Energy Transformation and GHG Emission Reduction Model: An empirical Strategy for Kupang City, NTT Province, Indonesia

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Abstract- Kupang city is situated in a strategic geographic location flanked by the countries of East Timor and Australia, rendering the city to possess potential prospects in regards to the economy and prosperity of the community. As a follow-up to the sustainable development goals agenda, the local authority is to oversee global collaboration to achieve sustainability of urban, energy and natural resources. This study aims to provide an integrated model between greenhouse gas emissions reduction due to urban activities and the sustainable energy under the SDGs agenda as a case study in Kupang city. The results show share of household mix electricity consumption under GHG constraint as 0%~20% coming from renewable energy which increased rapidly on 14%~18% while the electricity supply increased dramatically between 27.67%~28.73% of the total percentage compared to the electricity generated from diesel. On a certain level of the total of electricity consumed and its greenhouse gases emissions constraint compared to total electricity coming from diesel the ratio is getting raise. Therefore, the optimal constraints at 14%~18% give the most significant allocation of resources energy supplied from the renewable energy system, while the greenhouse gases emissions which decreased dramatically are 874.1 tCO_2e~833.4 tCO_2e with a balanced distribution of added value for each sector. This study supports not only zero emissions and sustainable city but also provides a reference inventory of greenhouse gases emissions refers to regional action plan-greenhouse gases emission reduction.

Keywords Emission reduction, model, renewable energy technology.

1. Introduction

As one of the archipelago countries rich in natural resources potential, Indonesia has positioned itself as an integral part in supporting the sustainable development goals (SDGs) by continuing to play an active role and taking part in addressing sustainable environmental issues. Kupang city as the capital of Nusa Tenggara Timur (NTT) Province in the eastern part of Indonesia which, is the heart of the economy in the province. The city is situated within a strategic geographic location flanked by two countries of East Timor and Australia, making the city a prospect in progressing in the economy activity. Through the SDGs agenda, there is opportunity for supporting local authorities to oversee activities in the SDGs include global collaboration between stakeholders to conduct significant actions in supporting sustainable urbanism, energy and natural resources to mitigate and adapt to climate change [1]–[4]. The current level of global warming has significantly affected the economy such as in Kupang City [5]. Climate change has a negative effect on human life in various fields because of greenhouse gas (GHG) emissions are increasing rapidly due to the industrial development [6], [7]. The activities that use fossil fuels causes GHG emissions around up to 25% of the GHG contributed by heat and electricity generation [8]. These conditions need to get controlled through a comprehensive mathematical approach [8]–[10]. Several studies were conducted regarding energy security in Indonesia. Amheka, et al., [5]–[7], [11] predict and assess the GHG coefficient and total amount of GHG emission caused by economic activities indicated in the Kupang Input-Output (IO) Table. Mujiyanto and Tiess [12] have developed energy trend scenarios to achieve energy balance by 2025. Martosaputro and Murti [13] discuss natural resources potential from wind and the barriers. Suganthi and Samuel [14] reviewed various energy demand forecasting models using time series, regression, econometric and soft computing techniques for optimized new techniques to energy demand forecasting. Recently Adrianus et al. [15] optimize the energy demand in NTT Province using LEAP model and then counts the emission from energy sector. Chang and Li [16] introduced a dynamic model to integrate energy market and policy implication in Southeast Asia. The same and modified models have also been applied to several specific places in assessing the energy policy trends [17]–[21]. Amheka [22] investigated the GHG emission in Kupang through an applied model synchronized to the economic structure. Pan, et al., [23] predicts reduction effect of chief atmospheric pollutants and GHG to show energy consumption using several models and scenarios. The Southeast Asia energy outlook [24], developed by International Energy Agency, focuses on fossil fuel resources potential and energy efficiency policies. Based on several past and current references, the researcher identifies a gap in literature regarding the optimization of energy management specifically at a regional level in Indonesia by using the IO Table with a case study in NTT Province.

2. Electricity System and Renewable Energy Resources in Kupang

Electricity system in Kupang City has been planned and managed by the public electricity company through an integrated network management mechanism of a power plant in Indonesia. The Indonesian government provided targets and identified sources of electricity production by type of renewable energy technology (RET) [25]. However, production and supply of electricity from Solar Power (SP), Wind Power (WP) and Biomass Power (biomass methane fermentation or BMF technology) still yields a very small contribution to the total share of electricity in Indonesia [11]. It is a challenge for the government at the regional level, including Kupang government to harness local natural resources that contribute to the share of electricity produced by SP, WP as well as BMF technology. Integrated network management of electricity produced from RET and non-RET sources should become the focus of government and private sectors. Infrastructure constraints to connect among grids are fundamental problems in the Province where Kupang City is located. Therefore, comprehensive information regarding the introduction of RET and its impact on economic development in Kupang city linked to GHG emissions controlled are necessary to provide a recommendation to NTT Provincial Government [5], [6], [11].

In Kupang nowadays, electricity is generated from a Diesel Power Plant (DPP) operated by a state power company called "PLN Kupang Branch." PLN also serves as administrator of electricity distribution in Kupang. To produce electricity, the government provides sizable subsidies approximately 37.32% covering the production costs to reduce electricity prices which is charged to customers [11] The in-grid system integrated to consumers are very conventional, while electricity infrastructure still needs to be improved [5], [11] Although the electrification ratio (ER) is exceptional, according to the data in Table 1 and Figure 1. Most of PLN customers are households including home industries which on average consumes around 950Wh of electricity per day.

Table 1. Electrification ratio in Indonesia 2008~2013

Unit: %

Year	ER National	ER NTT province	ER Kupang city
2013	80.1#	56#; 37.2*; 70†	no data available
2012	76.56	46; 62.2†	no data available
2011	72.03	44.17	99
2010	67.20	44.37	92.14
2009	66	38.93	96.23
2008	65.10	36.13	95.15

[11], # as of November 2013, *energy outlook & statistic target; † PLN target.

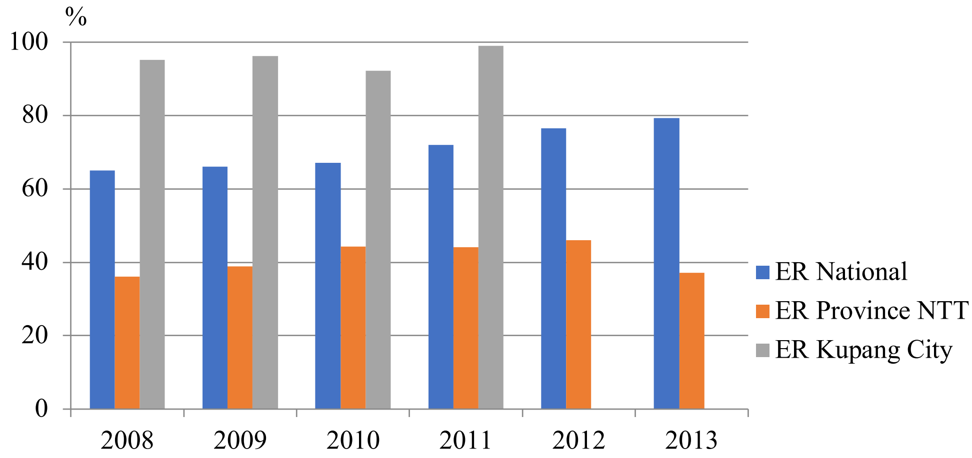

Figure 1. Electrification ratio in Indonesia [11]

One of the problems regarding electricity in Indonesia other than its infrastructure is related to difficulty in data collection, one which is prominent especially in Kupang City. Therefore, electricity data collection including renewable energy potential for further assessment becomes a challenge [7]. To achieve the GHG emission reduction targets along with successful implementation of the Regional Action Plan- GHG emission reduction (abbreviated as RAD-GRK in Indonesian language) program, the utilization of renewable energy to substitute energy supply in the future in is needed [7], [11], [26]–[30]. The current electricity system in Kupang lacks reliability which renders that an integration of the RE system is a solution to anticipate not only reliability but also electricity supply guarantee for the future along with GHG emissions reduction. To build and develop renewable energy sector in Kupang, it requires comprehensive analysis about the availability of resources such as wind, sunlight, geographical situation and other technical data, while possibility to build a biomass power plant and availability of raw materials should be carefully considered. Electricity prices produced by the RET sector is one of many issues which need to be solved. Deals for the feed-in tariff are currently in the negotiation stage. Although the government has issued a standard Feed-in tariff, it is yet finalized and needs more discussion among stakeholders in local level to enable private sectors taking part in the RET investation [11]. Data presented in Figure 2 was taken from the Agency of Meteorology and Climatology (BMKG) Kupang, which shows an average wind speed 2009~2011 around 6-10 m/s/day[11][31]. The wind speed has potential to develop WP on a scale adjusted to average wind speed per day. Determination of proper windmill type will provide effectiveness in electricity production for sharing with DPP in Kupang.

Data released by National Renewable Energy Laboratory (NREL) US Department of Energy [37] suggest that wind speed in Kupang is adequate to establish WP at around 5.5 m/s/ day to 6.3 m/s/day. It firmly mentioned a possibility to construct and develop WP in Kupang to support future electricity supply. Another RE potential possible to develop is the SP as shown in the breakdown data in Table 2.

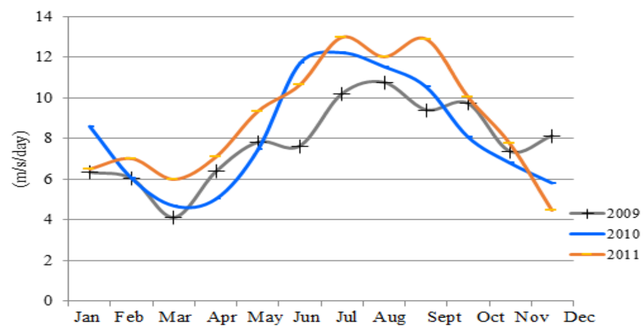

Figure 2 Trends of wind speed 2009~2011 in Kupang, [31] and re-elaborated by Amheka)

In Kupang, the average summer temperature reaches 40 degrees Celsius and solar radiation occurs almost all days of the year, while rainfall is limited. Thus, the development of these new energy industries is feasible. NREL has indicate that in the Eastern region of Indonesia and its surrounds, solar radiation is about 5.1 kWh/m2/day with a monthly variation of around 9% and can be utilized by installing a photovoltaic solar energy system to fulfill electricity demand [32]. Exploiting the potential of renewable energy in Kupang, will not only boost the share of electricity production for domestic needs but also achieve GHG emission reduction.

Table 2. The trend of average temperature and solar radiation in Kupang [31]

Month	1	2	3	4	5	6	7	8	9	10	11	12
Season	RAINY		SUMMERS									
Ave. Temp.	(27 - 33) °C		(30 - 35) °C			(30 - 39) °C					(27 - 33) °C	
Rainfall monthly	460mm										400mm	
Ave. Solar radiation	7-10 Hrs/day		9- 11 Hrs/ day								7 - 9 Hrs/day	

Development of micro-hydro is less precise due to natural conditions in Kupang being quite dry and the absence of a river with a flow rate could reasonably be used for micro-hydro power generation [11]. Renewable energy potential in Kupang can be achieved through SP and WP, while utilization of BMF technology is also promising by using raw material from agricultural and household kitchen wastes. The possibility utilizes geothermal, and natural gas in other areas of NTT Province such as Flores, Rote, Sumba and Alor which are rich in these natural resources. Specification selection of PV modules and windmills to develop RET sector in Kupang should carefully consider the cost [11]. Provision of data concerning national electricity especially regional data in Indonesia is necessary and obligatory. It is necessary to assess any obstacles and challenges, and then to overcome the problems. Moreover, future electrical potential development including the potential for renewable energy development particularly in Kupang city is identified and expressed in this study. Important data provided to conduct simulation in this paper are electrification ratio for Kupang city and NTT province for the last five years, electricity supply for the last ten years, and mapping renewable energy potential for WP and SP for the purpose of data inventor.

3. Empirical Method

This study applies an input-output (IO) Table for the base year 2010 [5] [11] to fit into a panel data, which is then integrated into the model constructed which RET as the new sector to be introduced in Kupang. To analyze impact of RET into the Kupang economy, sector 17 of the original IO Table is arranged separately into Electricity (sector 17) and Water Supply (sector 18). Therefore, the new IO Table has 28 sectors. Sector 18 through 27 in the original IO Table becomes sector 19 through 28 in the same order i.e. 01Paddy rice; 02Corns; etc.

Market Flow Condition (Demand and Supply for Goods and Services)

The total supply of commodities must meet the total demand which is sum of intermediate and final demand. The final demand is composed of household and local government consumption, capital formation, change in stock, and net export, see Eq. 1.

$$X \geq AA \cdot X + A^{RT} \cdot X^{RT} + CP + CG + INV + ST + EX - IM \quad (1)$$

and for 17th sector, the breakdown of the market flow condition is shown in Eq. (2).

$$X(17) + \frac{\eta \cdot \sum X_{RT}(i)}{\varepsilon_i} = \sum AA(17,i) \cdot X(i) + A^{RT}(17,i) \cdot X^{RT}(i) + CP(17) + CG(17) + INV(17) + ST(17) + EX(17) - IM(17) \quad (2)$$

where, X: production vector of usual sectors (en); X^RT: production vector of RET sectors (en); AA: IO coefficient matrix of usual industries including DPP sector (ex); A^RT: IO coefficient matrix of RET sectors (ex); η: IDR value unit of power electricity (via DPP); ε_i: i=1 through 5, is the IDR value unit for solar power electricity generation sectors, i=6 through 10, is the IDR value unit for wind power generation sectors, and i=11 through 15, is the IDR value unit for biomass power generation sectors (ex); CP: consumption vector demand by household (en); CG: consumption vector of local government (en); INV: private and government capital formation vector (en); ST: changes in stock vector (en); EX: export vector; (endogenous but confined within an interval); IM: import vector (endogenous but confined within an interval).

$$INV_p(i) = i\_rate_p(i) \cdot I_p, \quad (3)$$

$$INV_g(i) = i\_rate_g(i) \cdot I_g, \quad (4)$$

where, I_p: total investment (capital formation) in monetary terms by the industrial (private) sectors (en); I_g: total investment (capital formation) in monetary terms by the government (en); $i\_rate_p(i)$: demand coefficient for product of i-th industry that is induced by one unit capital formation in the industrial sectors (ex); $i\_rate_g(i)$: demand coefficient for product of i-th industry that is induced by one unit capital formation by the government (ex).

The stock change in Kupang was influenced by investment and the contribution from the national government via a mechanism support funding called special funding. The trend of stock describes as in Eq. (5):

$$ST(i) = st_{ratio}(i) \cdot S_T \quad (5)$$

where, S_T : total stock increase if positive or decrease if negative in monetary terms (en); $st_{ratio}(i)$: rate of increase in stock of i-th product induced by increase the quantity of total stock (ex).

It is assumed that exports and imports are to some degree inflexible against changes in the demand-supply of products:

$$lower_{EX} \cdot \overline{EX(i)} \leq EX(i) \cdot upper_{EX} \cdot \overline{EX(i)}, \quad (6)$$

$$lower_{IM} \cdot \overline{IM(i)} \leq IM(i) \cdot upper_{IM} \cdot \overline{IM(i)}, \quad (7)$$

where, $\overline{EX(i)}$: export data of the i-th product (ex); $\overline{IM(i)}$: import data of the i-th product (ex); $lower_{EX}$: parameter which defines the lower boundary for export ($lower_{EX}$ is less than one (1)) (ex); $upper_{EX}$: parameter which defines the upper boundary for export ($upper_{EX}$ is greater than one (1)) (ex); $lower_{IM}$: parameter which defines the lower boundary for import ($lower_{IM}$ is less than one (1)) (ex); $upper_{IM}$: parameter which defines the upper boundary for import ($upper_{IM}$ is greater than one (1)) (ex).

GHG Emission Reduction Constraint

It refers to the data regarding GHG emission in Kupang:

$$ZZ = \sum coeff_c(i) \cdot X(i) + coeff_c^{RT}(i) \cdot X^{RT}(i) \leq \left(1 - \frac{red_r}{100}\right) ZZ_{bar} \quad (8)$$

where, ZZ_{bar}: the total CO_2 emission in Kupang in 2010 (ex); red_r: GHG reduction rate in percentage (ex); ZZ: GHG emission after introduction of GHG constraint (en).

Household income is the total of wages and surplus net of corporation tax. It is assumed the corporation tax ratio is 10%. It describes value-added and distribution [11], [22].

Objective Function

To drive this market-oriented economic system, the gross regional product (GRP) is maximized and economic status after the introduction of policies area described with solutions to maximize the GRP by taking into account the added value rate and quantity output of both usual and RET industries. A breakdown of the formula is as follows:

$$\text{MAX } GRP = \text{MAX } \sum vv(i) \cdot X(i) + \sum vv^{RT}(i) \cdot X^{RT}(i) \quad (9)$$

Where, $vv(i)$: (gross) added value ratio of usual sectors (en); $vv^{RT}(i)$:(gross) added value ratio of RET sectors (en); X^{RT} : the maximum number of facilities or plants which can be installed with i–th RET sectors.

4. Results and Discussion

The energy structure transformation will be analyzed to find amount for the share of electricity consumption of households and share of electricity supply in Kupang. Thus, the merits and demerits of SP, WP and BMF technology can be realized.

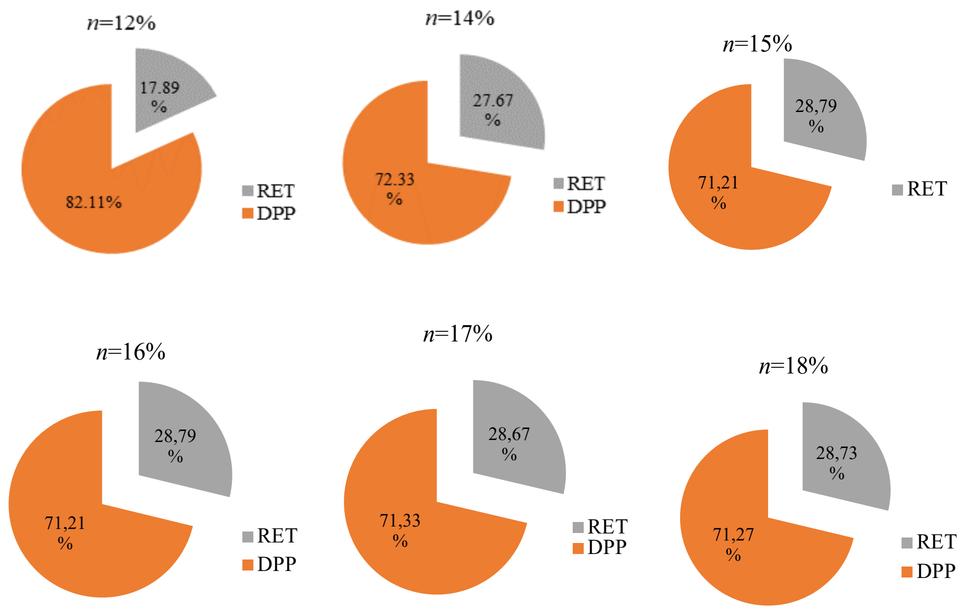

Figure 3. Share of RET electricity consumed by households under differences *n*

As identified in Figure 3, under GHG emission constraints the share of RET electricity consumption increased rapidly after *n*=14%~18%. For example, at *n*=12% the share of consumption contributed by RET is only 17.69%, for *n*=14%~18%, shared rapidly increases to between 27.67%~28.73% of total share of consumption compared to DPP. For *n*=19%~20% reached 25%~26% of the total share, while compared to the total shared consumption with the DPP at level *n*=0%~12% is around 16.69%~18.89%. Therefore, the optimal constraints are around *n*=14%~18% which gives the largest share of RET electricity. Total breakdown shares of electricity consumed by household compared to the DPP in every constraint is indicated in Table 3.

Table 3. Share of RET electricity and household consumption

n	RET (%)	DPP (%)
0	16.69	83.31
1	16.85	83.15
2	16.45	83.55
5	16.17	83.83
7	16.52	83.48
10	17.03	82.97
12	18.89	82.11
14	27.67	72.33
15	28.79	71.21
16	28.79	71.21
17	28.67	71.33
18	28.73	71.27
19	26.25	73.75
20	24.93	75.07

We assessed the total electricity supplied from new energy power generation compared to the DPP, and the same previous assumptions hold, that an increase of GHG constraints will improve the supply of electricity produced under new power generation with different constraints as indicated in Table 4.

Table 4. Share of electricity produced by RET sector to total electricity

n	RET sector (%)	DPP (%)
0	12.39	88
1	12.39	88
2	12.39	88
5	13.90	86
7	14.96	85
10	15.30	85
12	16.07	84
14	23.12	77
15	25.85	84
16	25.85	74
17	26.04	74
18	25.85	74
19	23.63	76
20	23.25	77

The distribution pattern of the electricity share produced by new energy power generation compared to the DPP is similar for *n*=14%~18% compared to *n*=0%~12% and *n*=19%~20%. The highest share of electricity produced in level *n*=14%~18% is 23.12%~25.85% then reduced to around 24% after *n*=19%. While for *n*=0%~12% total electricity share produced is around 12.39%~16.07%. Therefore, the most optimal solution to be recommended is on the *n*=14%~18%. In addition to optimal in the distribution of share electricity, the model also enables to reduce the GHG emission on *n*=14%~18% around 874.1 tCO_2e~833.4 tCO_2e compared to GHG emission in Kupang year 2010 as the base year in this study.

Kupang government requires support from various parties in the framework of supply and utilization of secondary energy, especially electricity sourced from renewable energy. The framework is necessary to achieve energy security to improve the economic development of Kupang City to realize a low carbon and/or sustainable city in the near future as concrete efforts in supporting SDGs. The proposed model is applicable in local areas both in Provincial and urban levels that has similar economy structures The model can further be applied in other local regions which would require certain adjustments including rural area, although on the other hand, it must consider the WTP from the community as consumers for the development of the model [33] The implications of this study directly support government programs, especially the regional government of the NTT Province which was proclaimed by the governor Mr. Viktor Bungtilu Laiskodat through middle-term development plan 2018-2023, which in Indonesian language is known as *Rencana Pembangunan Jangka Menengah Daerah (RPJMD) Pemerintah Provinsi NTT*, to synchronize government middle-term performance and SDGs targets, realizing NTT as a world element in creating green prosperity to reach SDGs targets. The implications of this study allow this energy management model to be applied in other regions.

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