(x_i \cdot y_i)}_{\text{Electricity billing cost}} + \underbrace{\sum_{i=1}^{I}\frac{\beta_i}{2}\left(D_{i_{max}} - y_i\right)^2}_{\text{Discomfort cost}} \tag{9}$$

$$s.t. \quad 0 \le y_i \le D_{i_{max}}, \qquad \forall_i \in I \tag{10}$$

$$\sum_{j=1}^{I} y_i \le \sum_{i=1}^{J} K_j \tag{11}$$

The Level 3 objective function focuses on minimizing the operational expenditures of power generation units through an optimized energy mix. The value of Z_3 is determined by allocating production to generator types with the lowest costs to fulfill the demand load mandated by the consumer level. Optimization at this hierarchy is required to satisfy the energy balance constraint (supply-demand balance), ensuring that the total output from all generation units is sufficient to meet the aggregate community demand. Furthermore, each unit is subject to technical capacity constraints (K_j) which restrict production levels from exceeding the installed power capacity of each specific generation technology. The objective function formulation for Level 3 is presented as follows:

$$min\ Z_3 = \sum_{j=1}^{J} \underbrace{C_j}_{\text{Production cost}} \cdot \underbrace{z_j^*}_{\text{Electricity production}} \tag{12}$$

$$s.t \quad \sum_{j=1}^{J} z_j \ge \sum_{i=1}^{I} y_i^* \tag{13}$$

$$0 \le z_j \le K_j, \ \forall_j \in J \tag{14}$$

In the structure described above, equation (7) represents the government's objective to minimize national subsidies, subject to the tariff policy constraints defined in equation (8). Consumer response is modeled in equation (9) to minimize economic costs, constrained by demand flexibility in equation (10) and the total system capacity limit in equation (11). Finally, producer operations are formulated in Equation (12) to achieve internal cost efficiency, governed by the mandatory fulfillment of the aggregate load demand in equation (13) and the technical capacity limits of each individual generation unit in equation (14).

III. RESULTS AND DISSCUSSION

Following the determination of all parameters, the subsequent stage involves integrating these specific values into the tri-level programming model formulation. The hierarchical integration of this empirical model is structured in a nested configuration as follows:

a. **Level 1 (*Upper Level*)**

$$min\, Z_1 = \sum_{j=1}^{7} C_j \cdot z_j^* + E - \sum_{i=1}^{6} x_i \cdot y_i^*$$

$$\min Z_1 = (0{,}4645z_1^* + 0{,}7869z_2^* + 1{,}2207z_3^* + 1{,}2389z_4^* + 1{,}4732z_5^* + 8{,}7483z_6^* + 11{,}6197z_7^*) + 160.053{,}211 - \sum_{i=1}^{6} x_i \cdot y_i^*$$

subject to:

1. Electricity tariff limits

$x_i^{min} \leq x_i \leq x_i^{max}, \;\; \forall_i \in I)$
$0{,}92492 \leq x_1 \leq 1{,}38738$
$0{,}86426 \leq x_2 \leq 1{,}29638$
$1{,}00852 \leq x_3 \leq 1{,}51278$
$0{,}66558 \leq x_4 \leq 0{,}99838$
$1{,}27034 \leq x_5 \leq 1{,}90550$
$1{,}36734 \leq x_6 \leq 2{,}05102$

b. **Level 2 (Middle Level)**

$$\min Z_2 = \sum_{i=1}^{6} \left[(x_i \cdot y_i) + \frac{\beta_i}{2} (D_i^{max} - y_i)^2 \right]$$

$$\begin{aligned} \min Z_2 = & \left[x_1 y_1 + \frac{0{,}00026034}{2} (146.807{,}63 - y_1)^2 \right] \\ & + \left[x_2 y_2 + \frac{0{,}00002084}{2} (106.305{,}22 - y_2)^2 \right] \\ & + \left[x_3 y_3 + \frac{0{,}00006307}{2} (68.534{,}40 - y_3)^2 \right] \\ & + \left[x_4 y_4 + \frac{0{,}00072370}{2} (13.795{,}32 - y_4)^2 \right] \\ & + \left[x_5 y_5 + \frac{0{,}00120180}{2} (6.342{,}14 - y_5)^2 \right] \\ & + \left[x_6 y_6 + \frac{0{,}02363891}{2} (4.338{,}23 - y_6)^2 \right] \end{aligned}$$

subject to:

1. Maximum electricity consumption limits

$(0 \leq y_i \leq D_{i_{max}}, \;\; \forall_i \in I)$

$y_1 \leq$ 146.807,63 GWh

$y_2 \leq$ 106.305,22 GWh

$y_3 \leq$ 68.534,40 GWh

$y_4 \leq$ 13.795,32 GWh

$y_5 \leq$ 6.342,14 GWh

$y_6 \leq$ 4.338,23 GWh

2. Total generation production limits

$$\sum_{i=1}^{6} y_i \leq \sum_{i=1}^{7} K_j$$

$y_1 + y_2 + y_3 + y_4 + y_5 + y_6 \leq 395.325{,}12\; GWh$

c. Level 3 (Lower Level)

$$min\ Z_3 = \sum_{j=1}^{7} C_j \cdot z_j$$

$$min\ Z_3 = 0{,}4645z_1 + 0{,}7869z_2 + 1{,}2207z_3 + 1{,}2389z_4 + 1{,}4732z_5 + 8{,}7483z_6 + 11{,}6197z_7$$

subject to:

1. Equilibrium between total production and consumption

$$\sum_{j=1}^{7} z_j \geq \sum_{i=1}^{6} y_i^*$$

$$z_1 + z_2 + z_3 + z_4 + z_5 + z_6 + z_7 \geq y_1^* + y_2^* + y_3^* + y_4^* + y_5^* + y_6^*$$

2. Generation production capacity limits

$$0 \leq z_j \leq K_j,\ \forall_j \in J$$

$z_1 \leq 31.510{,}77$ GWh

$z_2 \leq 179.053{,}52$ GWh

$z_3 \leq 5.074{,}32$ GWh

$z_4 \leq 24.212{,}38$ GWh

$z_5 \leq 105.900{,}52$ GWh

$z_6 \leq 48.990{,}48$ GWh

$z_7 \leq 283{,}21$ GWh

The solution of the tri-level programming optimization model for the EES was executed via numerical simulation utilizing Python. To verify the validity of the formulated tri-level programming model, a convergence analysis was conducted [22]. This convergence analysis tracks the trajectory of the objective function values for Level 1 (government) aimed at minimizing the national subsidy burden, Level 2 (consumers) targeting the minimization of the consumer economic cost (generalized cost), and Level 3 (producers) focusing on the minimization of operational generation costs. These values are recorded across each iteration and are presented in Table 4 as follows:

Tabel 4: Convergence analysis of the model

Iteration	Subsidy (Billion IDR /GWh)	Consumer Economic Cost (Billion IDR /GWh)	Generation Cost (Billion IDR /GWh)	Relative Change
1	81.806,23	355.179,77	232.176,04	1,00000000
10	72.677,60	363.522,75	228.726.22	0,02903045
20	40.184,16	393.706,88	216.358,58	0,21001562
30	30.536,64	40.2952,08	212.762,24	0,09512918
40	24.043,54	409.368,72	209.918,38	0,01004949
41	24.043,54	409.368,72	209.918,38	0,00000000
…	…	…	…	…
150	24.043,54	409.368,72	209.918,38	0,00000000

Based on Table 4, the simulation results indicate that the model reached convergence at the 41st iteration with a relative change value of 0.000000. This convergence point signifies the attainment of the Stackelberg Equilibrium, where the upper-level tariff policy aligns with the optimal responses of the lower-tier levels. The consistent decline in the subsidy value throughout the iterative process demonstrates that the Nelder-Mead algorithm effectively navigates the non-linear solution space to identify the global optimum without being trapped in local minima.

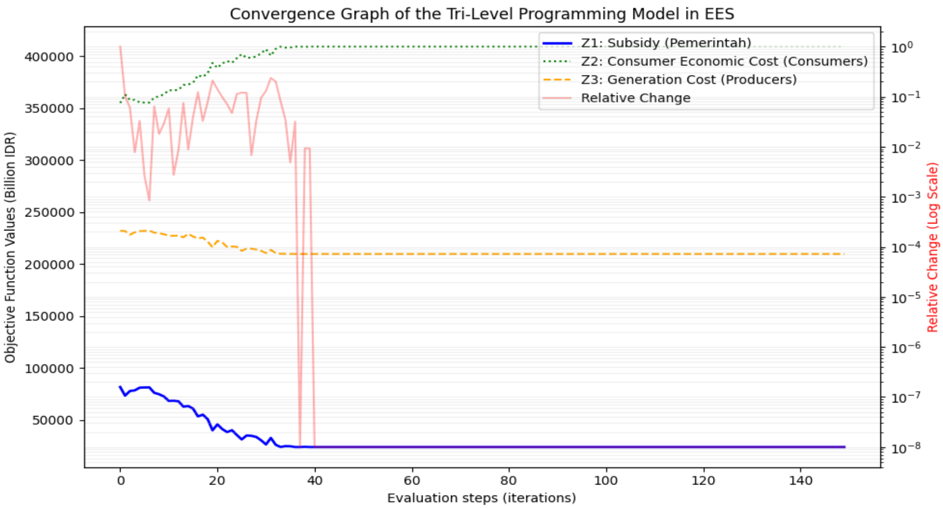

Figure 2: Convergence analysis graph of the model

Figure 2 visualizes the mechanism of the nested optimization algorithm in attaining equilibrium among the three principal actors. During the initial phase (iterations 1–40), significant hierarchical interaction dynamics occurred. The government subsidy value (Z_1) exhibited a consistent downward trend, decreasing from 81,806.23 billion in the initial state to 24,043.54 billion at the 40th iteration. This reduction in subsidy implies a shift in the economic burden toward the consumer side (Z_2) which saw an increase from 355,179.77 billion to 409,368.72 billion. Simultaneously, producers (Z_3) successfully enhanced operational cost efficiency, reducing costs from 232,176.04 billion to 209,918.38 billion through energy mix optimization.

The model attained absolute convergence at the 41st iteration, evidenced by a relative change value of exactly 0.000000. This stable condition is reflected in the constant curve pattern maintained through iteration 150, signaling the attainment of the Stackelberg equilibrium. These results demonstrate that the system has reached an optimal steady state where government fiscal policy is harmonized with the rational responses of both consumers and producers, devoid of further numerical fluctuations.

Upon establishing model stability through convergence analysis, the subsequent step involves dissecting the optimal values generated by the algorithm. The following sections present the integrated optimization results, encompassing government tariff policies, community consumption responses, and producer energy mix strategies.

Tabel 5: Optimization results of the Level 3 objective function

Decision Variable	Description	Production Before Optimization (GWh)	Production After Optimization (GWh)
z_1	Optimal production for HPP	10.655,07	31.510,77
z_2	Optimal production for CSPP	114.598,55	179.053,52
z_3	Optimal production for GPP	4.310,50	5.074,32
z_4	Optimal production for GTPP	1.652,05	24.212,38
z_5	Optimal production for CCGT	36.726,23	12.282,05
z_6	Optimal production for DPP	3.407,29	0
z_7	Optimal production for Solver PV	12,84	0

The Level 3 objective function centers on minimizing power generation operational expenditures through an optimized energy mix:

$$\begin{aligned} min\, Z_3 &= (0{,}4645 \cdot 31.510{,}77) + (0{,}7869 \cdot 179.053{,}52) + (1{,}2207 \cdot 5.074{,}32) \\ &+(2389 \cdot 24.212{,}38) + (1{,}4732 \cdot 12.282{,}05) + 0 + 0 \\ &= 209.818{,}83 \text{ Billion IDR} \end{aligned}$$

The optimization results yield an internal cost (Z_3) of IDR 209,818.83 billion, demonstrating that generation operations have been fully optimized to satisfy the load demand mandated by Level 2.

Tabel 6: Optimization results of the Level 2 objective function

Decision Variable	Description	Consumption Before Optimization (GWh)	Consumption After Optimization (GWh)
y_1	Optimal consumption for the household sector	122.339,69	141.480,61
y_2	Optimal consumption for the industry sector	88.587,68	44.096,60
y_3	Optimal consumption for the business sector	57.112,00	44.572,59
y_4	Optimal consumption for the social sector	11.496,10	12.417,58
y_5	Optimal consumption for the government buildings sector	5.285,12	5.285,39
y_6	Optimal consumption for the street lighting sector	3.615,19	4.280,27

The calculation for the minimization of consumer economic costs yields the following result:

$$\begin{aligned} \min Z_2 &= [196.287{,}36 + 692{,}30] + [57.166{,}13 + 39.845{,}42 \\ &+[67.428{,}53 + 18.150{,}71] + [12.397{,}42 + 68{,}69] \\ &+[6.714{,}22 + 67{,}23] + [5.852{,}60 + 4.697{,}98] \\ &= 345.846{,}26 + 63.522{,}33 \\ &= 409.368{,}59 \text{ Billion IDR} \end{aligned}$$

The minimized Z_2 value of IDR 409,368.59 billion represents an optimal outcome where the community attains energy efficiency with the lowest possible discomfort burden relative to the newly established tariff structure.

Tabel 7: Optimization results of the Level 1 objective function

Decision Variable	**Description**	**Tariff Before Optimization (Billion IDR /GWh)**	**Tariff After Optimization (Billion IDR /GWh)**
x_1	Optimal tariff for the household sector	1,15615	1,38738
x_2	Optimal tariff for the industry sector	1,08032	1,29638
x_3	Optimal tariff for the business sector	1,26065	1,51278
x_4	Optimal tariff for the social sector	0,83198	0,99838
x_5	Optimal tariff for the government buildings sector	1,58792	1,27034
x_6	Optimal tariff for the street lighting sector	1,70918	1,36734

The results of the Level 1 subsidy minimization are as follows:

$$\begin{aligned}\min Z_1 = &((0{,}4645 \cdot 31.510{,}77) + (0{,}7869 \cdot 179.053{,}52) + (1{,}2207 \cdot 5.074{,}32)\\ &+(1{,}2389 \cdot 24.212{,}38) + (1{,}4732 \cdot 12.282{,}05) + (8{,}7483 \cdot 0)\\ &+(11{,}6197 \cdot 0) + 160.053{,}21) - 345.846{,}26\\ &= 369.872{,}04 - 345.846{,}26 = 24.025{,}78 \text{ Billion IDR}\end{aligned}$$

The optimization yields a Z_1 value of IDR 24,025.78 billion, equivalent to IDR 24.03 trillion. This outcome demonstrates a significant saving in the state budget, amounting to IDR 44.61 trillion, compared to the initial baseline subsidy of IDR 68.63 trillion

IV. CONCLUSION

This study successfully developed a tri-level programming model for the EESto support national energy policy objectives. By employing a nested optimization approach, the model effectively integrates the competing interests of the government, consumers, and producers within a unified and systematic decision-making framework. Numerical simulation results demonstrate that the model achieved stable convergence at the 41st iteration, evidenced by a relative change value of exactly 0.000000. The implementation of this model proved highly effective in enhancing fiscal efficiency, with the national subsidy allocation successfully reduced by 65%, specifically from a baseline of IDR 68.64 trillion to IDR 24.03 trillion under optimal conditions.

This significant reduction in the subsidy burden was realized through the synchronization of upper-level tariff policies, which triggered an equilibrium consumption response of 252,133.04 GWh, complemented by merit-order-based energy mix optimization at the lower level, yielding a total internal operational cost of IDR 209.82 trillion. Overall, this model serves as a reliable strategic decision-making instrument for energy authorities in designing electricity policy frameworks that maintain a critical balance between national fiscal sustainability and the protection of public utility.

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