Investigating Techno-Economic Feasibility of Geothermal Polygeneration in Nusalaut Island, Central Maluku District, Maluku Province

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Abstract: As an archipelagic country crossed by the Ring of Fire, Indonesia has significant geothermal potential, and Nusa Laut Island is one of the islands with this potential. Thus, this research was conducted to study how to utilize low-medium geothermal energy to produce the needs of the population on Nusalaut Island. The configuration of geothermal poly generation is used to produce electricity, clean water, and a cooling system to preserve marine catches. The modeling confirms that it will generate 1.9 MWe of electricity, 21.8 m³ of fresh water production/hour, and a cold storage capacity of 36 tons of fish/ day.

1. Introduction

One of the most promising sources of renewable energy in Indonesia is geothermal energy[1,2]. The utilization is still low in comparison to Indonesia's geothermal energy potential, which is being worked on to enhance[3,4]. Due to technological constraints, the geothermal exploitation only focused on high temperature geothermal resources, with a smaller proportion on medium and low temperature geothermal resources[5]. However, these resources are favorable in terms of location, because it spreads evenly not only in high terrain, but also in low terrain and coastal area. It was believed that the cascade system was a method for optimizing the use of low and medium-enthalpy geothermal resources in range 125 °C -225°C with varying temperatures to generate multiple products[6]. Cascade systems, also known as polygeneration systems, refer to the use of multiple energy sources at the same time to produce a variety of products. Polygeneration is a sustainable energy system that maximizes the use of energy and natural resources while reducing emissions and increasing economic feasibility[7,8]. The polygeneration system plays a significant role of improving the performance of energy system. It shows promise as a long-term solution because of its efficient use of resources, increased effectiveness, and environmental friendliness[8]. The polygeneration utilization scheme varies according to the temperature of the resources; the

higher the temperature, the greater the opportunities. Lindal's diagram depicts the variety of applications of a geothermal resource based on temperature. Higher temperature geothermal resources correspond to higher pressure geofluids and are primarily used to generate electricity or for indirect use, whereas low to medium temperature geothermal resources correspond to lower pressure geofluids and are used for direct use such as heating, cooling, desalination, and electricity generation using the binary cycle. However, the limitation of geothermal direct utilization is that flowing geothermal fluids must be aided by a pump[9].

Many authors conducted studies on geothermal polygeneration, the majority of which were theoretical in nature (modelling and simulation). One of the earliest researchers on poly-generation systems was conducted by Ratlamwala et al. (2012), they proposed an integrated system to generate electricity, cooling, heating, hot water, and hydrogen that used geothermal energy as its prime mover[10]. Lee et al. (2019) carried out a thorough examination of geothermal energy systems from the standpoints of systems analysis, design, and optimization[11]. The use of low and medium enthalpy geothermal resources in a cascade system that has been successfully implemented in several places around the world was reviewed by Maya et al. (2015)[5]. Ambriz-Diaz et al (2020) studied analysis of exergy and

exergoeconomic of a geothermal polygeneration plant[12]. Calise et al. published numerous papers in which they investigated the thermodynamics and economics of hybrid solar and geothermal polygeneration in various configurations[13-15].

1.1 Site Description

The geothermal potential in Nusalaut, specifically in Nalahia village on Nusalaut Island, has been selected as the sole focus for this case study. Nusalaut geothermal potency isthe only geothermal potency located in Nalahia village, Nusalaut island, was chosen for the case study. Nusalaut island located in central Maluku Province, the geographical location of the study area is illustrated on a map as shown in Fig. 1. Reconnaissance survey has been conducted of Nusalaut geothermal field by Geological Agency in 1977 and find the existence of geothermal manifestation at coordinates 3039.286 south latitude – 128046.852 east longitude, and 3038.714 south latitude – 128046.621 east longitude[16-19].

A medium-temperature geothermal system with an estimated temperature ranging from 170 °C to 218 °C, determined using a Geothermometer NaK, exhibits speculative resources totalling 25 MWe[20,21]. The phenomenon of a medium geothermal field, which is commonly not self-flowing wells, was not considered in this study because the authors did not perform groundwater level analysis to ensure the ability of the well to be self-flowing wells.
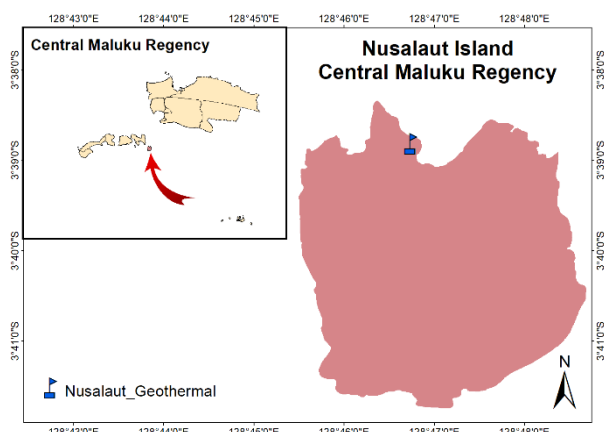

Fig. 1. A modified map of Nusalaut island [17,19]

Nusa Laut Island has a total area of 32.5 km², and a population of 5,780 people or 1,488 households[23-24]. The electricity in this Island is solely dependent on a diesel power plant with installed capacity of 1.107 kWe (net electrical capacity of 620 kWe)[25]. This location's geothermal potential creates an opportunity to substitute diesel power plants and provide a more secure supply of a 24-hour. Depend on the location and for long term generation, the costs of producing geothermal energy are thought to be much lower than those of the diesel generators they substitute (approximately half)[26]. Rural electrification could improve living standard, including

healthiness and education, while also empowering the community[27]. The electricity demand of Nusalaut island is calculated using the net electrical capacity of 620 kW to meet the needs of 1488 households. Currently, electricity consumption in Nusalaut is relatively low; however, the presence of geothermal power plants is expected to increase energy consumption. Small-scale geothermal power plants can be built to meet current needs and resources. Related to this study, small-scale geothermal power plants have been developed by Agency for the Assessment and Application of Technology (BBPT) which has successfully design 100 kW binary cycle power plant and built a condensing type wellhead pilot plant with a capacity of 3 MW in Kamojang, West Java[28-29].

Apart from electricity, fresh water is also a basic need particularly for people living in coastal areas. The need for filtered or desalinated water is essential for human life on this planet due to population growth[30]. Fresh water needs are met by existing water sources on the island; however, other alternatives are required to meet fresh water needs. On Nusalaut island, there are six main sources of fresh water[24], which are based on minumun basic water requirement for human activity is considered insufficient. Geothermal energy can be used directly by multiple-effect distillation (MED) technology, or indirectly using the electrical energy by reverse osmosis (RO) technology. According to Goonsen et al. (2014), water desalination using renewable energy is economically and environmentally feasible in remote or isolated areas[31]. It is obvious that geothermal-sourced desalination facilities are the most practical choice for nations with an abundance of geothermal energy resources because they can produce fresh water at a reasonable cost[32]. The basic needs of fresh water are assumed to be 175 litre/capita/day which is a realistic everyday acceptable limited needs consumption[33].

Nusalaut is a coastal area with the main commodities are plantation and fishery products. Plantation commodities like nutmeg and cloves have a high market value and furthermore, commodity processing has the potential to increase added value[23,24]. Nusalaut is well-known for its high-quality fishery products such as fish, seaweed, pearl, and sea cucumber[23,24]. These commodities necessitate cold storage in order to keep good quality caught fish and aquatic commodities in the best condition for extended periods of time. Fishery product preservation allows for a higher selling price. Six of the seven villages on Nusalaut Island are classified as developing villages, which means that their social, economic, and ecological resources have not been managed optimally[34]. The food and agriculture organization (FAO) code of practice for frozen fish recommends that products should be stored at -18 to -30°C[35]. Applications for the cooling system include air conditioning, pharmaceutical storage, and food processing, etc. However, the estimated electrical energy consumption for refrigeration systems is 15% of total

global consumption[36]. Absorption refrigeration system just needs low-grade heat as an energy source[37].

The utilization scheme for a geothermal resource is tailored to the needs of the population in the area where it is found. The proper resource mapping is critical when designing a polygeneration system[8]. It is necessary to map available natural resources in order to select suitable polygeneration outputs. Since resources and other factors vary, the design of a polygeneration system is distinctive; therefore, proper mapping of available resources is crucial. As a result, proper mapping of available resources is critical. In general, power is a significant output of polygeneration. The type of power plant is chosen based on input fuels, its characteristics and availability. In order to meet local needs, outputs from decentralized polygeneration should be in line with local demand. Supply and demand should be matched for distributed polygeneration plants[8]. This paper provides an overview of the best use of geothermal resources, particularly energy, on the island of Nusalaut. This research aims to evaluate the viability of geothermal polygeneration on Nusalaut island.

1.2 System Description

Once the needs of a community in a rural area have been identified, the configuration of geothermal polygeneration can be carried out to determine the most appropriate utilization. The appropriate configuration of geothermal polygeneration to be used is based on the needs of the coastal community on Nusalaut island. A polygeneration system proposed in this study was designed based on local needs: a binary cycle for generating electricity, a desalination unit for producing fresh water and cold storage for preserving fishery commodities as illustrated in Fig. 2 .
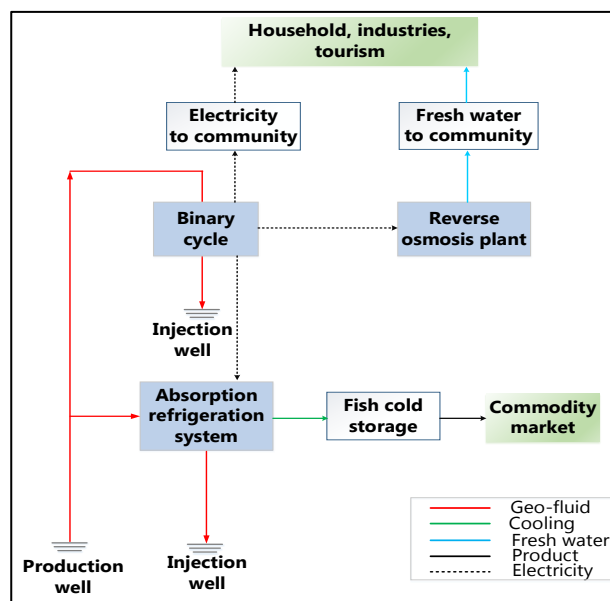

Fig. 2. A proposed schematic geothermal polygeneration system in Nusalaut island

A basic Organic Rankine Cycle (ORC) was employed in this study to generate electricity, a reverse osmosis desalination plant was chosen in this study with consideration the flexibility of product capacity and Absorption refrigeration systems are preferred for refrigeration because they can use a low-temperature heat source. LiBr-H_2O system is commonly used for air conditioning because its refrigeration temperature limited to 0°C, whereas NH_3-H_2O is preferred for deep refrigeration despite its lower COP value[38]. Excess electricity and fresh water supply could be used to develop industry and tourism.

Fig. 3 is a schematic representation of the planned geothermal polygeneration system. As shown in Fig. 3, the geothermal polygeneration system is an integration of ORC, a Reverse Osmosis (RO) for desalination and an Absorption Refrigeration Cycle (ARC) with a mixture of ammonia-water. The description of the schematic diagram is as described in Table 1. Hot geofluid coming from a production well produce from production well at point 1 to evaporator (ORC unit) and to generator (ARC unit), leaving at point 3 outlet preheater and at point 4 directly to injection well. The geothermal fluid from the production well is estimated to have a temperature of 170 C and a total flow rate of 28 kg/s (25 kg/s to ORC and 3 kg/s to ARC). In the organic rankine cycle, the working fluid is pumped into evaporator (point 5), to absorb the thermal energy from hot geofluid.
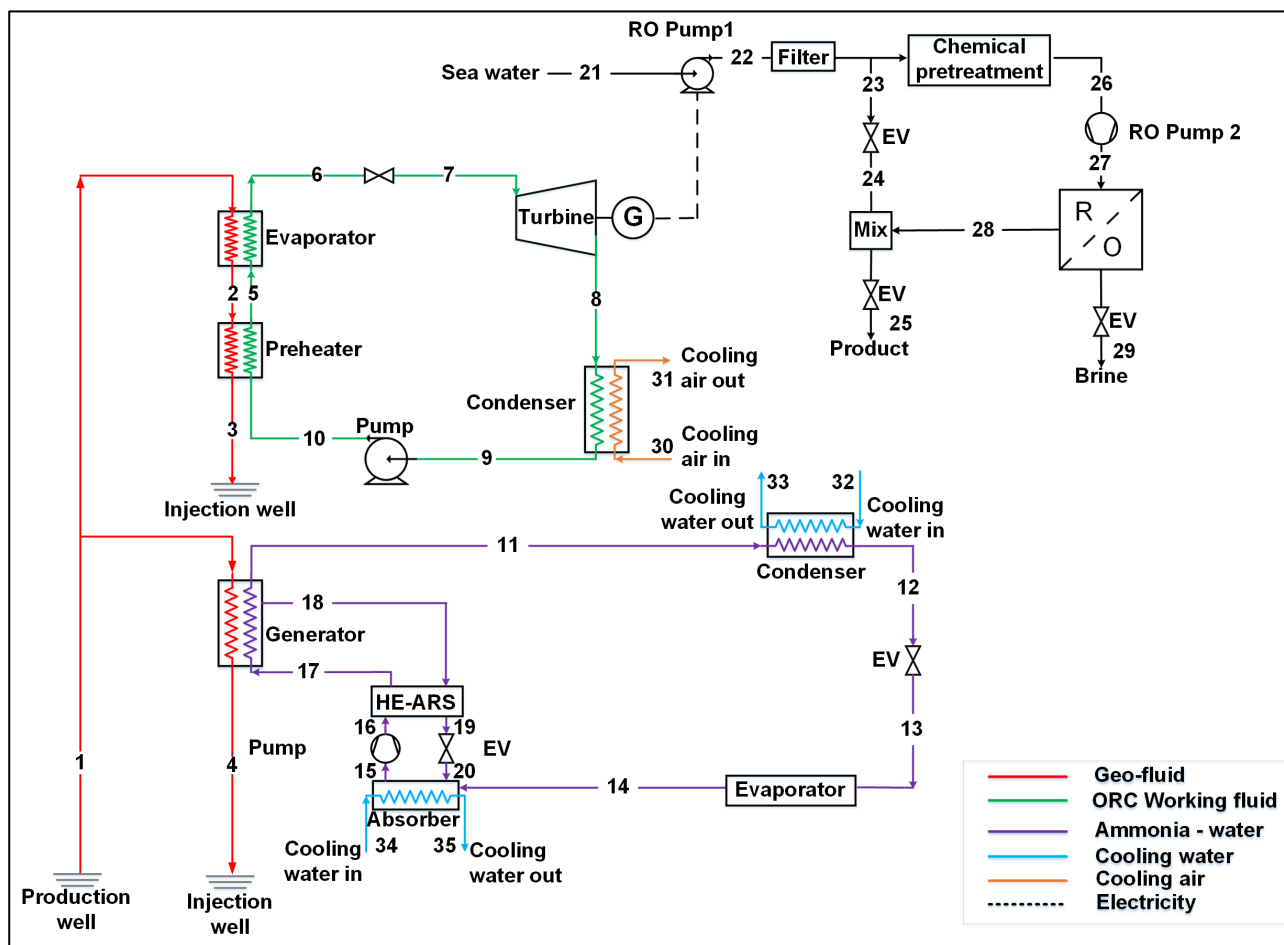
Fig. 3. The Schematic diagram of the proposed geothermal polygeneration

The saturated vapor of the working fluid leaving the evaporator then enters the turbine for expansion work (point 7). The turbine exhaust is cooled in the condenser (point 8) then returning to the pump (point 69). In the absorption refrigeration cycle, the ammonia-rich vapor is heated by geofluid in the generator, this vapor is cooled in the condenser to a saturated liquid (point 12). This stream is sent into the evaporator to absorb the heat from the surroundings. The outlet of the evaporator is the two-phase ammonia (refrigerant) enters the absorber (point 14) then absorbed by strong solution leaving from generator (point 18) to form weak solution (point 11) then pumped into the generator (point 17) and leaving as the high-pressure ammonia-rich vapor. The expansion valve (point 19) repressurizes the strong solution, which then returns to the absorber (point 1). The main component of the RO system is a pump unit that delivers high-pressure feed water to a group of membrane modules. RO pump 1 boosts the flow of seawater through the filter (point 19). The filter outflow is split into two, for chemical pretreatment (point 23) and pretreatment outflow enters the RO membrane, where it is divided into low salinity product (point 26) and high salinity brine (point 25).

Table 1. Description of the schematic diagram

State no	Description	Fluid
1	Geothermal fluid from production well to ORC and ARS	Brine
2	Geothermal fluid outlet evaporator to preheater	brine
3	Geothermal fluid outlet ORC unit to injection well	Brine
4	Geothermal fluid outlet ARS unit to injection well	Brine
5 – 10	ORC cycle	n-Pentane
11 – 20	ARS cycle	NH_3-water
21 – 29	RO unit	Seawater
30 – 31	Condenser cooling air (ORC)	Air
32 – 35	Cooling water (ARS)	Water

2. Methodology

Polygeneration can be evaluated from different points of view. The polygeneration system is designed with the most possible combinations in mind. There are four steps for designing possibility of utilization a low/medium geothermal potential;

a. Identifying rural energy (electricity and thermal) and basic needs

b. Develop a specific configuration for matching needs and geothermal potential to optimize the utilization
c. Develop a thermodynamic model and exergy analysis of geothermal polygeneration
d. Evaluation of economic analysis

2.1 Energy and exergy analysis

Exergy refers to the greatest work production that each system could theoretically achieve in relation to its surroundings. As there is no possibility for producing work when fluids are in thermodynamic equilibrium with their environment, this state is commonly referred to as the dead state, and the fluid may be termed "dead"[36]. The exergy rate can be calculated from multiplying the mass flow rate by the specific exergy as follows:

$$\dot{E} = \dot{m}\big(h - h_o - T_o(s - s_o)\big) \qquad (1)$$

T_o is the ambient or dead state temperature, h_o and s_o represent the enthalpy and the entropy at the dead state whereas h and s are specified at each stage. According to Kotas (1985), rational efficiency is defined as the ratio of exergy recovered to exergy provided to the system or process:

$$\eta_e = \left(\frac{E_{desired}}{E_{input}}\right) \qquad (2)$$

$$\dot{E}_{input} = \dot{E}_{output} + \dot{E}_{destroyed} \qquad (3)$$

$$\dot{E}_{output} = \dot{E}_{desired} + \dot{E}_{waste} \qquad (4)$$

where
$\dot{E}$ input $\quad$ = the amount of energy input of the system
$\dot{E}$ output $\quad$ = the amount of energy output of the system
$\dot{E}$ desired $\quad$ = the total amount of exergy outputs that are wanted (net work done by the system);
$\dot{E}$ destroyed = the quantity of exergy lost in the system due to its irreversibility.
$\dot{E}$ waste $\quad$ = energy that leaves the system but can still do work.

The thermodynamic goal in evaluating polynegeration systems is energy efficiency. Exergy analysis assists in determining the causes, locations, and magnitude of system inefficiencies associated with chemical reaction, heat transfer, mixing, and friction, as well as providing an accurate measurement of how far the system deviates from its equilibrium state [40]. The thermodynamic model, energy and exergy analysis of the proposed configuration has been conducted using Engineering Equation Solver (EES) software. The following formulas can be used to calculate the mass balance, energy balance, and exergy balance:
Mass balance equation:

$$\sum_i \dot{m}_{in} = \sum_i \dot{m}_{in} \qquad (5)$$

Concentration balance equation:

$$\sum(\dot{m}_{out}Y) = \sum(\dot{m}_{in}Y) \qquad (6)$$

Energy balance equation:

$$\dot{Q}_{cv} - \dot{W}_{cv} = \sum(\dot{m}_{out}Y) - \sum(\dot{m}_{in}Y) \qquad (7)$$

Exergy balance equation:

$$\dot{X}_{des} = \sum_{out}\left(1 - \frac{T_{amb}}{T_j}\right)\dot{Q} - \sum_{in}\dot{m}.E_x - \sum_{out}\dot{m}.\dot{E}_x \qquad (8)$$

Several assumptions to be taken are:
- The system operates in a steady state condition
- The system is adiabatic or without thermal losses
- The pressure drop in pipes and heat exchangers is regarded as insignificant.
- The heat exchangers are well insulated, heat lossess are neglected

2.2 Design parameters

Design parameters of the geothermal polygeneration were based on the data of Nusalaut geothermal resources. The operating parameters of each component should be determined before running the simulation as shown in Table 2, Table 3 and Table 4. The thermodynamic goal in evaluating polynegeration systems is energy efficiency (η) and exergy efficiency (ε)[41]. Exergetic efficiency represents the proportion of the fuel exergy supplied to a system that is found in the product exergy.

Table 2. Operation parameters for ORC unit

Parameters	Value
Geofluid	
$\quad$ Mass flow	$m_1 = 25$ kg/s
$\quad$ Temperature	$T_1 = 170$ °C
$\quad$ Pressure	$P_1 = 20$ bar
Working fluid	n-Pentane
$\quad$ Pressure inlet turbine	$P_4 = 15$ bar
Temperature pinch point vaporizer	$T_{pp\_vap} = 10$ °C
Temperature pinch point condenser	$T_{pp\_cond} = 7$ °C
Delta temperature of condenser	$\delta T_{cond} = 7$ °C
Temperature superheat	$T_{superheat} = 2$ °C
Efficiencies	$\eta_{Tur} = 0.85$, $\eta_{Pump} = 0.75$, $\eta_{Fan} = 0.65$
Temperature of air inlet	$T_{air} = 30$ °C
Temperature of air outlet	$T_{air\_out} = T_{air} + T_{pp\_cond}$
Temperature of condensation	$T_{Cond} = T_{air\_out} + T_{pp\_cond}$

Table 3. Operation parameters for Desalination unit

Variable	Symbol	Unit	Range
Mass flow of seawater	msw	kg/s	28
Mass flow of fresh water	mfw	kg/s	21.8
Recovery rate for a product	Rr	-	0.4-0.7
Salinity of seawater	Ssw	ppm	35.000
The salinity of the Product	Spw	ppm	450
Salinity permeation		ppm	20
Brine salinity	Sbw	ppm	70.000
Efficiency of RO LP pump	η_{LP}	-	0.87
Efficiency of RO HP pump	η_{HP}	-	0.91
Reference of salt enthalpy	hs,o	kJ/kg	21.05
Reference of salt entropy	ss,o	kJ/kg.K	0.077328
outlet pressure of LP pump	P_{LP}	kPa	650
outlet pressure of HP pump	P_{HP}	kPa	6.000
outlet pressure of Brine	P_b	kPa	5.100
outlet pressure of Permeate	P_p	kPa	110
volume flow rate of Permeate	V_{el}	m^3	1.5
coefficient of Salt permeability	Ks	$m^3/m^2.s$	2.03×10^{-5}
coefficient of Water permeability	Kw	$m^3/m^2.s.kPa$	2.05×10^{-6}
duration of Annual operation	τ	hours	7,000
factor of Maintenance	Ø	-	1.12
Effective interest rate	i	%	12
Plant life	n	years	10

Table 4. Operation parameters for Absorption Refrigeration Unit (ARS) unit

Parameters	Value
Absorber output temperature	$T_{12} = 40 \,°C$
Generator output temperature	$T_8 = 120 \,°C$
Condensing	$T_{10} = 40 \,°C$
Evaporating	$T_{11} = -23 \,°C$
Efficiency of the pump,	$\eta_P = 0.85$
Other efficiencies:	$\varepsilon_{HE} = \varepsilon_{rect} = \varepsilon_{abs} = 0.95, \varepsilon_{gen} = 0.98$
Vapor quality in the output evaporator	$q_{11} = 0.915$
Mass fraction at the rectifier output	$x_7 = 0.99$
Difference in the composition of recirculation of absorber	$x_1 - x_5 = 0.3$

2.3 Economic and cost analysis of the system

The first step in any comprehensive cost estimation is to calculate the cost of the purchased equipment (including replacement parts and components)[48]. The Log Mean Temperature Difference (LMTD) was used to figure out the heat transfer surface area (A) of each heat exchanger. The cost of other major components, such as the turbine and pump, is estimated based on power capacity. The purchase equipment cost (PEC) for each component in geothermal polygeneration system was calculated using the following formula[43,49]:

ORC components:

$$PEC_{ph,ORC} = 450 \cdot A_{ph,ORC} \tag{9}$$

$$PEC_{ev,ORC} = 450 \cdot A_{ev,ORC} \tag{10}$$

$$PEC_{cd,ORC} = 600 \cdot A_{cd,ORC} \tag{11}$$

$$PEC_T = 450 \cdot \dot{W}_T \tag{12}$$

$$PEC_P = 450 \cdot \dot{W}_P \tag{13}$$

$$PEC_F = 450 \cdot \dot{W}_F \tag{14}$$

$$PEC_{abs,ARS} = 500 \cdot A_{abs}, ARS \tag{15}$$

$$PEC_{shx,ARS} = 500 \cdot A_{shx}, ARS \tag{16}$$

$$PEC_{des,ARS} = 500 \cdot A_{des}, ARS \tag{17}$$

$$PEC_{cd,ARS} = 500 \cdot A_{cd}, ARS \tag{18}$$

$$PEC_{ev,ARS} = 500 \cdot A_{ev}, ARS \tag{19}$$

$$PEC_{rec,ARS} = 500 \cdot A_{rec}, ARS \tag{20}$$

$$PEC_{P,ARS} = 2100 \cdot \dot{W}_{P,ARS} \tag{21}$$

$$PEC_{,RO} = N \cdot PEC_m \tag{22}$$

$$N = r_r \cdot \dot{V}_{RO} \Big/ \dot{V}_{el} \tag{23}$$

$$PEC_m = 10 \cdot A_{RO} \tag{24}$$

$$A_{RO} = \frac{\dot{m}_{el} \cdot y_{s,RO}}{ks \cdot (\bar{y} - y_{s,RO})} \tag{25}$$

$$\bar{y} = \frac{(\dot{m}_{feed} - \dot{m}_{bypass}) y_{s,t} + \dot{m}_b \cdot y_{s,b}}{\dot{m}_{feed} - \dot{m}_{bypass} - \dot{m}_b} \tag{26}$$

$$\dot{m}_{bypass} = \dot{m}_p \left[\frac{y_{s,p} - y_{s,RO}}{y_{s,p} - y_{s,RO}} \right] \tag{27}$$

3. Result

The minimum requirements of Nusalaut community are shown in Table 5, which was estimated using information and data in public domain and tailored to the island's population. The calculation was based on assumption the basic water requirement and the basic electricity requirement for lighting. The capacity of the diesel generators that are intended to be replaced by geothermal plants is used to estimate the amount of electrical energy required. The estimated electricity generation is 1.6 MWe

whereas the basic needs is only 620 kW, the excess electrical energy is used to operate desalination plants and cold-storage facilities, as well as to develop the industrial and tourism sectors on the island of Nusalaut. The desalination unit is designed to fulfill the people of Nusalaut's in need of fresh water that estimated can reach up to 21.8 kg/s whereas the minimum water requirement is about 11.7 lt/s, and the cold storage is designed to accommodate the commodity fish caught in Nusalaut up to 36 tons fish/day. The excess clean water produced is used to develop the industrial and tourism sectors.

Table 5. Minimum requirement to fulfill basic needs of Nusalaut community

Basic needs	Minimum requirement	Capacity generated
Electricity	620 kW	1.6 MWe
Fresh water	175 lt/capita/day, or 0.002 lt/capita/s, or 11.7 lt/s for 5,780 peoples	21.8 kg/s
Cold storage	-18 ˚C 36 ton fish/day	-18 ˚C

3.1 Exergy analysis of the system

Table 6 shows numerous thermodynamic properties for geothermal fluid, working fluid (n-Pentane), NH₃-water solution, seawater and air, such as temperature, pressure, and exergy rate following the state number in specific diagram in Fig. 3. State 0,0',0'',0''',0'''' are the restricted dead states condition for the brine, n-Pentane, NH₃-water solution, sea water and air, respectively. The cooling water flow rate is adjusted to enter at 18˚C and leave at 20˚C.

The Sankey diagram in Fig. 4 can be used to determine the process flow from energy supply to energy consumption and its balance. Geofluid from the production well has amount of energy 4.766 kW, mostly used for ORC unit 3.854 kW, for ARS unit 175 kW and
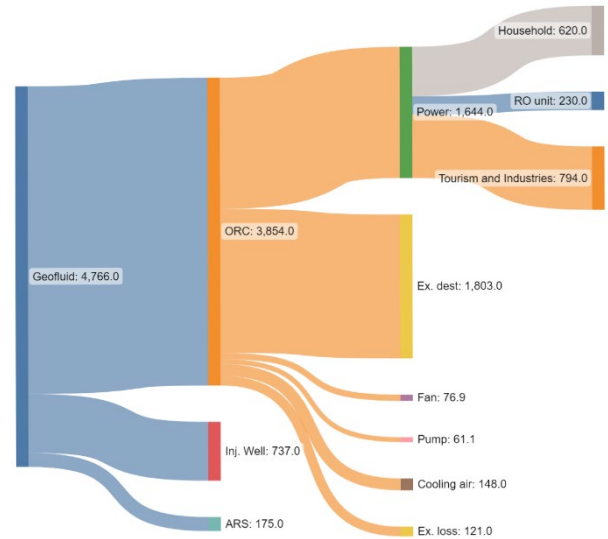

Fig. 4: The Sankey diagram of the proposed geothermal polygeneration

the rest is reinjected to injection well 737 kW. It is about a half of the energy used in ORC unit converted into electricity energy 1.644 kW, which will be used to fulfill the household demand of about 620 kW, RO unit for desalination of about 230 kW and the excess power will be used to develop tourism and industries of about 794 kW.

3.2 Validating energy and exergy mathematical models

The available data in the literature acts as a comparison to the simulation results to validate the validity of the mathematical model. Data in Ref.[42] validate the absorption refrigeration cycle, ref.[43] validate organic rankine cycle and ref.[44] validate the desalination system.

Table 6. Thermodynamic properties and exergy flow rates for the geothermal polygeneration system

State no	Description	Fluid	Phase	T (˚C)	P (bar)	h (kj/kg)	s (kj/kg.K)	e (kj/kg)	$\dot{E}$ (kW)
0	-	Brine	Dead state	25	1.01	104.80	0.37	0	0
0'	-	n-Pentane	Dead state	25	1.01	-2.08	-0.01	0	0
0''	-	NH3-water	Dead state	25	1.01	104.80	0.37	0	0
0'''	-	Seawater	Dead state	25	1.01	103.90	0.36	0	0
0''''	-	Air	Dead state	25	1.01	298.60	5.70	0	0
1	Evaporator inlet	Brine	Liquid	170	20	908.70	2.45	183.60	4591
1'	Generator inlet	Brine	Liquid	170	20	908.70	2.45	183.60	4591
2	Preheater inlet	Brine	Liquid	155.1	20	655.2	1.89	95.68	2392
3	Preheater outlet	Brine	Liquid	92.15	20	387.5	1.21	29.49	737.2
4	Generator outlet	Brine	Liquid	120	20	2726	10.29	178.60	643
5	Evaporator inlet	n-Pentane	Liquid	144.40	15.20	317	0.88	55.09	1750
6	Expansion valve inlet	n-Pentane	Vapor	149.40	15.20	559.90	1.46	125.80	3995

State no	Description	Fluid	Phase	T (°C)	P (bar)	h (kj/kg)	s (kj/kg.K)	e (kj/kg)	Ė (kW)
7	Turbine inlet	n-Pentane	Vapor	148.90	14.90	559.90	1.46	125.30	3980
8	Condenser inlet	n-Pentane	Vapor	92.85	1.59	485.8	1.46	40.40	1283
9	Pump inlet	n-Pentane	Liquid	50.00	1.59	30.81	0.18	2.47	78.58
10	Preheater inlet	n-Pentane	Liquid	50.85	15.20	60.41	0.18	4.81	153
11	Condenser inlet	NH$_3$-water	Vapor	45.10	1.55	1310	4.22	56.79	7.20
12	Condenser outlet	NH$_3$-water	Liquid	40	1.55	190.70	0.66	0.09	0.01
13	Evaporator inlet	NH$_3$-water	Mixing	-23.30	0.16	190.70	0.79	-39.79	-5.04
14	Absorber inlet	NH$_3$-water	Mixing	-23	0.16	1206	4.84	-230.60	-29.21
15	Absorber outlet	NH$_3$-water	Liquid	40	0.16	-21.88	0.50	-166.30	-166.30
16	HE-ARS inlet	NH$_3$-water	Liquid	40.10	1.55	-20.30	0.50	-164.70	-164.70
17	Generator inlet	NH$_3$-water	Liquid	113.00	1.55	301.80	1.43	-117.90	-117.90
18	Generator outlet	NH$_3$-water	Liquid	145.40	1.55	491.70	1.83	-47.72	-41.67
19	HE-ARS outlet	NH$_3$-water	Liquid	61.90	1.55	122.90	0.85	-124.00	-108.30
20	Absorber inlet	NH$_3$-water	Liquid	60.70	163.60	122.90	0.85	-125.40	-109.50
21	RO pump 1 inlet	Seawater	Liquid	25.20	1.00	101.90	0.38	-8.07	-2145
22	Filter inlet	Seawater	Liquid	25.20	6.50	103.20	0.39	-7.60	-2021
23	Expansion valve inlet	Seawater	Liquid	25.20	6.17	103.20	0.39	-7.63	-11.22
24	Mixing chamber inlet	Seawater	Liquid	25.20	1.10	102.70	0.39	-8.12	-11.95
25	Fresh water outlet	Seawater	Liquid	25.20	1.01	111.90	0.39	-0.17	-25.16
26	RO pump 2 inlet	Seawater	Liquid	25.20	5.80	103.20	0.39	-7.66	-2026
27	RO unit inlet	Seawater	Liquid	26.70	60.00	114.10	0.41	-2.87	-759.10
28	RO unit outlet	Seawater	Liquid	26.70	1.10	112.00	0.39	0.02	2.74
29	Brine outlet	Seawater	Liquid	26.70	1.01	106.30	0.42	-13.92	-1667
30	Cooling tower inlet	Air	Gas	30	1.01	303.6	5.71	0.03	15.33
31	Cooling tower outlet	Air	Gas	40	1.01	313.6	5.75	0.34	148.3
32	Condenser ARS inlet	Water	Liquid	20	1.01	83.93	0.29	0.17	1.25
33	Condenser ARS outlet	Water	Liquid	30	1.01	125.8	0.43	0.17	1.23
34	Absorber ARS inlet	Water	Liquid	20	1.01	83.93	0.29	0.17	2.50
35	Absorber ARS outlet	Water	Liquid	30	1.01	125.8	0.43	0.17	2.45

3.3 Cost estimation of the geothermal polygeneration system in Nusalaut Island, Central Maluku District, Maluku Province

Thermo-economic evaluation was performed using licensed engineering equation software (EES). Small geothermal projects need special attention because of the financial and operational problems that come with their size. The capital cost of geothermal projects is resource dependent and varies by site[45]. Power plant expenses, drilling costs, resource quality, and financing costs all have a significant impact on the costs of small geothermal projects[46]. The overall costs of geothermal plants include, of course, exploration and drilling costs, as well as field development (piping, etc.), and while these costs are shared among the various applications in geothermal polygeneration, it would be an artificial approach for an integrated energy production device[26]. Table 7 estimates the initial cost of a geothermal project, which is divided into two categories: exploration costs for detailed surveys (TEM, MT, and AMT) and confirmation and drilling costs.

Table 7. Estimated upfront cost of geothermal project for geophysical and exploratory drilling phase

Type	Unit	Cost
a. Exploration cost		
Surveys (TEM, MT, and AMT)	USD	650,000
b. Confirmation and drilling cost		
Drilling*	6,000,000 USD/Well	12,000,000
Other costs	USD/Project	20.000
Well test	140,000 USD/Well	280,000
Administration	USD/Project	469,500
Compliance reports	USD/Project	626,000
	Total	14,045,500

*) The wells are production and injection.

The cost of geothermal projects is divided into two categories: investment costs and operation and maintenance costs. Preparation, exploration, geothermal well field development, power plant, and indirect costs are typical investment costs, with geothermal well field development accounting for more than half of overall investment cost. Depending on the size and type of plant, as well as the location and design of the power plant, the cost of operation and maintenance ranges between 1.5 and 2.5% of the overall cost of installation.[47] Based on the assumption that the plant capacity is (80% - 7000 hours/year), the operational hours of each subsystem in the geothermal polygeneration systems are calculated in the same manner.

The total purchased equipment costs for the polygeneration system including ORC plant, absorption refrigeration plant and reverse osmosis plant are presented in Table 8.

Table 8. The total purchased equipment cost of the geothermal polygeneration system.

Component	Cost (USD)
Plant cost	
-ORC	2,086,225
-ARS	14,644
-RO	22,294
Total purchased equipment cost	**2,123,163**

The sum of the estimated costs presented in Tables 7 and 8 represents the total up-front cost of a geothermal polygeneration system, which comes to US$ 16,168,662 in this example. In general, the cost of confirmation and drilling accounted for nearly 80% of the upfront cost of a geothermal project. The cost of a polygeneration plant system is 15.5%, with the ORC plant dominating over the ARS and RO plants.

3.4 Thermo-economic evaluation

An indicator of how efficiently a system performs thermodynamically is exergetic efficiency. Exergetic efficiency provides an accurate assessment of an energy system's performance from a thermodynamic approach. The values of the time rates of exergy destruction are presented in Table 9 to show the thermodynamic measures of a plant's inefficiencies. Pump has the highest exergy efficiency compared to other components because mechanical process in pump only increasing the pressure of the fluid. Condenser has the lowest exergy efficiency because the thermal process releases a huge amount of thermal energy to surroundings.

Table 9. Exergy efficiency

Component	Exergy efficiency (%)
Preheater	79.3
Evaporator	81.9
Turbine	74.3
Condenser	30.0
Pump	97.5

4. Conclusion

The use of geothermal energy can benefit rural communities in Nalahia Village, Nusalaut island by fulfilling some of the basic needs, thereby stimulating economic activity. The findings indicate that geothermal polygeneration provides advantages such as low environmental impact, high reliability, and high resiliency. Geothermal polygeneration developments meet the needs of the isolated sites like Nusalaut island. For coastal area like Nusalaut island, geothermal energy is best suited to fulfill the basic needs of rural community. According to the condition of Nusalaut island, the suggested configuration of geothermal polygeneration are electricity to substitute diesel power plant, cold storage to preserve fish, and desalination to obtain potable water. The generated electricity capacity is 1.6 MWe, with an actual need of 620 kW, while the desalination unit produces 21.8 kg/s of fresh water, which is greater than the actual need for fresh water for the people of Nusa Tenggara, which is 11.7 kg/s, and the cold storage can accommodate to store 36 fish/day The surplus electricity is used to operate desalination plants and cold-storage facilities, as well as the excess supply of fresh water could be used to develop the industrial and tourism sectors on the island of Nusalaut.

Nomenclature

A	:	surface area of the subscript component
A_{RO}	:	membrane area
AMT	:	audio-frequency magnetotelluric
h	:	enthalpy
Ks	:	salt permeability coefficient
MT	:	magnetotelluric
N	:	number of membranes
P	:	pressure
T	:	temperature
TEM	:	transient electromagnetic
s	:	entropy

V_{el} : permeate flow rate

W : power of the subscript component (turbine, pump and fan)

Y : average membrane salinity

Subscript

abs : absorber

cd : condensor

des : desorber

ev : Evaporator

F : Fan

shx : heat exchanger

ph : Preheater

P : Pump

rec : Rectifier

T : Turbine

o : ambient or dead state condition

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