JIMESE
Journal of Innovation Materials, Energy, and Sustainable Engineering
JIMESE 3(2): 150–170
ISSN 3025-0307

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

AQUANOVA as an innovation in thermosaline otec-pro power generation technology based on anfis-fuzzy logic for optimizing sustainable air quality

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Received Date: December 18, 2025 Revised Date: January 23, 2026 Accepted Date: January 27, 2026

ABSTRACT
Background: In 2024, the Meteorology, Climatology, and Geophysics Agency reported that the average global temperature had exceeded the threshold of 1.5 °C compared to the pre-industrial era. The rate of global warming is caused by the greenhouse gas (GHG) effect, which is dominated by carbon dioxide. The increase in atmospheric temperature is caused by CO_2 from carbon emissions from the use of fossil energy sources, land conversion, and deforestation. This study examines technologies that can be used to optimize air quality and the types of renewable energy that can be integrated into air quality optimization technology designs. **Methods:** The methodological approach chosen in this study is a Systematic Literature Review (SLR). Data searches were conducted on several websites using the keywords "global warming," "CO_2 levels in Indonesia," and "power generation technology." **Findings:** Based on these issues, AQUANOVA was developed as an innovative air purification technology that can absorb CO_2 in the atmosphere and be integrated with OTEC, PRO, and air purifiers to reduce carbon emissions in the air. **Conclusion:** This study developed the AQUANOVA innovation as a technology that can reduce CO_2 emissions based on ANFIS (Adaptive Neuro Fuzzy Inference System)–Fuzzy Logic management as an effort to achieve SDG points 7 and 15 in producing affordable renewable energy and restoring ecosystems. **Novelty/Originality of this article:** The integration of two electricity-generating technologies and the ANFIS-Fuzzy Logic automation system has created an innovative automatic and energy-efficient air purifier technology.

KEYWORDS: ANFIS-fuzzy logic; greenhouse gases; renewable energy.

1. Introduction

Global warming has become an international issue due to its potentially dangerous impact on living things around the world. In 2024, Indonesia's Meteorology, Climatology, and Geophysics Agency/*Badan Meteorologi, Klimatologi, dan Geofisika* (BMKG) stated that the global average temperature had risen above pre-industrial levels, exceeding 1.5 °C. The increase in global temperature is caused by global warming due to the greenhouse effect, which is dominated by carbon dioxide at 421.5±0.2 parts per million (ppm). This condition not only impacts climate change but also causes air pollution, which kills more than 8.3 million people a year (Kalair et al., 2021).

Cite This Article:
Jariyah, A., & Elfina, S. (2026). AQUANOVA as an innovation in thermosaline otec-pro power generation technology based on anfis-fuzzy logic for optimizing sustainable air quality. *Journal of Innovation Materials, Energy, and Sustainable Engineering, 3*(2), 150-170. https://doi.org/10.61511/jimese.v3i2.2026.2593

The BMKG's 2024 climate and air quality report states that Indonesia is facing its hottest year on record, with an average temperature of 27.5 °C. The increase in atmospheric temperature is caused by CO_2 from carbon emissions resulting from the use of fossil fuels, land conversion, and deforestation (Pratiwi, 2025). The figure of 1.24 gigatons is Indonesia's record greenhouse gas emissions for 2022 according to official data from the European Commission, making Indonesia the largest emitter in Southeast Asia (Irma & Gusmira, 2023). According to the International Energy Agency (IEA), in order to remain on track for carbon neutrality in the energy sector by 2050, emissions must be reduced by 35% by the end of 2030 (Oppermann et al., 2023).

Indonesia has committed to reducing greenhouse gas emissions by 834 million tons of carbon dioxide. The energy sector is the main focus, with a target of reducing carbon emissions by 314 million tons of carbon dioxide (Abduh et al., 2025). Amidst the promising potential of New and Renewable Energy (BBT), Indonesia's primary energy structure is still dominated by fossil fuels, with actual BBT achievement reaching only 12.3% in 2022 (Parsaulian et al., 2025). Therefore, the transition to a clean energy system is a strategic necessity to achieve national energy security.

Therefore, to support national development targets in preventing global warming and reducing carbon emissions in Indonesia, this study presents AQUANOVA as an ANFIS-Fuzzy Logic-based OTEC-PRO Thermal-Saline Power Plant Technology Innovation for Sustainable Air Quality Optimization. AQUANOVA technology is integrated with OTEC and PRO, which can generate electricity by utilizing the temperature and osmotic pressure differences between two solutions with different salinities (Ahmed et al., 2024). The electricity generated will be managed by the ANFIS-Fuzzy Logic system in operating an air purifier to filter air consisting of dust, bacteria, and particles (Fadil et al., 2023). AQUANOVA's technological innovation is an effort to reduce carbon emissions and realize the implementation of Sustainable Development Goals (SDGs) points 7 and 15 in producing affordable renewable energy and restoring ecosystems. This technology is in line with the Indonesian Ministry of Transportation's program to prevent global warming and reduce greenhouse gas emissions. This study aims to examine the development of technology to improve air quality using renewable resources.

2. Methods

A literature review is a type of research that involves collecting and examining data from various sources, such as journal articles, books, and other references, to obtain information for further analysis. The methodological approach chosen in this study is a Systematic Literature Review (SLR). This method is applied to examine available research on a specific topic. SLR aims to examine, identify, and assess research related to a specific research topic.

This study analyzed various previous studies, and the results of the analysis are presented in tabular form to facilitate understanding of the use of power generation technology innovations for air quality optimization. The steps taken include, formulating Research Questions (RQ), searching for sources relevant to the topic, conducting a review, analyzing the findings. Research data was collected relevant articles and reviewed them from various sources such as Google Scholar. Data searches were conducted on several websites using the keywords "global warming," "CO_2 levels in Indonesia," and "power generation technology." Before reviewing the articles obtained, this study prepared Research Questions (RQ) for this study, which included, (1) RQ1, What are the conditions of climate change due to dependence on fossil fuels in Indonesia?; (2) RQ2, What types of renewable energy can be integrated into the design of air quality optimization technology?

The inclusion criteria for this study are articles that serve as literature in the form of research articles and literature reviews. The articles discuss the utilization of renewable resources from differences in temperature and salinity pressure in seawater published from 2021 to 2025. The articles were identified using Scopus and Google Scholar, then imported into the Mendeley reference management program to avoid duplication. Researchers manually reviewed the articles to ensure that the content was relevant to the topic of renewable energy. Articles that met the suitability criteria were then further examined as potential material for research. The suitability criteria included: (1) the main topic of the article and journal was in line with the theme of renewable energy and energy transition, (2) full accessibility of the article for researchers, and (3) the research was related to global renewable energy developments and could be adapted as a reference for research in Indonesia.

This study applied data collection techniques using inductive analysis by collecting articles published between 2021 and 2025. After the data was collected, the author was able to draw conclusions based on the general statements in the articles. This type of research was selected to obtain comprehensive and detailed findings, accompanied by in-depth analysis, thereby facilitating a clearer understanding of the article's content. The identities of the literature used to support this research are presented in Table 1.

Table 1. Literature references used for each power generation technology

Author's Name (Year)	Title	Results
Ulum (2025)	Global Warming: Causes, Effects, and Mitigation Efforts	CO_2 gas is classified as a greenhouse gas, with estimated emissions of around 18.35 billion tons of CO_2 annually. As the intensity of greenhouse gases in the atmosphere increases, these gases act as insulators that absorb more heat from sunlight reflected back to Earth, thereby triggering global warming. Global warming can be minimized by reducing greenhouse gas emissions through the use of clean energy sources, including solar, wind, water, geothermal, and bioenergy variants such as biogas and bioethanol. These clean energy options offer ecological solutions that can shift dependence away from fossil fuels.
Febriyanti et al. (2025)	Smart Algae Photobioreactor as CO_2 Filtration in Environmentally Friendly Smoking Areas	Smart Algae Photobioreactor is a technological innovation that utilizes algae for air filtration. More specifically, the Smart Algae Photobioreactor is a technological innovation that utilizes the photosynthesis process of algae to help reduce carbon dioxide and produce oxygen. This system is considered suitable for application in areas with high pollution levels. The Smart Algae Photobioreactor, which uses algae as an air filter, can be applied in public spaces or enclosed areas.
Novitasari & Pratiwi (2025)	Addressing Global Warming: Analysis of Causes, Impacts, and Solution Measures	Global warming can be defined as the phenomenon of increasing atmospheric and surface temperatures on the planet triggered by the accumulation of carbon emissions. The continuous increase in Earth's temperature has caused various consequences that affect living things and the surrounding environment. In facing the increasingly urgent challenge of global warming, efforts or solutions are needed that include technological innovation, environmental policies, and changes in people's behavior. Some of the efforts that can be made include saving water, saving electricity, reforestation, minimizing the use of private vehicles, and using alternative energy sources.
Harpawi et al. (2022)	IoT-Based Air Quality Monitoring and Control on	An air purifier is a device that works by sucking air from a room and then processing it through a filter to clean the air. In this project, this study used Honeywell HHT-080, which has two filters: a pre-filter and a HEPA filter. In this study, the sensor was

	Honeywell HHT-080 Air Purifiers	upgraded using an MQ-7 gas sensor and an IoT-based scheme, allowing carbon monoxide concentration data to be obtained continuously and sent to Google Spreadsheet and forwarded to the relevant parties. In addition, automatic control has been added to the air purifier. If the air quality is classified as unhealthy, the air purifier with a HEPA filter will activate to improve the air quality in the room.
BMKG (2024)	Indonesian Climate and Air Quality Records	Globally, the level of atmospheric saturation by GHG emissions (CO_2, N_2O, and SF_6) will escalate to its highest point in the 2024 period. The CO_2 concentration was 421.5±0.2 parts per million (ppm). Globally, 2024 continued to experience an increase in CO_2, although it was slightly lower than in 2023. This trend confirms the importance of long-term monitoring of CO_2 concentrations.
Kim et al. (2023)	Carbon Pricing Conditions and Trends International Carbon Market	In 2022, the energy sector recorded the highest greenhouse gas emissions, reaching 37 gigatons of carbon dioxide. As the largest contributor to global emissions, the International Energy Agency (IEA) has determined that in order to remain on track for carbon neutrality in the energy sector by 2050, emissions must be reduced by 35% by the end of 2030. The main challenge comes from fossil fuel assets, which are expected to contribute 600 Gt CO2 by mid-century, a figure that exceeds the safe limit for keeping the Earth's average surface temperature below 1.5 ° C. Therefore, accelerating the transition to renewable energy and optimizing energy efficiency are key pillars in mitigating the climate crisis to reduce the massive use of coal.
Ahmed et al. (2024)	Techno-economic analysis of a pressure-driven osmosis (PRO) - seawater reverse osmosis (SWRO) hybrid: a case study	Seawater Reverse Osmosis (SWRO) is currently the mainstay of desalination technology due to its effectiveness in producing clean water from seawater sources. On the other hand, there is Pressure-Driven Osmosis (PRO) technology, which is capable of generating electricity by utilizing the osmotic pressure gradient that arises due to differences in salinity. The PRO mechanism works by pumping seawater and filtered freshwater through a semipermeable membrane. The integration of both in a PRO-SWRO hybrid system offers great potential for optimizing energy efficiency and realizing a more environmentally friendly desalination process.
Azharil et al. (2025)	The Future of Renewable Energy at Sea: The Role of Ocean Energy Technology in Climate Change Mitigation	The use of renewable energy is a strategic step to minimize the systemic impact of climate change while reducing structural dependence on conventional fuels. Among the various natural resources available, marine energy technology has emerged as a potential alternative. This technology converts the characteristics and dynamics of ocean movement into electrical energy. Specifically, this potential can be optimized through tidal power generation systems, ocean surface movement energy, and ocean thermal energy conversion (OTEC) methods.
Wijayanto & Zakia (2024)	The Potential of OTEC as a Clean Energy Source	As a maritime country, Indonesia has great potential for clean energy sourced from the sea. According to the Indonesian Ocean Energy Association (ASELI),

	for the Future of IKN Towards Sustainable Development	marine energy resources include various modalities, including tidal energy, wave energy, and Ocean Thermal Energy Conversion, technically known as OTEC. OTEC is the most promising marine resource to be developed as clean energy because it has greater practical potential than other marine resources. The working principle of OTEC is based on the thermal energy difference between surface water exposed to solar heat and cold deep sea water as the driving force of the generation cycle.
Abbas et al. (2023)	Review of improvements to the thermal energy conversion system	Improvements in the optimization of Ocean Thermal Energy Conversion (OTEC) systems are highly dependent on optimizing steam turbine performance. Given that the available water temperature difference is relatively small, OTEC power plant efficiency tends to be low. To overcome this constraint, additional energy sources can be integrated to expand the existing temperature range. For example, the use of solar energy can increase the temperature difference in the system, which in turn will increase work output, optimize device efficiency, and reduce overall electricity production costs.

3. Results and Discussion

3.1 Air pollution in Indonesia

Air pollution is an increasingly complex environmental problem in Indonesia, especially in urban and industrial areas. Air pollution contributes to various health problems, environmental degradation, and climate change due to increased concentrations of pollutants and gases in the atmosphere. Some of the main sources of air pollution come from motor vehicle emissions, industrial activities, biomass burning, and forest and land fires. To understand fluctuations in pollutant concentrations in the atmosphere and determine effective management strategies, atmospheric modeling is needed that can simulate the interaction between meteorological factors and pollutants. One model widely used in atmospheric studies is the Weather Research and Forecasting coupled with Chemistry (WRF-Chem) model, which is capable of assimilating emission data and calculating the transport and chemical transformation of pollutants in the atmosphere (Dyana et al., 2025).

3.2 Analysis of previous solution gaps

Arduino program declaration variables are used to provide initial data, or initial values, for stages that will be executed with initialization for the first time. After detecting the presence of cigarette smoke, the MQ 7 sensor output will be compared to the threshold value specified in the Arduino program. Two digital conditions are generated as a result of this comparison: high and low. High indicates the presence of cigarette smoke, while low indicates the absence of cigarette smoke. Arduino automatically triggers the relay to turn on the AC blower fan and sound the alarm when cigarette smoke is detected. This device will continue to detect the presence of cigarette smoke even if no cigarette smoke is found. This procedure will continue to run repeatedly.

The test was conducted on two research objects with different room sizes. The experiment was conducted in two locations with different sizes, the first location measuring 2.5 m x 1.3 m, while the second location used a room measuring 2.5 m x 2.2 m. The sensor reads clean air quality (low smoke content detected) and cautionary air quality (high smoke content detected). The objectives of testing this device included response time range,

reliability in reading smoke indicators, and comparison of room size with indicator thresholds.
The evaluation of the effectiveness of the MQ-7 sensor aims to assess the precision of the device in detecting cigarette smoke in enclosed spaces. Normal CO levels in the first room were in the range of 0-70 ppm, which is a safe level of smoke pollution. Normal CO levels in the second room were in the range of 0-60 ppm. These values were obtained from the MQ-7 sensor parameters in the program. Efforts have been made by authors Karina and Dios in 2025 to use microalgae as air filters to reduce carbon dioxide (CO_2) from emission sources such as pollutants (Febriyanti et al., 2025). However, this technology has shortcomings in the form of integration with AI navigation systems that have not been implemented, monitoring dashboards that are not yet available, and tool usage models that are difficult to reconfigure, making it unsuitable for implementation in 3T areas.

3.3 The AQUANOVA

AQUANOVA is an air purification technology capable of absorbing CO_2 in the atmosphere and is integrated with OTEC, PRO, and air purifiers to reduce carbon emissions in the air. OTEC is used to generate electricity by utilizing the thermal gradient formed between the upper and lower layers of the ocean (Azharil et al., 2025). PRO is an energy harvesting technology that utilizes salinity gradients through osmotic pressure to generate electricity (Ahmed et al., 2024). Then, the electrical energy will be managed by the ANFIS-Fuzzy Logic system in determining the electric current to be used by the air purifier to filter air consisting of dust, bacteria, and fungi larger than 2 microns using a net (Harpawi & Syahputra, 2022).

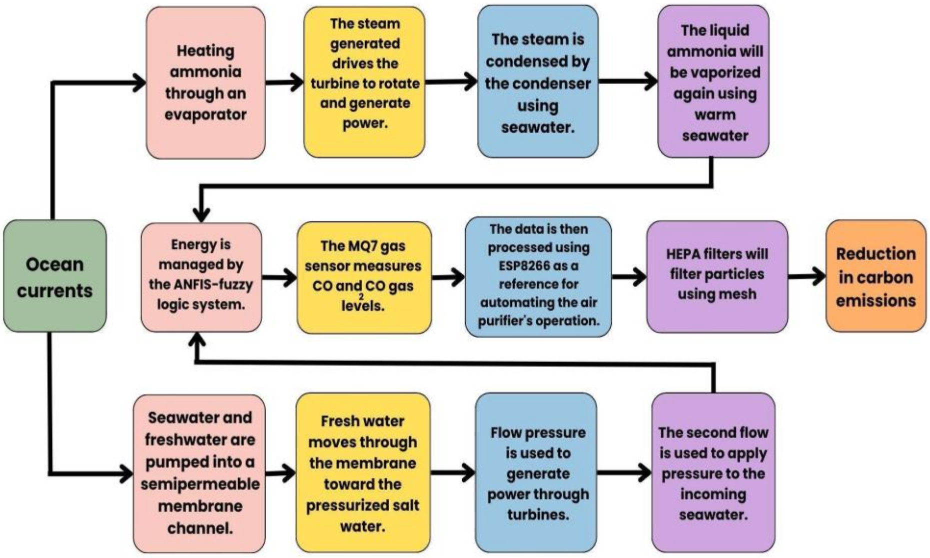

Fig. 1. AQUANOVA working mechanism

3.4 Ocean thermal energy conversion (OTEC)

Indonesian waters have great potential to be developed into a base for renewable power generation. Sunlight shining on the sea surface is effectively absorbed by the water, storing energy in the upper layer of the sea at a depth of 35 to 100 meters. In this layer, temperature and salinity mix due to the influence of wind and waves. Below this mixed layer, the temperature of the seawater begins to decrease with increasing depth, reaching 4.4 °C (40 °F) at a depth of 800 to 1000 meters. At depths of more than 900 meters, there is a reservoir of cold water formed from water and ice from the polar regions. This situation results in a significant temperature difference of 25 °C between surface water and deep seawater. OTEC (Ocean Thermal Energy Conversion) is a system that converts this minimum thermal gradient of 25 °C to drive an electric generator (Abduh et al., 2025).

In its operation, open-cycle Ocean Thermal Energy Conversion (OTEC) technology utilizes seawater as the working fluid. The working system of open-cycle OTEC can be described through several sequential stages. In the first stage, warm seawater with a mass of 23,984.50 kg, a specific volume of 0.001004 m^2/kg, a surface temperature of 302.05 K, and a pressure of 1 atm (0.1013 MPa) enters the evaporator unit. Within this unit, the pressure is reduced until it reaches 1.088 MPa, allowing the seawater to undergo further thermodynamic processes. The warm surface seawater is transported through a pipe measuring 15 meters in length using a pumping system. The seawater has a density of 1.026 kg/m^3 and flows at a rate of 23.38 m^3/s with a velocity of 1.004 m/s inside a pipe with a diameter of 5 meters and a friction factor of 0.05. Based on these parameters, the power required by the warm seawater pump is calculated to be 1.77 kW, which ensures continuous circulation of seawater into the evaporator system. Within the evaporator, the seawater undergoes a phase change and is converted into low-pressure saturated steam below the saturation pressure corresponding to its temperature. This process requires a significant amount of heat energy, with the evaporator needing approximately 250,997.79 kJ/s to produce the required saturated steam. The resulting low-pressure saturated steam is then directed into the turbine system. As the saturated steam enters the turbine, it drives the turbine blades at an angular velocity of 195.03 m/s, achieving an angular efficiency of 93%. To maintain this operational performance, a saturated steam mass flow rate of 103.576 kg/s is required. The turbine converts the thermal energy of the steam into mechanical energy through rotational motion. Finally, the mechanical energy generated by the turbine's rotation is transferred to an alternating current (AC) generator, which converts the mechanical energy into electrical energy. This process completes the open-cycle OTEC power generation system, enabling the conversion of thermal energy from seawater into usable electricity (Wijayanto & Zakia, 2024).

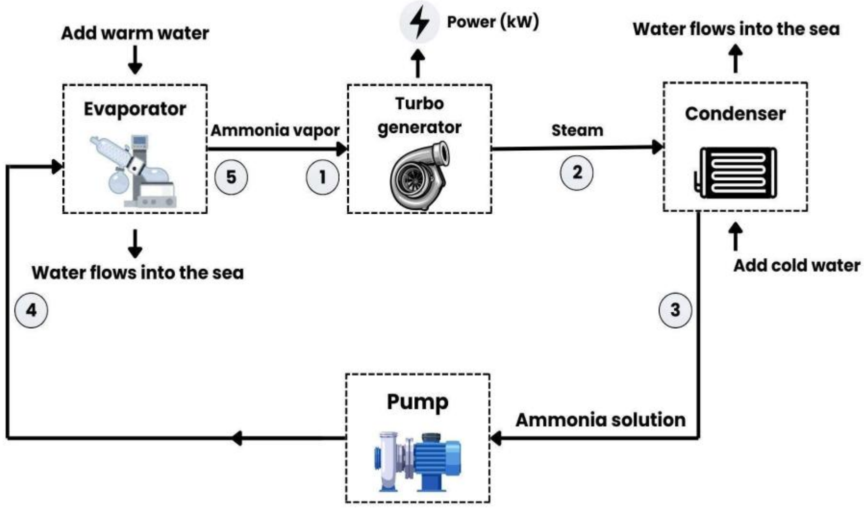

Fig. 2. OTEC system diagram

In research conducted in the West Sumatra Sea, the Carnot efficiency figure was 70%, combined with the assumption of temperatures in Celsius. Maximum efficiency of around seven percent can be achieved when using the temperature difference as a proportion of the absolute scale (kelvin), and actual net efficiency can be much lower than three percent when taking into account parasitic factors in real installations. The calculations show that the average energy efficiency of OTEC development in the West Sumatra Sea is 0.70, which means that if 100 kW of input power is required and the Carnot efficiency is 0.70, the net power becomes 70 kW (Parsaulian et al., 2025). Note Table 2, which shows the energy efficiency values based on Carnot efficiency calculations:

Table 2. Carnot value efficiency (η) monthly period

Month	Tw (°C)	Tc (°C)	ΔT	Depth (m)	Carnot efficiency (η)
January	29.86	8.96	20.90	600	0.70
February	30.17	8.88	21.29	600	0.71
March	30.57	8.82	21.75	600	0.71
April	30.36	9.09	21.27	600	0.70
May	30.36	9.08	21.28	600	0.70
June	30.21	8.90	21.31	600	0.71
July	29.90	8.99	20.91	600	0.70
August	30.01	8.98	21.03	600	0.70
September	29.66	8.74	20.92	600	0.71
October	29.64	8.81	20.83	600	0.70
November	29.28	9.25	20.03	600	0.68
December	29.48	9.06	20.42	600	0.69
Average	29.96	8.96	21.00	600	0.70

(Parsulian et al., 2025)

Pilot projects that have been designed with adequate size must be operated on site and run continuously for at least one year. A pilot plant of around 10 MW must be operated before the implementation of a 50–100 MW commercial plant. OTEC can provide Indonesia and many other countries with a competitively priced renewable resource. The immediate market for OTEC is likely to be islands or archipelagos (Hendrawan, 2020).

Calculating turbine power, assuming that the distance between each 100 MW OTEC plant built is 10 km, the estimated potential electrical power (P) that can be generated by OTEC is $P = \eta_{OTEC} \times JS \times \frac{100\ MW}{10\ KM}$. To generate this electrical energy, an alternating current (AC) generator is used. If the efficiency of the generator is η_5, then the electrical power that can be generated by OTEC (Wijayanto & Zakia, 2024).

$$P' = \frac{P}{\eta_5} \quad \text{(Eq. 1)}$$

The saturated steam mass required per unit of time to transfer energy from the turbine is:

$$M_t = \frac{P'}{\eta_4\ x\ (W_t - W_p)} \quad \text{(Eq. 2)}$$

The turbine shaft power can be calculated using the formula:

$$P_t = \eta_4\ x\ W_t\ x\ M_t \quad \text{(Eq. 3)}$$

OTEC is a marine resource that has the potential to be developed as a clean energy source because it has greater practical potential than other marine resources. Ocean Thermal Energy Conversion (OTEC) technology offers an approach to utilizing marine heat energy by using the temperature difference between the warm surface layer of the ocean and the cold deep ocean layer to generate electricity (Goma et al., 2025). In addition to generating electricity, OTEC also has the potential to produce 22,601 liters of clean water per day, which can help meet the clean water needs of communities during the dry season. One of the negative impacts of open OTEC system development is the discharge of large volumes of nutrient-rich seawater, which has the potential to cause harmful algal blooms, leading to mass deaths of fish and other marine life (Handoyo et al., 2024). The OTEC system is in the pre-commercial phase, with several experimental projects showing that this technology is advancing but moving towards commercialization. Thus, OTEC can provide Indonesia and many other countries with a renewable resource at a competitive price.

Amidst the shortage of fossil fuels, natural gas, and other terrestrial energy sources, Ocean Thermal Energy Conversion (OTEC) can be used as a long-term alternative energy source. This is because OTEC has a more environmentally friendly energy source and unlimited availability. In addition, OTEC has relatively low engine efficiency compared to conventional power plants. Therefore, OTEC can be used as a long-term alternative energy source. However, the main factor that must be considered when implementing OTEC is the high cost of assembly and maintenance. On the other hand, OTEC has lower machine efficiency than conventional power plants. However, if used in the long term, the costs will not increase and become a problem for OTEC generator engines (Putri & Nurfadilah, 2023).

The use of renewable energy has become an important issue worldwide, in terms of environmental, economic, and social policies. This issue is growing rapidly given the increasingly urgent need to reduce dependence on fossil fuels, reduce carbon emissions, and preserve the environment. As an archipelagic country located in the tropics with vast oceans, Indonesia has great potential to develop OTEC technology. The significant temperature difference between surface water and deep water in tropical waters makes this country suitable for OTEC applications. The use of OTEC not only has the potential to provide environmentally friendly electricity but can also help overcome the problem of freshwater availability in coastal areas and other small islands. With this technology, Indonesia can maximize its marine resources to support the transition to renewable energy (Abduh et al., 2025).

3.5 Pressure retarded osmosis (PRO)

The energy capacity that can be obtained with osmosis technology is 2,000 TWh/year. PRO is a system that relies on the salinity gradient between low salinity water and high salinity water as its energy source. In the PRO mechanism, low salinity water naturally flows through a semipermeable membrane into high salinity water. Seawater with high salt concentration increases pressure, causing its concentration to decrease and its volume to increase. This causes water to flow through a water turbine to generate electricity (Yunita et al., 2023).

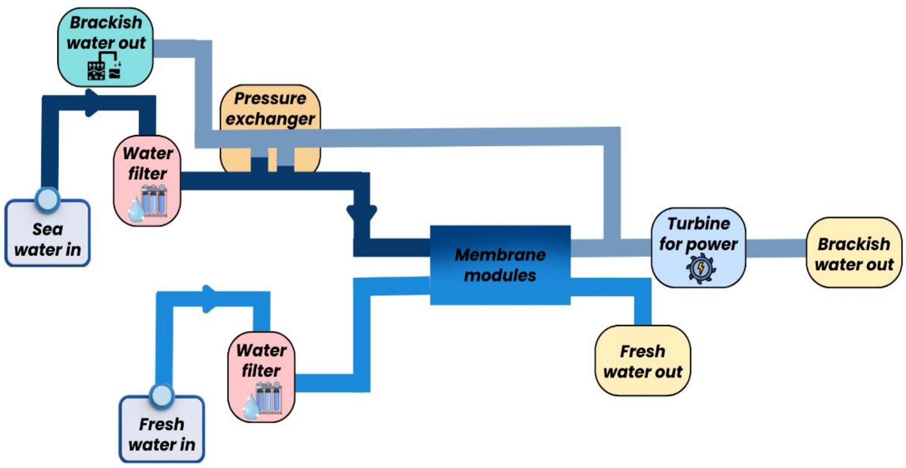

Fig. 3. PRO system diagram

The process of generating osmotic energy begins by supplying brackish water and seawater to the generator and turbine. Seawater and brackish water are first cleaned to reduce impurities. Then the brackish water and seawater are treated separately; the brackish water is fed directly into the permeable membrane module, while the seawater is pressurized before entering the membrane module. The osmosis process occurs within the membrane module, allowing 80–90% of the brackish water to pass through the membrane into the high-pressure seawater, after which the water leaves the permeable membrane module. Conversely, about two-thirds of the power supplied to the pressure converter flow passes through the turbine unit to generate electrical energy. The PRO power plant can generate 1 MW of energy for every 1 cubic meter per second of freshwater flowing through the membrane (Ahmed et al., 2024).

When river water meets the ocean, an average of 0.7–0.75 kWh (2.5–2.7 MJ) is lost when 1 m^3 of fresh water flows into seawater. Each 1 m^3/s of seawater has the potential to generate 2.5–2.7 MW. The maximum osmotic power ever achieved is 1,650 TWh/year. In inland lakes with high salinity, such as the Dead Sea, the osmotic pressure difference formed is equivalent to 5,000 m of hydraulic head.

Table 3. Maximum energy obtained from mixing seawater with high salinity water from different sources

	Theoretical Energy (kWh/m^3)	Theoretical Power (MW m^3/s)
Seawater	0.75	2.7
SWRO brine	1.5	5.4
Salt dome solution	8.8	31.6
Great Salt Lake	10.4	37.5
Dead Sea	14.1	50.7

The Great Salt Lake model that has been tried is the Jordan River, with an estimated energy output of around 66 MW. The *Maximum net power* ($PW\frac{MAX}{NET}$) that can be produced with this ideal PRO is the difference in quantity provided by the hydro turbine, P_D (V+ΔV) and power entering the system P_D V:

$$PW_{NET}^{MAX} = P_D\ (V+\Delta V) - P_D V = P_D\ \Delta V \quad \text{(Eq. 4)}$$

Where P_D.ΔV is the net power, assuming 100% mechanical efficiency for all components and no energy loss. This scheme is obtained by assuming that the feed solution enters the system due to gravitational force. The ideal operating pressure for maximum power output is half the osmotic pressure difference. In a river water and seawater RO scheme, the osmotic pressure difference is approximately 26 bar, the ideal operating pressure is approximately 13 bar, and the maximum power output is approximately 1.3 MW per m3 s-1 of permeate. For mechanical efficiency, if it is less than 100% for PRO system components, in reality it will not be possible to achieve 100%. The net power that can be generated is:

$$PW_{NET}^{MAX} = P_D\ \Delta V\ \eta \quad \text{(Eq. 5)}$$

Where η is the mechanical efficiency of the system, which is influenced by the efficiency of rotating components such as pumps, engines, turbines, and generators, friction losses in the flow section of the permeator, and the configuration of the equipment in the installation. For example, an average assumption of 20% of the maximum net power that can be achieved from a freshwater vs. seawater RO system (20% of 1.3 MW per m3 s-1 of permeate) will be lost due to the inefficiency of the RO system components (Wiraguna, 2024).

In terms of specific energy consumption, it was found that the specific energy consumption required for daily operations was only half of the specific energy consumption of the overall pretreatment process. This indicates the low power requirement for producing each m^3 of RO membrane feed water. This low power requirement is due to the use of relatively low operating conditions (pressure) in processing deep well water (around 3 bar), so that the power required by the motor as the driving force generator is also lower. From an economic perspective, the production of RO membrane feed water using well water as raw material is feasible, as the production cost of IDR 10.553,-/ m^3 is still relatively low compared to the PDAM tariff in the study area, which is IDR 16.984,-/ m^3 (Robbani, 2020).

A flow of 1 m^3/s from PRO technology can generate 1 MW of electrical energy. However, the electrical energy generated at 1 m^3/san be greater when the river meets the ocean. On average, 0.7–0.75 kWh (2.5–2.7 MJ) is lost when 1 $m^3$of fresh water flows into seawater, where 1 m^3/s of seawater has the potential to generate 2.5–2.7 MW. On a larger scale, the energy that can be harnessed from the difference in salinity between fresh water and sea water can reach 2.6 TW. The maximum osmotic power ever reported is 1,650 TWh/year. This figure is about half of the maximum flow reported for hydro power, which is around 3551 TWh/year (Saidiman et al., 2025).

A study on Pressure Retarded Osmosis (PRO) as a salinity gradient energy technology reveals its potential as a sustainable solution to future energy and water challenges. With a theoretical foundation rooted in osmotic pressure and thermodynamic constraints, PRO offers the opportunity to convert the chemical potential between freshwater and saltwater sources into usable energy. The application of PRO technology offers environmental benefits, such as reduced salinity of discharged brine and lower greenhouse gas emissions. Economically, PRO can lower operational costs by recovering energy from salinity gradients. However, challenges such as membrane fouling, concentration polarization, and structural limitations of membranes must be addressed to improve system efficiency and scalability. Technological innovations in membrane materials, system configuration, and hybrid integration with wastewater treatment desalination installations are essential to overcome these barriers. Environmental and economic evaluations also underscore the role of PRO in reducing carbon emissions, lowering the salinity of discharged wastewater, and improving the cost-effectiveness of water-energy nexus systems. Although PRO is still in the transition phase from experimental and pilot-scale to full-scale deployment, the synergy between technical innovation, environmental needs, and policy support positions this technology as an important component in the global renewable energy landscape. Collaborative initiatives between academia, industry, and government agencies will play a vital role in advancing PRO technology from pilot-scale demonstrations to widespread commercial applications (Menon, 2025).

Pressure Retarded Osmosis (PRO) is a promising renewable energy technology. However, there are several drawbacks to this technology. First, when compared to other renewable energy sources such as solar or wind power, PRO systems often have lower power density. This means that in order to generate a sufficient amount of power, larger infrastructure and membrane surface area are required. Second, membrane fouling, where particles, organic debris, and salts can accumulate on the membrane surface, limiting the efficiency and lifespan of PRO. Third, salt concentration polarization can occur in PRO systems. In this condition, salt accumulation near the membrane surface reduces the osmotic driving force and affects overall power efficiency. Fourth, after the power generation process, the highly concentrated brine solution used in PRO must be disposed of. Receiving water bodies can experience environmental impacts from the disposal of concentrated solutions if they are not treated properly. Fifth, the commercialization and development of PRO technology is still in its early stages. Therefore, PRO systems are more expensive than traditional energy production techniques (Anjani et al., 2025).

The greenhouse effect occurring in the world today is causing extremely detrimental negative impacts. This is becoming increasingly apparent as the world's population grows. Many countries around the world are taking action to address this issue. One such action is the use of alternative energy sources to replace fossil fuels in the future, such as solar energy, geothermal energy, and ocean wave energy. One energy source with potential for development as an alternative technology is known as “salinity gradient power.” In this technology, energy is generated by controlling the mixture of high-salinity water, such as seawater, with low-salinity water, such as liquid waste or fresh water.

One technology that falls under salinity gradient power is Pressure Retarded Osmosis (PRO). PRO osmotic power is claimed to have very little environmental impact compared to other power generation methods. This is because PRO is a power plant that produces zero emissions. Additionally, the brackish water produced from the application of PRO is similar to the water found at the meeting point between river water and seawater in nature. From an environmental perspective, PRO has the advantages of being CO2-free and a renewable technology, requiring an efficient power plant installation area, and not producing harmful emissions (Gunaldi et al., 2025).

3.6 Air Purifier

An air purifier is a device for monitoring air quality by detecting CO_2 and CO gas levels. This system works by sucking air through a filter to clean it. The air quality monitoring system is controlled by an ESP32 module. It is equipped with an MQ135 sensor to detect CO_2 levels and an MQ7 sensor to detect CO levels. The system also has LEDs as indicators for each sensor and a suction fan that activates if CO_2 and CO levels exceed safe limits. The electronic design is divided into three main parts; input, process, and output. The input consists of MQ-135, MQ-7, and ultrasonic sensors that function to detect air quality, temperature, humidity, and altitude. This process is carried out by an ESP32 microcontroller that processes data from the sensors. The output is the activation of the ventilation fan, air humidifier, and information display on the LCD.

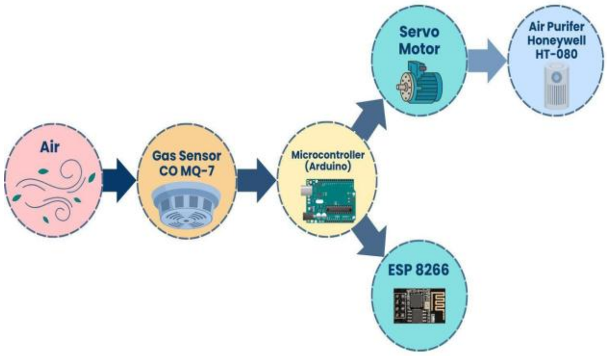

Fig. 4. Air purification System Diagram

The air purifier starts operating when the system initializes and reads sensor parameters such as temperature, humidity, CO_2 levels, and CO levels, which are monitored via the LCD screen. LED indicators provide visual warnings for CO_2 and CO levels in three colors: green, yellow, and red, with the following conditions, the green LED will light up when the CO_2 gas level is ≤ 1000 PPM or the CO gas level is ≤ 9 PPM. The yellow LED will light up when the CO_2 gas level is > 1000 PPM or the CO gas level is > 9 PPM. The red LED will light up when the CO_2 gas level is > 1000 PPM and the CO gas level is > 9 PPM.

This device includes an air extraction mechanism via an exhaust fan that can be operated in automatic mode. When the CO_2 gas level reaches >1000 PPM or the CO gas level reaches >9 PPM, the exhaust fan will turn on. This exhaust fan will help suck in contaminated air to be filtered and released as fresh air. Readings from the DHT22, MQ-135, MQ-7, and ultrasonic sensors, namely temperature, humidity, CO_2 levels, CO levels, and output status, will be displayed on the LCD (Irdayanti et al., 2025). The High Efficiency Particulate Air (HEPA) filter will filter air consisting of dust, bacteria, fungi, and all particles larger than 2 microns using a mesh (Harpawi & Syahputra, 2022).

3.7 ANFIS energy management system–fuzzy logic

The output voltage control of the buck converter will be controlled using an artificial intelligence method called ANFIS (Adaptive Neuro Fuzzy Inference System). ANFIS is a mechanism that integrates the advantages of artificial neural networks with the elasticity of fuzzy logic into a single framework. Artificial neural networks are part of artificial intelligence systems as artificial representations of the human brain that attempt to simulate the learning process. Fuzzy logic is a way of describing inputs into outputs. ANFIS is an intelligent computing model that combines the principles of fuzzy logic with the adaptive capabilities of neural networks. Through the application of hybrid learning procedures, this mechanism is able to build a mapping between input data and output results by utilizing human insight. ANFIS utilizes the combination of fuzzy reasoning and neural network learning capabilities to become a more powerful entity (Syafitri & Yuhendri, 2024).

In a fuzzy logic system, the process begins with fuzzy input, which consists of definite and unambiguous numerical values represented within an input set. These input values serve as containers of concrete data that will be processed by the fuzzy algorithm. Although the values are precise, they are mapped into fuzzy sets to allow further analysis, enabling the transformation of numerical data into fuzzy representations.

The next stage is fuzzification, in which the definite numerical inputs are reconstructed into degrees of membership within fuzzy sets. This process translates crisp data into membership values that indicate the extent to which each input belongs to a particular fuzzy category. Through fuzzification, numerical data become suitable for processing in fuzzy logic–based systems. Following this, the fuzzy inference system performs the reasoning process by interpreting the membership values generated during fuzzification. Using fuzzy logic rules, the system evaluates these values to produce meaningful outputs. This inference mechanism is particularly effective in handling uncertainty and complexity, allowing the system to generate decisions that more closely reflect real-world conditions.

The reasoning process is supported by a knowledge base, which contains a set of rules expressed in IF–THEN statements. These rules define the relationships between specific conditions and their corresponding outcomes, providing a structured framework for decision making. By applying these logical rules, the system can process information efficiently and determine appropriate responses based on observed inputs. Finally, the system performs defuzzification, which converts the fuzzy results produced by the inference process back into concrete numerical values. This stage ensures that the outputs can be directly interpreted and applied in real-world applications. As the final step in a fuzzy logic system, defuzzification determines precise fuzzy variable values, enabling the results of fuzzy analysis to be used effectively and accurately. In this study, the variables used are electrical energy and air pollution levels as inputs. Meanwhile, the output is an IR transmitter used to send infrared signals that can control the Air Purifier device. The electrical energy variable consists of the amount of electricity generated by OTEC and PRO. Meanwhile, the air pollution level variable consists of the detected CO and CO_2 levels.

The development of an energy management system involves a combination of technologies, including OTEC and PRO, which are integrated with a Battery Storage System (BSS) and a series of supporting electronic power instruments. On the output side, the system configuration includes AC loads, DC loads, and air filtration units. To optimize the management of these loads, an Adaptive Neuro-Fuzzy Inference System (ANFIS) model is implemented, which is integrated with a Maximum Power Point Tracking (MPPT) technique based on fuzzy logic. This approach aims to improve the efficiency of the OTEC and PRO hybrid system in regulating power distribution, the mechanism of which is highly dependent on the battery charging status of the generated electrical energy.

The Energy Storage System (ESS) serves to store excess energy from renewable sources while overcoming electricity supply shortages. In this system, ANFIS technology plays a role in automatically controlling the DC bus voltage to remain stable. Furthermore, DC power is converted by an inverter into AC power to meet load requirements.

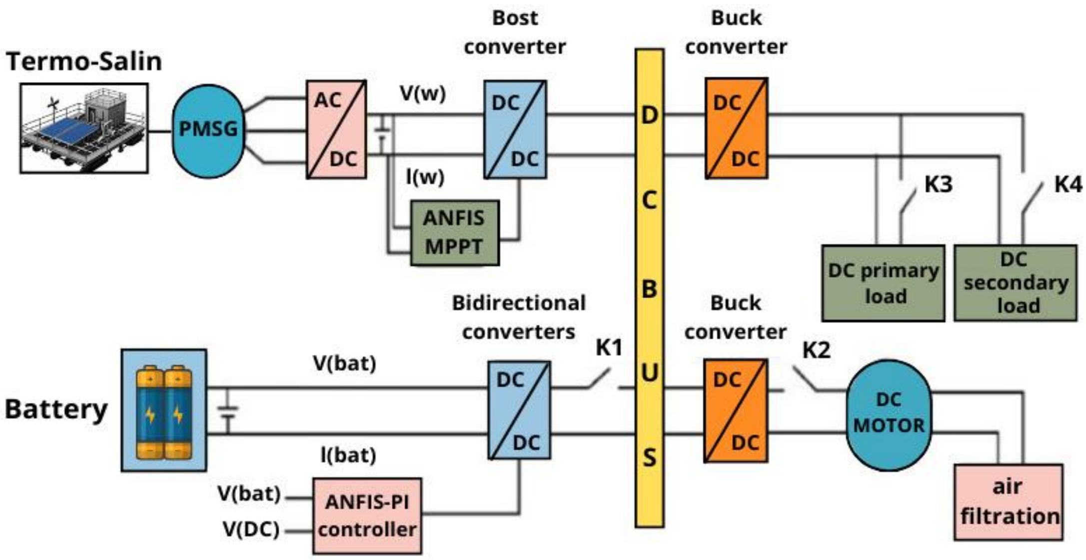

Fig. 5. ANFIS–fuzzy logic energy management system structure

The ANFIS fuzzy logic system operates based on power generation levels and battery charge conditions to manage system loads and energy storage efficiently. When the generated power exceeds 150 kW, all electrical loads and the water filtration system are activated. Once the available power reaches 85% of the required level, the battery is automatically disconnected from the system to prevent overuse. When the generated power falls within the range of 100 kW to 150 kW, system operation depends on the battery charge ratio. If the battery charge is below the 85% threshold, the DC2 unit is automatically deactivated to prioritize battery charging until full capacity is reached. However, if the battery charge exceeds 85%, the battery is disconnected from the system. Under power generation conditions between 50 kW and 100 kW, only DC1, AC1, and the water filtration system remain in operation, while DC2 and AC2 are turned off. In this state, system continuity depends on the battery charge level. If the battery charge ratio is above 50%, the loads continue operating normally. Conversely, if the charge drops below 50%, the AC2 load is automatically disconnected, and the battery enters a charging process until its capacity exceeds 50%. In the absence of power generation (Pgen_\text{gen}gen = 0 kW), the system operates AC1 using battery power alone. The battery continues to supply energy until its charge level reaches 20%, at which point the entire system is shut down to protect the battery from deep discharge (Kechida et al., 2024). This system is capable of delivering good production results with fast response times, enabling it to store large amounts of energy. In technologies that use renewable energy sources, storage systems are essential for maintaining consistent power quality.

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a combination of fuzzy inference system mechanisms described in neural network architecture. The fuzzy inference system used is the first-order Tagaki-Sugeno-Kang (TSK) fuzzy inference system, considering its simplicity and ease of computation. To explain the ANFIS architecture, it is assumed that the fuzzy inference system (FIS) has only two inputs, x and y, and one output, denoted by z. In the first-order Sugeno model, the rule set uses a linear combination of the existing inputs, which can be expressed as follows: If x is A1 and y is B1, then f1 = p1x + q1y + r1; if x is A2 and y is B2, then f2 = p2x + q2y + r2 (Subowo & Asfa, 2025).

The application of OTEC in the western Sumatra sea region as a pilot project found that the average sea surface temperature in the western Sumatra sea region was 29.3°C to 30.57°C °C and deep water temperatures (≥ 600 m) ranging from 8.74 °C to 9.25 °C, resulting in an average vertical temperature difference (ΔT) of around 21 °C, which is above the minimum threshold of ~20 °C for OTEC system operation. Under tropical sea conditions, ΔT is technically categorized as good for energy conversion. Overall, the measured ΔT results are stable at 21°C, sea water depth >600 m, consistent thermocline thickness, and theoretical Carnot efficiency of 0.70, which is in line with the potential identified in national OTEC studies and floating power plant designs. Based on these analysis results, water areas with characteristics similar to those of the Sumatra Sea have strong potential for the application of OTEC as a renewable energy technology (Absahan & Mokodompit, 2025).

In addition to OTEC technology, which has the potential to be implemented, there is also PRO renewable energy technology. PRO utilizes the energy-producing potential of the salinity gradient between freshwater, brackish water, and seawater sources. Abundant resources enable sustainable energy production. From small-scale applications to large-scale power plants, PRO systems can be used on various scales. In addition, this technology contributes to reducing climate change and improving air quality by not emitting pollutants when used. A pilot application of PRO technology is the development of a 240 m^3/day SWRO–PRO hybrid plant in South Korea, which combines Seawater Reverse Osmosis (SWRO) with PRO to reduce energy consumption and environmental impact. During a two-year operational period, this system showed a 20% reduction in energy consumption in the SWRO process and a 63% reduction in the dilution of high-salinity seawater (Yunus et al., 2025).

Table 4. AQUANOVA cost estimate analysis

Needs	Price
Turbine OTEC (Ocean Thermal Energy Conversion)	IDR 10,000,000
PRO Unit (Pressure-Retarded Osmosis)	IDR 20,000,000
Floating Solar Panel	IDR 405,000
Sea water temperature sensor (thermistor)	IDR 15,000
Water Pressure Sensor (Pressure Transducer)	IDR 100,000
Salinity sensor (EC Meter + TDS Sensor)	IDR 99,000
Ai Nov System (ESP 32 + OPS Module + Digital Compost)	IDR 60,000
Navigation Prepulse (DC Meter/Propeller)	IDR 110,000
Seawater pump (submersible pump)	IDR 85,000
Microprocessor control system (Raspberry Pi / ESP 32)	IDR 57,000
IoT Communication Module (LoRa)	IDR 70,000
Separator & flow regulator tank	IDR 300,000
Integrated module frame (HDPS material)	IDR 194,000
LifePO4 battery energy storage system	IDR 380,000
Air Purifier	IDR 240,000
MQ-7	IDR 25,000
Total	IDR 32,140,000

The application of OTEC, which has been supported by a pilot project in the Sumatra sea region, shows promising potential for implementation in Indonesia. PRO renewable energy technology, with its advantages and having been implemented in South Korea, proves that this technology is also suitable for implementation in Indonesia. The advantage of PRO technology, which can be effectively combined with other technologies, opens up great possibilities for this technology to be integrated with OTEC, thereby creating renewable energy technology that has the potential to work together significantly.

3.8 Political, economic, social, technology field, environmental impact, and legal (PESTEL) analysis of AQUANOVA

3.8.1 Political analysis

Indonesia's national policy framework for emission reduction commitments is a key factor in realizing clean energy innovation. Reducing greenhouse gas emissions by 834 million tons of carbon dioxide is the main target of the government's commitment to Indonesia's sustainability. The energy sector is the main focus, with a carbon emission reduction target of 314 million tons of carbon dioxide (Abduh et al., 2025). To support this commitment, Indonesia recently announced its emission reduction targets. Based on the latest Nationally Determined Contribution (NDC) document published by the Coordinating Ministry for Economic Affairs, Indonesia has renewed its commitment by increasing its emission reduction target to 31.89% by 2030, and to 43.20% if it receives international assistance.

The Ministry of Energy and Mineral Resources, through the Directorate General of New, Renewable, and Energy Conservation, stated in 2025 that the Indonesian government is also determined to promote a fair, inclusive, and sustainable energy transition by strengthening policies, decarbonization strategies, and the development of effective indicators. AQUANOVA's technological innovation occupies an important position as a new breakthrough that can accelerate the energy transition and at the same time offer solutions to reduce carbon emissions in a sustainable manner. AQUANOVA's technological innovation is an effort to reduce carbon emissions and realize the implementation of Sustainable Development Goals (SDGs) points 7 and 15 in producing affordable renewable energy and restoring ecosystems. The presence of this technology is in line with the Indonesian Ministry of Transportation's program to prevent global warming and reduce greenhouse gas emissions.

3.8.2 Economic analysis

The negative impact of air pollution on the economy should not be underestimated. Expenditures on medical care, decreased productivity, and significant challenges to the capacity of public health systems have reached trillions of rupiah annually. According to the 2022 Lancet Commission report on Pollution and Health, the estimated global economic losses caused by air pollution have exceeded USD 4.6 trillion per year. This shows that air pollution is not only an environmental and health issue, but also closely related to the sustainability of a country's development (Haya et al., 2025).

Along with political commitment to energy transition, the shift towards clean energy provides significant opportunities to stimulate economic growth and create new opportunities for innovation such as AQUANOVA. The use of technologies such as AQUANOVA is not only important from an environmental perspective, but also promises great benefits in economic and social aspects. Through job creation, the development of new industries, and the promotion of sustainable economic growth, AQUANOVA can reduce dependence on external resources such as electricity and save on operational costs because this technology uses seawater as an energy source. In addition, the long-term operation of this technology will be more economically efficient despite requiring a fairly high initial investment.

3.8.3 Social analysis

Data from the World Health Organization (WHO) shows that almost the entire world population, or around 99%, is exposed to air pollution at levels that exceed health safety standards. Increased air pollution contributes to premature death and exacerbates long-term health problems such as heart disease, asthma, and lung cancer (Laoly & Djaman, 2021). Growing public awareness of environmental health has fostered strong social support for any innovation that promises to provide clean energy while improving air quality. This situation presents a significant opportunity to implement AQUANOVA technology.

Technologies such as OTEC and PRO, which are part of the AQUANOVA system, offer great potential for use in coastal areas with limited access to fossil fuels. This directly supports national energy equity efforts and improves the standard of living of local communities. With the convergence of increased environmental awareness, the need for fairer energy distribution, and the economic prospects offered by green energy, AQUANOVA has a strong social foundation for widespread implementation in Indonesia.

3.8.4 Technology field analysis

The Ministry of Energy and Mineral Resources, specifically through the Directorate General of Electricity, stated that to achieve the energy transition target, the government, through the Ministry of Energy and Mineral Resources, is encouraging the implementation of technological digitalization in clean energy power plants. The collaboration between digitalization and renewable energy is recognized as a vital strategy to ensure national energy independence and security. OTEC, as a component of AQUANOVA, has a theoretical potential of 57 GW, a technical potential of 52 GW, and a practical potential of 43 GW.

Strengthening digital infrastructure and smart algorithm integration capacity are key drivers for the development of advanced clean energy systems, such as AQUANOVA, which combines OTEC-PRO and control automation. Specifically, AQUANOVA, with the integration of ANFIS-Fuzzy Logic in energy management and air purification systems, provides a great opportunity to accelerate the adoption of smart technologies in the energy and environmental sectors. This adoption is in line with the government's digitalization agenda and can serve as a concrete example of efficient and adaptive clean energy innovation. Furthermore, AQUANOVA's technological innovation is a combination of various disciplines, ranging from electrical engineering, mechanical engineering, environmental engineering, to intelligent control systems, making AQUANOVA a manifestation of integrative technology.

3.8.5 Environmental impact analysis

Open-cycle OTEC construction, in addition to generating electricity, also produces large volumes of nutrient-rich seawater. The abundance of nutrients produced by OTEC has the potential to cause harmful algal blooms, which are rapid growths of phytoplankton that result in a decrease in oxygen levels in seawater through a process called eutrophication, causing mass deaths of fish and other marine life. One of the preventive measures against potential environmental damage caused by OTEC is to measure seawater nutrients at depths of 20 m, 600 m, and at the depth of the discharge pipe, measure plankton abundance using MOCNESS periodically, control water flow in cold water pipe installations, and conduct acoustic monitoring (Wijayanto & Zakia, 2024).

The presence of AQUANOVA technology marks a significant innovation in efforts to minimize dependence on fossil fuels. This breakthrough has the potential to become a real reference for the implementation of environmentally friendly technology in Indonesia. In addition to producing environmentally friendly energy, this technology can also be applied throughout Indonesia, which is largely surrounded by oceans. Ultimately, this technology can be an advantage for the energy sector in Indonesia.

3.8.6 Legal analysis

In recent years, Indonesia has strengthened its regulatory policies to facilitate energy transition and reduce carbon emissions. This has been realized, among other things, through the issuance of Presidential Regulation (*Peraturan Presiden*/Perpres) No. 98 of 2021 concerning Carbon Economic Value, which forms the basis for emissions trading schemes, pollution control, and the implementation of low-carbon technologies. Furthermore, the government provides regulatory support through Presidential Regulation No. 112 of 2022 as an instrument to accelerate energy transition in the electricity sector, which guarantees the legitimacy of clean energy technology development, including marine energy types such as OTEC.

This entire set of regulations reinforces the Indonesian government's commitment to an agenda that promotes alternative energy mixes, ensures sustainable governance, and creates a climate conducive to green technology innovation. Thus, the existing legal framework provides a fundamental basis for implementing advanced technology-based energy systems such as AQUANOVA. In addition, AQUANOVA technology has great potential to be more widely accommodated within the framework of continuously updated legal policies. However, this adoption depends on the condition that its development must comply with the safety, efficiency, and low-carbon energy standards set by the government.

4. Conclusion

CO_2 emissions are a major factor causing systemic warming of the Earth's surface temperature, which has a significant impact on the sustainability of biotic and abiotic structures in ecosystems. High levels of CO_2 emissions from fossil fuel combustion, land use change, and deforestation are the causes of high CO_2 emissions. AQUANOVA is an air purification technology that can absorb CO_2 in the atmosphere and is integrated with OTEC, PRO, and air purifiers to reduce carbon emissions in the air. AQUANOVA's innovation is designed to reduce CO_2 emissions based on ANFIS-Fuzzy Logic management as an effort to achieve SDG points 7 and 15 in producing affordable renewable energy and restoring terrestrial ecosystems. By collaborating with relevant parties, it is hoped that AQUANOVA can become a technology capable of reducing CO_2 emissions as part of the government's commitment to reducing the carbon footprint generated by the conventional energy sector.

Acknowledgements
Thanks to the article editors who have helped during the writing process. The author would not have been able to complete this manuscript without the help of various parties who have contributed. In addition, various books and other references also facilitated the author during the writing process. The author expresses his deepest gratitude to all those who have helped, either directly or indirectly, in the writing of this article.

Author Contributions
The authors were actively involved in literature search, data interpretation, and the drafting and revision process. The final manuscript has been reviewed and approved by all contributors for submission for publication.

Funding
This research received no external funding.

Ethics Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflict of Interest
The authors explicitly declare that there are no conflicts of interest related to the publication of this research.

Generative AI Declaration
During the drafting stage, the authors used DeepL tools to optimize grammar, clarity of information, and academic tone. After this process, the authors independently reviewed and edited the manuscript content, so that the entire publication remains the sole responsibility of the authors.

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