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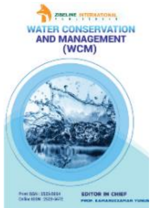

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RESEARCH ARTICLE

ADVANCED SUSTAINABLE MEMBRANE DESALINATION TECHNOLOGY FOR THE BAJAU TRIBE: A COMPREHENSIVE EXPLORATION OF TECHNOLOGICAL, ENVIRONMENTAL, SOCIAL, AND ECONOMIC IMPACTS

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ABSTRACT

In light of the escalating population growth within Indonesia's coastal regions, there is a corresponding surge in the demand for fresh water and sanitation facilities. Addressing this challenge, the deployment of membrane-based desalination technology emerges as a viable solution to augment the fresh water supply for coastal communities. This study delves into the application of titanium dioxide (TiO_2) as a material in membrane-based desalination processes—namely, electrodialysis (ED) and reverse osmosis (RO)—synthesized through an integrated approach that encompasses technological, environmental, social, and economic perspectives. Specifically, this approach is tailored for implementation among the Bajau Tribe in Pasikuta Village, located in the Southeast Sulawesi Province of Indonesia. The methodology encompasses technological research and a systematic literature review, supplemented by membrane design, desalination technology analysis, and a bibliometric study based on Scopus data. The findings reveal that the development of a simplified desalination system, which combines the ED-RO techniques utilizing TiO_2-modified membranes, exhibits promising potential for adoption in coastal communities. Moreover, this system is characterized by its minimal impact on the marine ecosystem, thereby facilitating its straightforward and cost-effective application through the integration of photovoltaic (PV) technology for harnessing renewable energy. Crucially, the success of this desalination technology's community-based application hinges on community engagement, educational initiatives, and enhancements in community income levels, thereby establishing a sustainable model for mitigating water scarcity and reducing environmental repercussions.

KEYWORDS

Desalination, coastal communities, TiO_2, electrodialysis, reverse osmosis

1. INTRODUCTION

Currently, Indonesia is experiencing irregular rainfall patterns spread across the region caused by climate change, which can exacerbate extreme events such as droughts and floods (Liu et al., 2022; Nurjani et al., 2020). Several regions of Indonesia have suffered severe disasters as a result of climate change (Sekaranom et al., 2021). The climate in eastern Indonesia tends to be inversely proportional to the climate conditions in the western region, which is experiencing dry season. For example, east Indonesia experiences dry season while western Indonesia experiences rainy season (Aldrian and Dwi Susanto, 2003; Alifdini et al., 2021). These condition tend to change the ecological environment of living creatures, especially human life (De Frenne et al., 2021; Jansson and Hofmockel, 2020). This condition is due to changes in the hydrological cycle and geographical location of Indonesia between the equator, which has only two seasons (Narulita et al., 2021). On the other hand, wind movements also affect climate change, which affects environmental damage, so Indonesians living in coastal areas must play an important role in survival (Djalante et al., 2021; Kuswanto et al., 2022).

Freshwater is an obstacle for coastal communities to survive in coastal areas, especially when climate changes in Indonesia (He and Silliman, 2019; Setyawan, 2022). For example, Pasikuta Village, Southeast Sulawesi Province – Indonesia, has an area of less than 2.0 km^2 surrounded by the oceans, and lives above seawater (BPS Muna, 2022). During the dry and rainy seasons, freshwater is the most challenging to obtain in the Pasikuta Village because the surrounding groundwater dries, and the rainy season is affected by bad weather which makes it impossible to sail to the nearest island so they rain to get freshwater (Nagatsu, 2017). Freshwater is essential for other aspects of daily life, including consumption for coastal communities (Rakib et al., 2019; Shammi et al., 2019). Besides, demand for water continues to rise as the population grows, which is the biggest challenge for the Pasikuta village. Some developed countries have explored freshwater using desalination technology, having a significant impact on their communities (Elsaid, Kamil, et al., 2020; Elsaid and Sayed et al., 2020). For example, Bahrain, Singapore, Taiwan, and the Middle East have successfully developed desalination industries to obtain freshwater sources (Al-Fazari and Teng, 2019; Basha et al., 2021). To support the environmental sustainability industry, they continue to study the

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effectiveness of improving the freshwater capacity that can be produced, water quality, and the resilience of the desalination industry in supporting the sustainability of the community's living standards (Ahmad et al., 2020; Ahmadi et al., 2020; Saleh and Mezher, 2021).

Desalination technologies applied in developed countries is thermal and membrane desalination technologies such as MSF and MED (thermal); RO and ED (membrane) (Figure 1) (Hassan and Awad, 2023). However, the thermal technology is high energy consumption and environmentally unfriendly, therefore the application of membrane technology for seawater desalination is mostly suitable for water treatment (Kim et al., 2019; Qasim et al., 2019). Reverse osmosis (RO) and electrodialysis (ED) techniques have provided real hope in seawater treatment due to their environmentally friendly, cheap, and simple technology (Mavukkandy et al., 2019; Tufa et al., 2019). Membrane technology has been shown to be effective in reducing salt ion content in seawater (Matin et al., 2021). For example, several researchers reported that the ED method can reduce salt ions in seawater by the movement of ions dissolved in the feed water (Alkhadra et al., 2020; Doornbusch et al., 2019). In addition, the RO technique plays an active role in selecting salt ions with particles less than 10 µm ± 5% (Yao et al., 2022). Thus, these techniques are a powerful way to reduce salt content in seawater.

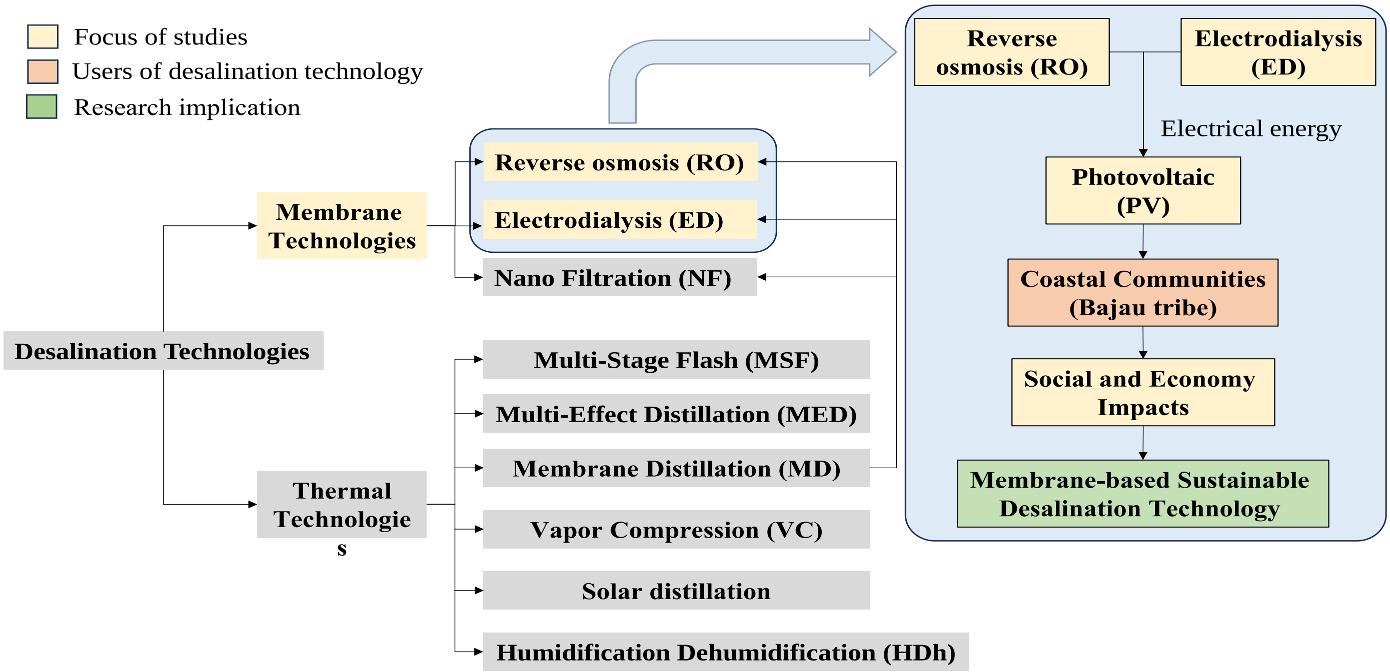

Figure 1: Main classification of desalination technologies in use worldwide and the relationship of sustainable application of membrane desalination technology

The application of ED and RO technology is heavily dependent on the materials used. In ED technique should pay attention to the ion-exchange membrane through ion movement and electrode resistance to initiate the reduction-oxidation (redox) reaction process to bind salt ions in the desalination process (Jarin et al., 2023; Jeong et al., 2020). On the other hand, RO technique also needs to consider the chemical composition for membrane fabrication in order to reduce fouling on the membrane surface (Mengesha and Sahu, 2022). Currently, the development of smart materials to improve performance in ED and RO by utilising Titania (TiO_2) material as a base material for working electrodes and membrane that is applied in ED and RO desalination (Mao et al., 2021; Subaer et al., 2022). TiO_2 is very promising and has been proven to have good performance in improving desalination work. Based on our last study reported that the titanium metal-based electrochemical process provides good conductivity in electron movement and resistance in reduction-oxidation (redox) reactions (Wibowo et al., 2018; Wibowo et al., 2022; Wibowo et al., 2022). Meanwhile, applying RO membrane improves antifouling, good hydrophilicity, environmentally friendly, and photocatalyst properties against organic pollutants (Mansor et al., 2023a; Nurdin et al., 2023; Wibowo et al., 2023). This material is very suitable for application in desalination technology to produce freshwater. In last publication, the combination of ED-RO with PV has significantly positive impact on energy efficiency to reduce the fossil energy to electrical supply for ED and RO desalination (Wibowo and Koestoer, 2023).

However, desalination technology should be implemented in the coastal community to impact freshwater provision positively (Rakib et al., 2019; Shammi et al., 2019). However, the application should be based on social and economic approaches in order to be accepted in the community. Based on research Liu et al. reported that the acceptable desalination technology in the coastal community should fulfil several important aspects so as not to affect changes in the standard order of life of coastal communities (Liu et al., 2022). Surveys and the community's technology readiness need to be studied to accept this technology and increase the environment's carrying capacity (Eltamaly et al., 2021). Therefore, this paper provides an understanding for readers regarding the basic theory of ED and RO desalination for the acceptance of this technology in coastal communities, especially in Pasikuta village, which is predominantly the Bajau tribe.

1.1 Overview of the study area

Pasikuta is a unique village in the Marobo Sub-district, Muna Regency, which has an area of less than 2.0 km² surrounded by ocean. The average population growth in Marobo is 6846 people, divided into 7 villages, so it is assumed that the average population growth is 978 people/year (BPS Muna, 2022). Pasikuta Island is in the western region of Muna Island with latitude 5° 1' 17" S and longitude 122° 16' 13" E (Figure 2c). The Bajau tribe on Pasikuta island is included in the Buton Cluster Enlarged category with the start of civilization in the region since 1995 and developed in 2011 (Nagatsu, 2017; Satria et al., 2020). The distribution of the Bajau tribe is very much in the coastal areas of Southeast Sulawesi Province because the waters are very shady, providing abundant marine natural resources, and business economic development (mining and plantation industry sectors). For the Bajau people, this is a key geo-demographic characteristic of the region, which occupies coastal areas and small islands. The Buton cluster has 59 areas occupied by the Bajau tribe, which has a population of more than 1000 people. The Bajau tribe in Pasikuta village have built their civilization on and around extensive coral reefs (Figure 2a,b) (Nagatsu, 2017).

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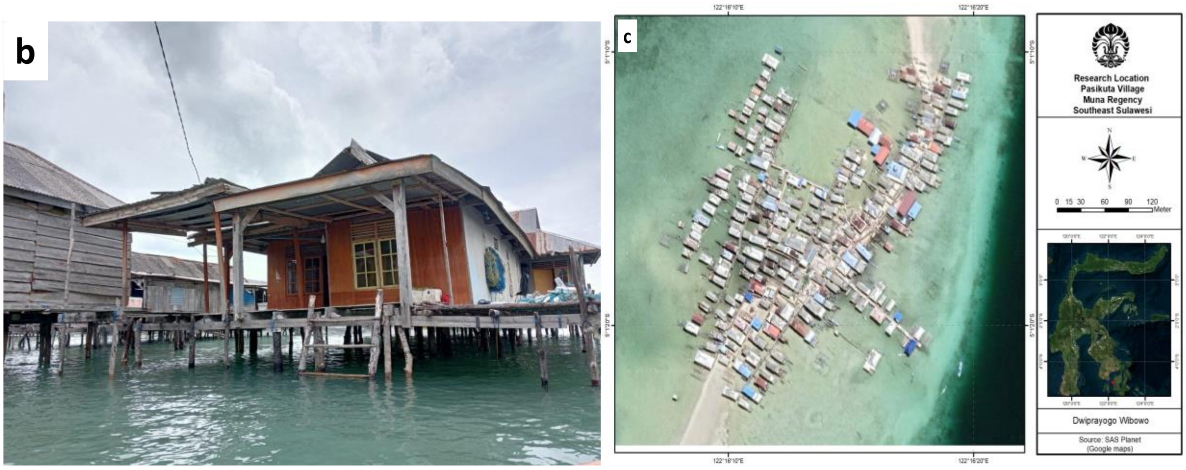


Figure 2: Pasikuta village, Muna Sub-district, Southeast Sulawesi Province, Indonesia; (a) Distant view of Pasikuta Island; (b) Residential building type of coastal community of Pasikuta Island; and (c) Satellite image of Pasikuta village location.

This island (Figure 2c) is considered a "Lost Island" because it has no clear land at high tide, while the land area can be seen at low tide (small islands and coastal regions) (Rianse et al., 2023). In particular, most of the population in Pasikuta Village is predominantly Bajau tribe, which requires an approach in the social, cultural, and economic fields (Nagatsu, 2017). The "Bajau core village" or Bajau tribe often functions as a social, economic, and symbolic centre in coastal cluster, which is the livelihood of residents as fishermen (Figure 2). Nagatsu et al. (Nagatsu, 2017) reported that Bajau is one of the most distinctive "sea peoples" in the Southeast Asian maritime world (Figure 3). The Southeast Asian marine world is defined here as the socio-cultural ecosphere of Southeast Asia, which is bound tightly through the seas (Nagatsu, 2017).

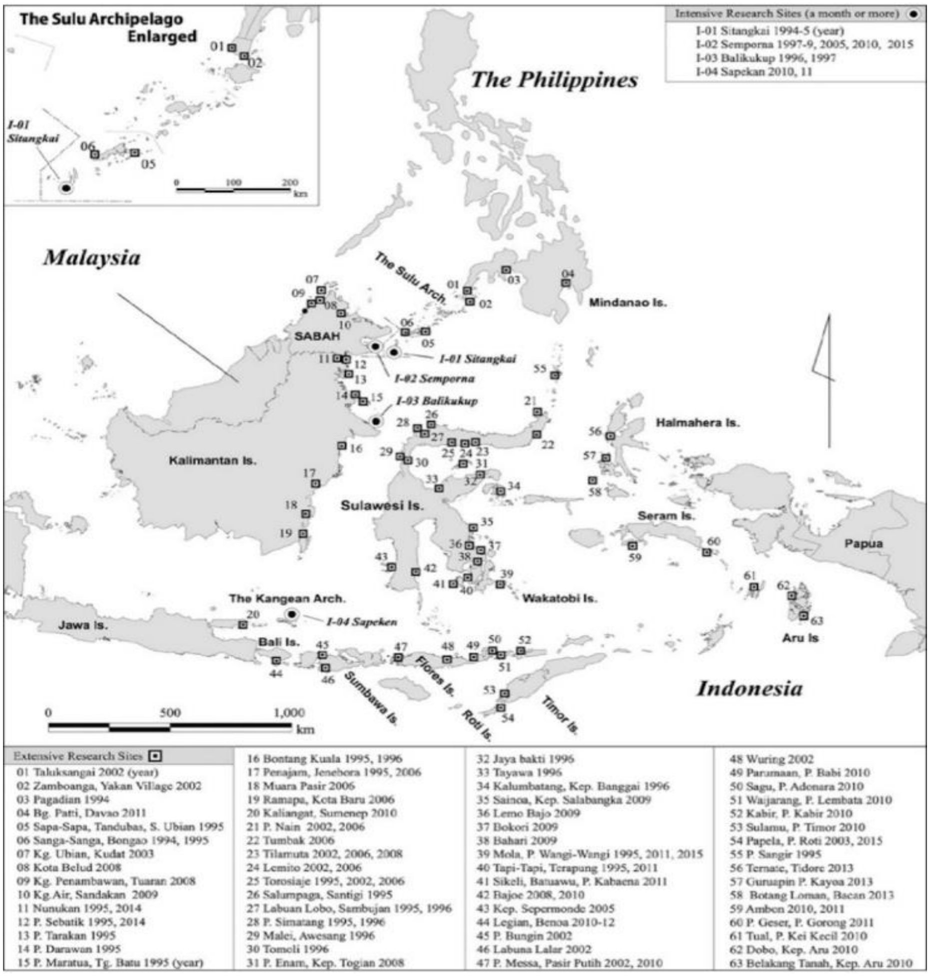


Figure 3: Distribution and clusters of the Bajau in Indonesia (Copyright permission from Nagatsu (Nagatsu, (2017)

Concerns about environmental waste management, health threats, and freshwater scarcity in coastal areas and small islands are important factors that should be considered for the Bajau communities to avoid dysentery, malaria, and skin diseases (Sinapoy and Djalante, 2021). Moreover, the prolonged drought that occurred between September and December caused drought along the coast of Muna Island, making it very difficult for people to obtain freshwater. Many researchers reported that the freshwater supply is inadequate to meet the needs of Bajau communities, so they use rainwater or take freshwater from another island (Djohani, 2005; Rahim et al., 2018).

Environmental conditions also affect the Bajau tribe's habits and the difficulty of changing their lifestyle to obtain clean water, because the water content in the area tends to be salty and brackish (Clifton, 2014). So desalination technology is needed to provide freshwater for the Bajau tribes by utilising abundant seawater sources (Djohani, 2005). It has been widely applied in Bahrain, Singapore, Algeria, Germany, India, Saudi Arabia, and Qatar to provide freshwater for coastal communities (Al-Fazari and Teng, 2019; Basha et al., 2021). Seawater desalination models include thermal and membrane technologies were applied in many countries. However, the commonly developed membrane technologies are considered very easy to operate and low cost such as ED and RO (Khodabandehloo and Farhadi, 2021).

Currently, the Indonesian government continues to support and advance coastal areas and small islands in supporting the availability of clean water through the Village Fund assistance programme and Village Fund Allocation which is the original income of the village and other sources (Arifin et al., 2020; Permatasari et al., 2021). These funds can be used for village expenditures, such as expenditures for village government administration, community development, community empowerment, and the implementation of village development (Larisu and Jopang, 2022). We believe that the Village Fund is best used to build sustainable desalination technology when some communities do not have sufficient funds to build or purchase desalination technology. Because the community's livelihood is 100% fishermen, the limited income has reduced the community's interest in buying technology, although this is also important, but primary needs such as clothing, shelter, and food are prioritised by the community.

Village progress in terms of health environment (sanitation) and economy are the benchmarks of good village development. Village funds received are approximately between 800-100 million IDR or 50,500-63,000 USD which can be managed wisely to build supporting facilities, especially clean water in coastal areas or small islands (Indra and Khoirunurrofik, 2022; Moita, 2022). Based on the lack of understanding and initiative of village leaders requires a mentor (an expert in the field of village development) to provide direction and opinions to advance the village, so it is certain that Pasikuta Village and other villages can also develop along with improved sanitation and adequate clean water distribution (Larisu and Jopang, 2022).

2. Research Methodology

2.1 Study area

Pasikuta village was the location of the preliminary survey with the dominated of the Bajau tribe located in West Muna Regency, Southeast Sulawesi Province, Indonesia (Figure 2). We observed the socio-economic conditions based on a literature approach that describes the culture and behaviour of the Bajau people in their daily lives. Socioeconomics will influence how the community's perspective patterns towards their readiness to accept technology. Water and economic needs are crucial in the existence of sustainable desalination technology. We also approached the social acceptance of desalination technology from several researchers from an environmental perspective. The purpose of this method is to decide that coastal communities or small islands are in dire need of clean water with the application of technology developed for a sustainable environment.

2.2 Qualitative study

This study explores literature reviews and research papers as initial references regarding the challenges faced in implementing desalination technology and its applicability to coastal communities. We relate this to the PV-ED-RO-based desalination technology that we have developed as a model to be implemented in Pasikuta village. The study of TiO_2 material-based membrane studies, building a prototype model of PV-ED-RO technology, and preliminary socio-economic studies of the Pasikuta village community (Bajau tribe) are discussed in this research. The last stage was identified a bibliometric analysis approach, data mined from the Scopus website and processed using the VOSviewer application version 1.6.19. In this paper, the problems solved to inform readers are 1) Fabrication of TiO_2 membranes applied into ED and RO desalination, 2) Eco-friendly design of ED combined with RO desalination based on PV Technology applied to the community, and 3) Social perspective in terms of feasibility of equipment to be applied in the community and acceptability of desalination equipment applied to coastal communities (positive and negative impacts).

We observed a synergistic relationship that has not been observed by many researchers on the complexity of the sustainability of desalination technology for small island communities. As we show in the flowchart (Figure 4), this relationship will be applicable if the utilisation of green technology and energy synergise to reduce the socio-economic impact of the community. Therefore, our concept paper explores the challenges that need to be addressed in the application of membrane desalination technology, especially TiO_2-based membranes, which have not been studied by many researchers.

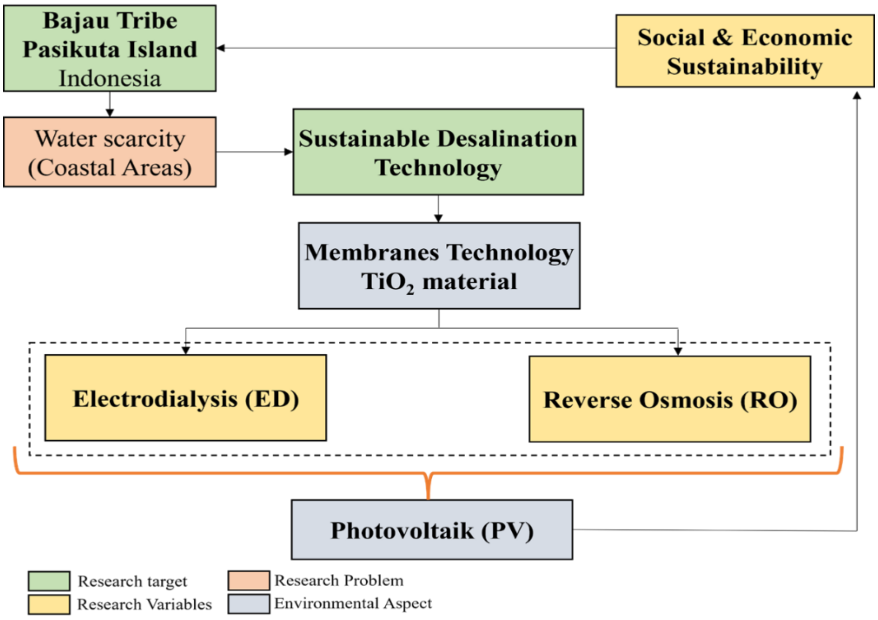


Figure 4: Research flowchart to identify the sustainable desalination technology for coastal areas (Pasikuta island)

3. Results and Discussion

3.1 Concept Of TiO_2 Material In Desalination Membrane

In general, a membrane is defined as a thin semi-permeable layer that acts as a selective barrier that separates dissolved or undissolved substances under the action of chemical or physical force. Smaller constituents can pass through the membrane under high-pressure (Alhalili et al., 2021). The structure of the membrane is an important factor because it will govern the mechanism of transport of the solutes and thus influence the field of membrane application (Alhalili et al., 2021). However, the constraints of desalination membranes in ED and RO are membrane fouling and low lifetime which will impact the cost incurred for membrane replacement.

The concept of building and developing ED or RO membranes synthesized can be by utilising some environmentally friendly chemicals such as cellulose acetate, aromatic polyamide polyether sulfone, polyolefin, polyethylene, polyacrylonitrile, fluoropolymer, and so on (Ounifi et al., 2022; Davari et al., 2021; Park et al., 2018; Mansour et al., 2018; Klaysom et al., 2013; Cui et al., 2014). Organic membranes are often used as membrane components in membranes-based desalination. If plastic-based is used, it takes a long time to degrade in nature and is not environmentally friendly (Bandehali et al., 2021; Kabir et al., 2020). Plastic membranes are exhibited excellent hydrophilicity, antifouling, and high porosity. However, the researchers found that cellulose-based organic membranes are earth-abundant biopolymers and have innate strengths including high hydrophilicity, cost-effectiveness, and low fouling (Jain et al., 2022; Mansor et al., 2023a). Unfortunately, these materials do not have the ability to fight back microorganisms or crusting on the membrane surface hence these membranes should be modified with inorganic materials that could oxidise or reduce crusting (Pichardo-Romero et al., 2020). Recent research has modified the membrane by combining TiO_2/ZnO resulting in changes in membrane properties so that it is very easy to absorb hydrophilic hydroxyl groups (-OH) to become hydrophilic, has a specific surface and good porosity due to the crystallographic structure for the filtration process, has antibacterial and antifungal properties because the photocatalytic properties of TiO_2 can initiate reduction-oxidation (redox) reactions assisted by ultraviolet (UV), low cost and non-toxic by (Alhalili et al., 2021). In the same research reported that the TiO_2 photocatalyst can degrade the fouling effect and high retention value on membranes by (Adibah et al., 2021). That the modification of membrane exhibited excellent hydrophilicity, consequently the water flux value become higher in multifold manner (Mishra et al., 2021). For these reasons, it is imperative for the development of ED or RO membranes to combine the basic material of commercial membrane manufacturing with TiO_2 material which logically has a significant effect on the durability and filtration ability of desalination membranes.

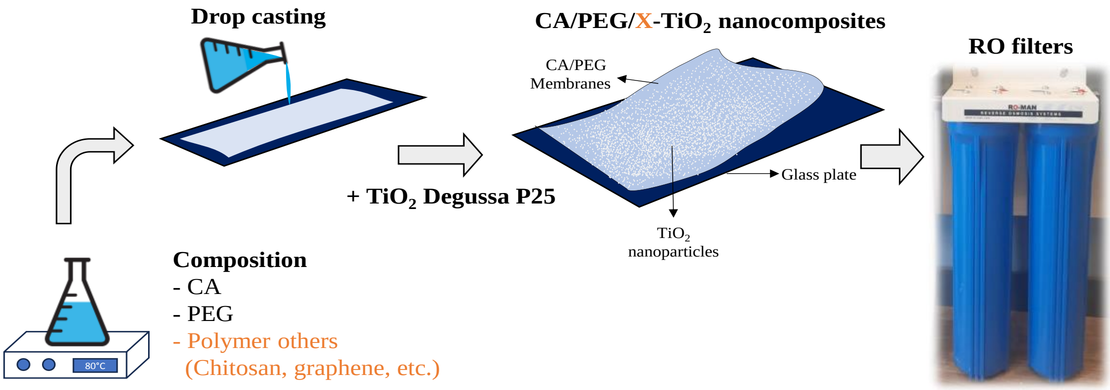


Figure 5: Schematic of membranes preparation based on TiO_2 material for RO desalination

The results of the review of several scholars related to the preparation of TiO_2-based desalination membranes in an easier and faster way as in Figure 5 like our previous research where the composition of cellulose acetate (CA), polyethylene-glycol (PEG), and other polymers if desired can be added in acetone solution (Wibowo et al., 2023). These materials are stirred using a magnetic stirrer with certain adjustments until the solution thickens slightly and poured on a flat glass plate until evenly distributed (Nurdin et al., 2023; Wibowo et al., 2023). In this condition, TiO_2 material that has been sieved in the size of 150-200 mesh is scattered on the surface of the membrane in a thick condition and allowed to dry normally. The drying process can be done under ambient or oven conditions with less than 30°C. If the temperature is high, it can cause damage to the membrane characteristics because some cases the membrane cannot survive in hot and acidic conditions (Vengosh et al., 2011).

The advantages of TiO_2 in blending synthesis membranes provides changes in membrane characteristics as reported by (Mansor et al., 2023a) that the addition of TiO_2 material by mixing can increase salt rejection by 99.52% and flux increased by 34.2%. The presence of TiO_2 also makes the flow of water easier through the membrane. Chemical oxygen demand (COD) and biological oxygen demand (BOD) values can also be reduced by the TiO_2 material-based membrane desalination method because of its photoactive nature in water media. Meanwhile, added SiC and graphene mixing materials to the membrane can increase the hardness of the membrane material which can also be used as an antibacterial medium (Chowdhury et al., 2022).

We learnt that the presence of substituted TiO_2 on the synthesized membrane initiates the redox reaction of UV light induction on the RO tube (Figure 8). When TiO_2 is induced by UV light, electron vacancies occur in the band gap thus initiating reduction and oxidation reactions, this process is known as photocatalysis (Maulidiyah et al., 2015; Wibowo et al., 2020). In the case of water medium, TiO_2 on the membrane easily destroys fouling caused by microbes or other organic compounds that pass through the ED or pretreatment process (Chowdhury et al., 2022). So chemically this condition will more easily reduce the impact of fouling, improve the mechanical properties of the membrane, and reduce harmful organic compounds on the RO membrane surface (Al Mayyahi, 2018; Chong et al., 2010). However, the drawback of using TiO_2 in the synthesis membrane is that there has been no study of membrane damage to the presence of TiO_2 material, the practicality of the material obtained, and how long TiO_2-based membranes are no longer capable as desalination membranes. These consequences will be further studied by our future research.

3.2 Eco-friendly design of ED-RO prototype based on PV technology

Several methods for obtaining freshwater in daily life include wastewater treatment, atmospheric water collection and seawater desalination (Sayed et al., 2022). Given the abundance of seawater in coastal and small-islands communities, seawater desalination is considered a valuable option for freshwater production (Cai et al., 2023). Most of the current research in the application of widely developed seawater desalination technology is membrane-based which is believed to have a valuable impact in the water filtration process due to its high efficiency, economy, easy to operate, low energy, and environmental friendliness (Ali et al., 2018; Goh et al., 2016; Shammi et al., 2019). The prospect of membrane technology is very promising considering the development of research on membranes continues to be intensively studied by researchers to investigate its durability, safety, antifouling, antibacterial, and selectivity (Ahmad et al., 2022; Wu et al., 2020; Zhang et al., 2022). However, these membranes need to be developed towards applications to be applied on a large scale and utilised by the community.

The application of TiO_2-modified CA/PEG membrane synthesized provides promising potential for desalination development (Mansor et al., 2023b; Wibowo et al., 2023). It provides good performance optimisation for both RO and ED applications. Figure 7 is a prototype model of PV-ED-RO desalination technology that we developed by combining PV-ED-RO to optimise the separation process of metal ions and TDS. Ghazi et al. explained that the incorporation of PV in desalination systems increases the efficiency of energy use in the operation of the technology (Ghazi et al., 2022). The use of batteries on the PV as electrical energy storage and efficiently distribute electrical energy to high-pressure pumps and electron transfer processes for ED systems. The process of stabilising the distributed electrical energy will establish a uniform level of freshwater supply has the benefit of avoiding membrane fouling, which is typically experienced with renewable energy-powered membrane desalination systems (Ahmed et al., 2022). Furthermore, some of the suggestions developed of reducing the surface area of solar panels are also worth noting, the developed approach reduces the required surface area of solar panels by 6% as the power generation capability of PVP cells increases by (Ghazi et al., 2022). The specific electricity consumption rate of RO desalination is also reduced by 0.5-2.5 kWh/m^3 (Alghoul et al., 2016; Antonyan, 2019). It has utilised the benefits of PV energy and tidal range energy in desalination technology for sustainable offgrid systems (Ayaz et al., 2022; Ghaithan et al., 2022; Delgado-Torres et al., 2020). Shokri and Sanavi Fard has explained the utilisation of PV and wind energy in RO provides promising energy efficiency and provides sustainable technology (Shokri and Sanavi Fard, 2022). On the other hand, the use of membrane desalination technology also needs to be considered because it plays a role in overcoming organic foulants, bacteria, calcium sulphate scaling, and colloidal foulants.

Our preliminary research of CA/PEG/TiO_2 membrane synthesized provides good performance in RO membrane applications placed in a transparent tube to lay the synthesis membrane, RO membrane position design using acrylic pipe combined with UV light illumination (Nurdin et al., 2023; Wibowo et al., 2023). Figure 7 design of PV-ED-RO desalination technology that we developed as a preliminary study to test the performance of membrane desalination technology. We used 2 pretreatment tubes to reduce feed water hardness to reduce the risk of membrane scaling. To suggested that an important strategy for pretreatment is disinfection because it can reduce microorganisms that produce membrane biofouling (Shokri and Sanavi Fard, 2022). In this case, TiO_2 on the membrane synthesized plays an important role to reduce biofouling on the membrane surface . The utilisation of photocatalysis of the inorganic material TiO_2 will initiate the redox reaction of bacteria occurring on the membrane surface due to scaling (Im et al., 2020; Jeong et al., 2020). In-situ monitoring of membrane efficiency is very important to assess the degree of fouling and then carry out appropriate self-cleaning needs to be developed (Shokri and Fard, 2022).

Supported by collaborating ED technology with RO is significant in reducing NaCl ion content in feed water (Chen et al., 2021). ED is an electrically driven membrane technology with the advantages of high concentration production and low operating pressure (Zhou et al., 2023). The movement of ions is used to move and reduce ions dissolved and attached to the membrane surface (Figure 6) (Cai et al., 2023). In addition, ED has been widely used for water purification, chemical recovery, and seawater desalination with ion-selective permeability of ion exchange membranes. Has applied ED to treat ammonium-containing waste showed that the ED membrane significantly reduced the levels of NH^{4+}, Na^{+}, K^{+}, Ca^{2+}, and Mg^{2+} ions as the applied current density and waste volume ratio increased (Yang et al., 2023). However, it is necessary to pay attention to the electrode material used for this ED process because the use in seawater will determine the durability of the electrode. When used for a long time, it will have an impact on the corrosion of the metal used, thereby reducing the performance of ED system.

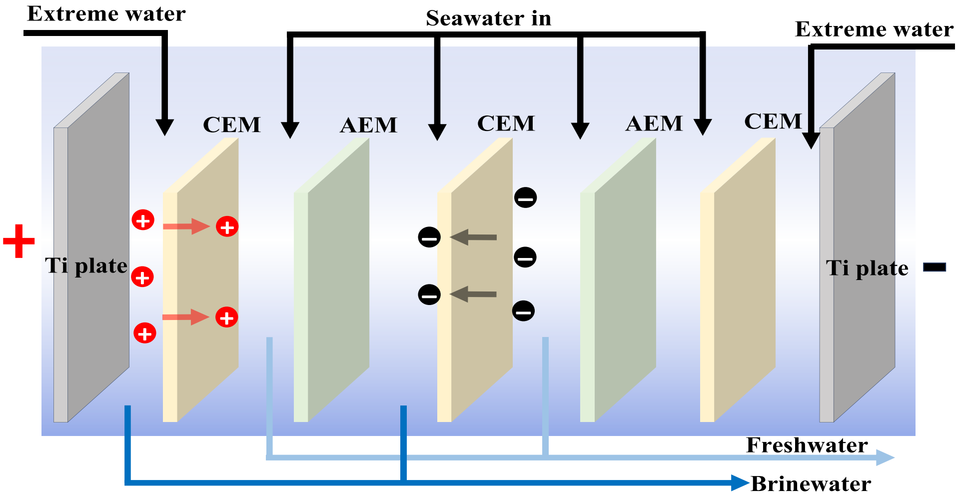
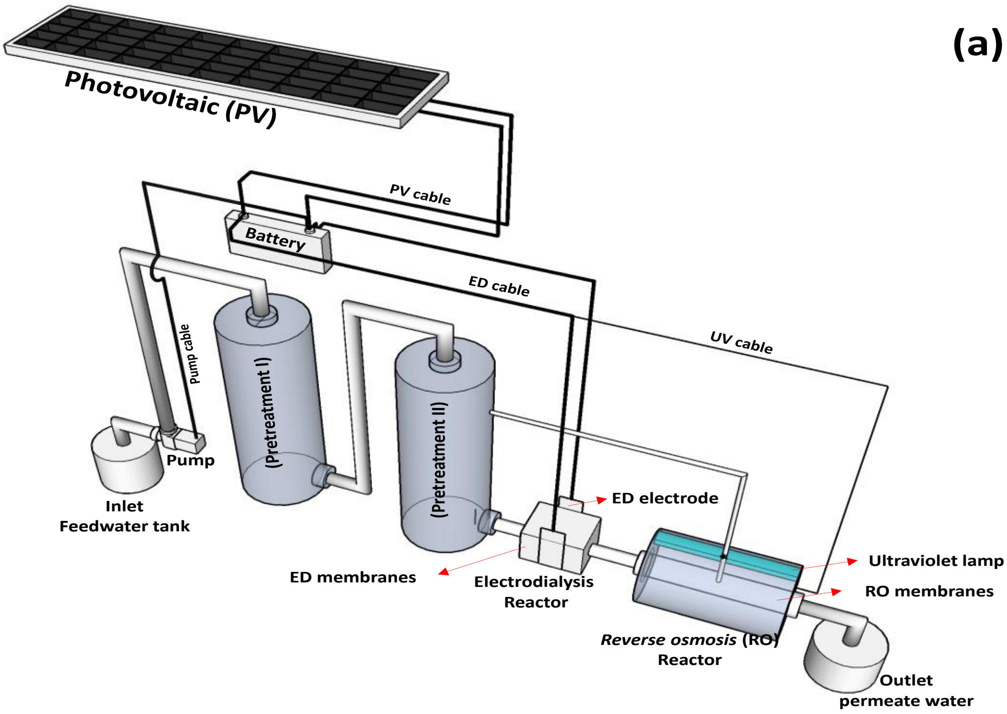


Figure 6: The electrodialysis seawater desalination device we developed as shown in figure 4 based on reference from (Cai et al., 2023)

In the ED simulation (Figure 6), the working principle of ED using working electrodes plays an important role in the transfer of current density in the movement of ions (Tedesco et al., 2016). Metal surface area, current movement, and membrane performance must work together in the application of ED to seawater. In the ED model, we suggest using a metal that is resistant to all seawater conditions, there may be many stable metals such as gold (Au) and platinum (Pt) but the cost is expensive which results in the high cost of ED in its application. The utilisation of titanium (Ti) metal which has been proven in the application of waste treatment technology, sensors, and metal coatings. Have reported that Ti metal in sewage treatment applications provides good performance and has good stability to solution conditions (Maulidiyah et al., 2017; Nurdin et al., 2017). Oxidation on the surface of Ti metal also provides changes in the structure of TiO_2/Ti enhancing the redox reaction process and plays a role in the performance of photoelectrocatalysis due to electrical current transfer from PV battery (Maulidiyah et al., 2018; Wibowo et al., 2018). The utilisation Ti metal is very promising for other application because the role of TiO_2/Ti photoelectrocatalysis for photodegradation over harmful compounds in water samples (Muhammad Nurdin et al., 2022; Mursalim et al., 2017; Wibowo and Muzakkar, et al., 2022). Therefore, the reinforcement of the ED process using electrodes in desalination systems is likely to significantly improve the performance in the separation of ions in the feed water.



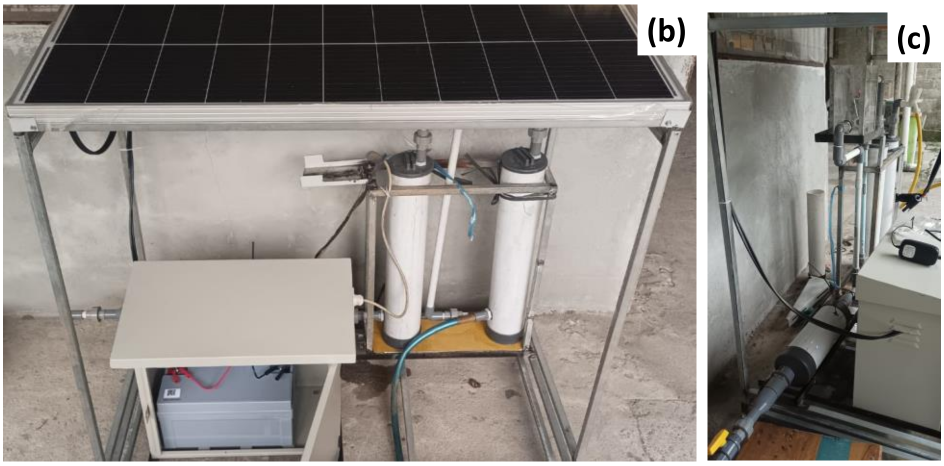


Figure 7: Design of ED-RO prototype based on PV technology (a) Schematic design, (b) Front view, (c) Side view

In the development of our PV-ED-RO prototype (Figure 7), the feed water is pumped under high pressure (25 bar) into two 60 cm pretreatment tubes to reduce impurities and hardness of the feed water (seawater) using conventional filters that are easily available on coastal or small-islands communities such as sand, gravel, charcoal, and silica with each height variation of 20 cm. The next stage, the feed water enters the electrodialysis (ED) stage to improve the separation process of metal ions by utilising CA/PEG/TiO_2 semipermeable membranes that can also function in RO membranes. CA membranes can also influence cationic/anionic properties by modifying with the incorporation of quaternary ammonium, aldehydes, and sulfonates, hence the outstanding adsorption ability of cellulose membranes (Liu et al., 2023). After going through the ED system, the feed water passes through the RO stage with a cylindrical tube system as shown in Figure 7a,c. The RO reactor is divided into two layers of pipes, the inner pipe with a diameter of 1.5 inch is a transparent acrylic type which consists of RO membranes arranged in layers. The outer pipe with a diameter of 4 inches to place the UV lamp RO technology model made can be seen in Figure 8.

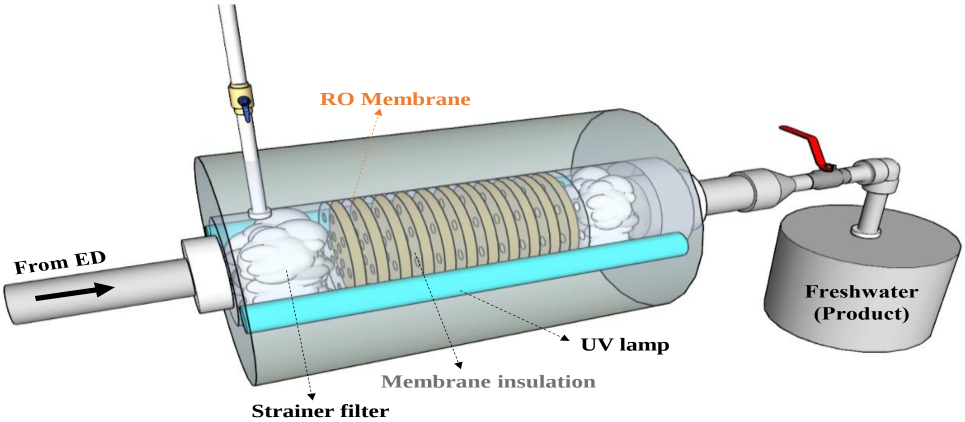


Figure 8: The RO membrane engineering technology model

Based on Figure 8, we fabricated the RO technology engineering model made based on the modified RO membrane using UV light irradiation. The RO model developed can be varied according to the development of research and applications such as the use of the number of membranes synthesised, filter strainers to reduce the impact of membrane fouling, and UV irradiation to inactivate bacteria and initiate redox reactions on membranes combined with TiO_2 material (Maulidiyah et al., 2017; Nurdin et al., 2015). The use of filter strainers serves to reduce fouling when the initial feed water hits the RO membrane, while when the feed water pressure is very high, a water return tap can be set to reduce water pressure that can result in membrane damage.

3.3 Social perspective for Bajau tribe in Southeast Sulawesi

The application of technology in society has a huge challenge to ensure that the technology applied can be accepted by the community. In the context of Indonesian society, which has a variety of different cultures, it is necessary to have a different approach so that technology can be understood and used by the community. Based on Portal Informasi Indonesia, Indonesia has 1340 ethnic groups, so the social approach to the application of technology in society needs good feasibility to be well received (Portal Informasi Indonesia, 2017). Indonesia being the largest archipelago has a variety of life between coastal and mainland communities, they are also different living habits with upholding the life of natural resources. In which, coastal or small-islands communities depend on marine resources for their livelihoods (fishermen), whereas the mainland communities are planters and farmers (Pratomo and Krisna, 2023). In the context of the desalination technology philosophy approach, the right target is coastal communities and small islands. We present one form of Pasikuta village as a model of a small island community that inhabits a sandy mainland area (Figure 2). The dominant community in Pasikuta village is the Bajau tribe who make their living as fishermen and uphold the marine environment (Rianse et al., 2023). The Bajau tribe in Southeast Sulawesi is one of the ethnic groups in Indonesia who originated from the Sulu islands, South Philippines and live above the sea (water) called sea gypsies (Dai and Manahung, 2020). They uphold local wisdom gained from experience and empirical knowledge that continues to be inherited and developed and maintained through the learning process from generation to generation in the maritime field (Maru et al., 2018).

The communicative habits of the Bajau tribe are influenced by the culture they embrace, because this culture is more oriented towards behavioural procedures (Sinapoy and Djalante, 2021). This form of communication behaviour can be seen as an expression of the Bajau tribe's understanding of the communal behaviour of mainland society. However, over time, the Bajau of Pasikuta village and other coastal areas in Southeast Sulawesi have been different from the Bajau in Sulu, Philippines, such as language, accent/intonation in speaking, and local beliefs (Hafid and Rauf, 2008). The community also uses modern tools such as fishing technology, household life, and telecommunication tools (Sinapoy and Djalante, 2021). The unique Pasikuta village also has a school, so it is important to improve the quality of education for coastal communities. The Indonesian government continues to improve the welfare of coastal communities by facilitating electricity services and telecommunication networks (Nain, 2022; Rochwulaningsih et al., 2019). Unfortunately, clean water is not yet fully accessible to coastal communities due to the high cost and difficult affordability in remote villages.

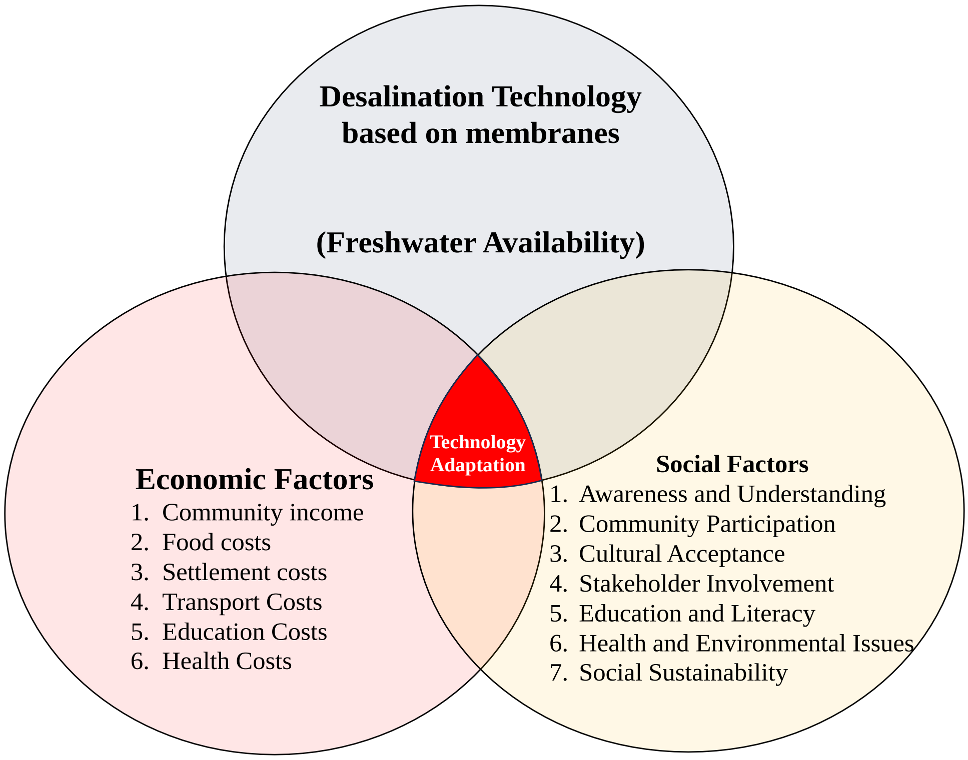


Figure 9: The problem gap of implementing desalination technology in coastal and small island communities, especially in Pasikuta Village

Figure 9 explains the problem gap in the application of desalination technology for the Bajau tribe in Pasikuta village, with the background of the benefits of providing clean water from desalination technology, but there are economic and social problems in the community so that the planning of desalination development also has obstacles (Maftouh et al., 2023). When simple desalination technology is to be developed in the Bajau tribal community, they will think about key aspects such as economic and social before building desalination technology. The main thought of economic factors should be the fulfilment of food income and expenditure, housing maintenance, transport costs, education, and health. While socially there is a change in community behaviour, understanding of education, social sustainability, and environmental issues.

The traditional culture of the Bajau tribe should be understood positively and should not always be interpreted as an obstacle to development and backwardness. In the context of introducing technology, the traditional culture of the Bajau tribe can also be unpretentious in accepting technology that provides sustainable development. In the context of this research, the use of membrane-based desalination technology is very suitable for application in coastal villages or small islands. The way to approach the application of desalination technology in the Bajau Tribe community is by means of:

- Ensuring that the technology introduced is understood for its purpose and benefits to the community.
- Education and training by providing education on the introduction of desalination technology, how it works, and things that might damage the technology and how to overcome them.
- Involvement of the Bajau community in the technology and providing economic opportunities so that motivation and enthusiasm for maintaining the technology is maintained.
- The economy and cost of the technology must be low so that it can provide benefits and encouragement for other communities to build simple desalination technology.

The application of simple desalination technology such as the one we developed is very suitable for the community because it is not too significant to produce saltwater waste that can damage the marine ecosystem (Liu et al., 2022). The fear is that when a desalination plant is developed, it will damage the marine environment while the marine environment for the Bajau tribe is a priceless treasure because it is a source of livelihood. Bajau people believe that they are destined to inhabit and protect the sea (Pauwelussen, 2015). They consider themselves as descendants of the sea gods, who have the right to design and determine their own direction of life at sea, therefore they cannot be separated from the sea. Their belief is enshrined in a philosophical expression that reads "*Mbo kita ne lino baka isi-isina, kita neje manusiana mamikker iyya batingga kole'ta mangelola iyya*" (God has given this world/sea with all its contents to humans, it remains for us to think and manage it properly and wisely) (La Ode Ali Basri et al., 2017).

The local wisdom of the Bajau tribe of Pasikuta village has a selective and flexible nature so that it can survive and continue to face various challenges such as changes in all elements of religious life, science, economics, technology, social organisation, language and communication, and art. So, the context of the acceptance of PV-ED-RO desalination technology is in accordance with the social life of the Bajau tribe by paying attention to environmental, social, and economic elements. Where, the environment relates to the negative impact caused by simple desalination technology such as separated salt water that does not have a significant impact on the marine environment, social how the community can accept this technology to create a clean water shortage for the Bajau tribe, and the economy that this simple desalination technology is easy to make and apply with materials available in the Indonesian region.

3.4 Feasibility study bibliometric analysis PV-ED-RO desalination technology

We linked this review with a bibliometric analysis study to determine the extent to which the development of TiO_2-modified CA/PEG synthetic membrane desalination technology was applied in the community. The results of the keyword study entered the bibliometric search system based on "article title" sourced from Scopus Web, we did not find a relationship between the keywords "tio2", "reverse AND osmosis", and "sustainability". So, we tried to map between desalination research and public perception. Based on this technique, we can identify the relationship between the keywords that are the research gaps of sustainable TiO_2-based desalination technology. Based on the simulation results using VOSviewer software (Figure 10), TiO_2-based desalination technology research still emphasises the synthesis, characterisation, and modification of TiO_2 nanocomposite membranes and their application in RO systems to purify chlorine (salt) solutions. Currently, TiO_2 membranes in desalination technology continue to develop towards nanoparticles and membrane surface modifications. In recent years, it can be concluded that researchers are more focused on the fundamental development of TiO_2 membranes and have not focused on developing towards "sustainability". If we further examine the development of research towards a "sustainable environment", it is important to study the influence of fundamental research on the application of technology to obtain an environmental sustainability relationship from the application of TiO_2-based desalination technology in environmental science (social, economic, and environmental). The VOSviewer software overview in Figure 10 simulates this scenario.

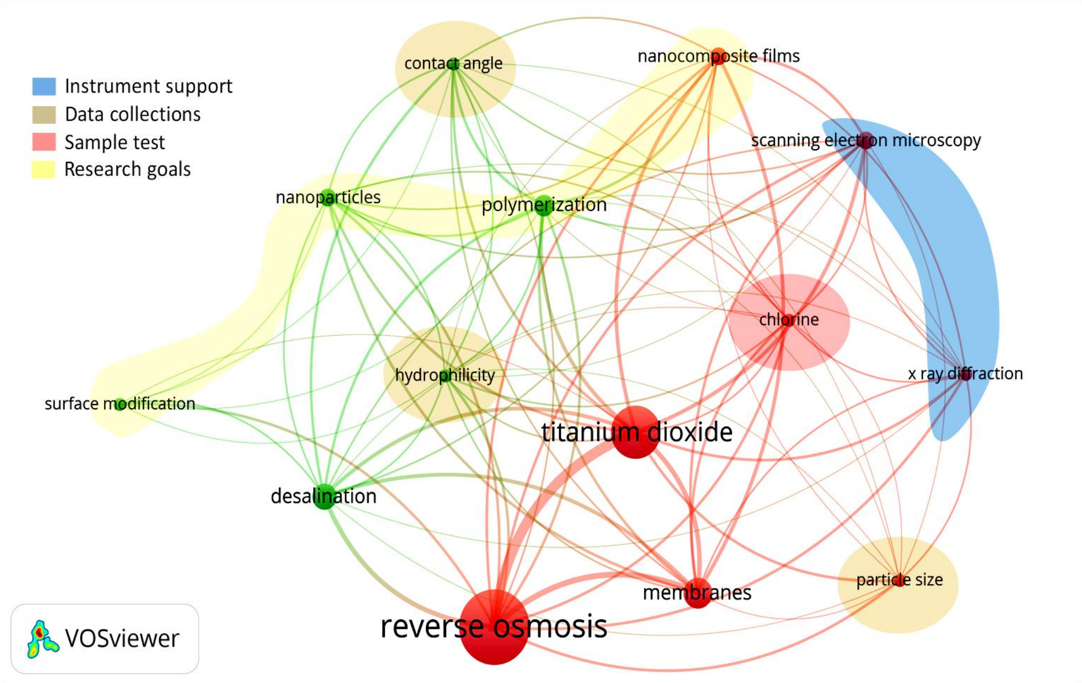


Figure 10: Visualisation of TiO_2-based desalination membrane technology network from various researchers

When we entered the keywords "reverse AND osmosis" with "sustainable", we found links to 12 journal papers discussing RO and sustainability. However, we did not find any article titles relevant to the discussion of "tiO2" material, "desalination technology", and "sustainability". If researchers examine the depth of the discussion of some of the journals that have been studied, some journal papers explain that the development of desalination technology using TiO_2 material modified membranes should be able to support technological sustainability. The results of this literature review explain that fundamental research on TiO_2-based desalination can be applied to large-scale development research. The literature review has research limitations including: (1) fundamental desalination research is only limited to TiO_2 membrane modification (synthesis, characterisation, and modification of TiO_2 nanocomposite membranes), (2) desalination development research emphasises water filtration, wastewater treatment, and water purification to support sustainability (Figure 11), (3) desalination technology approach studies on community perspectives.

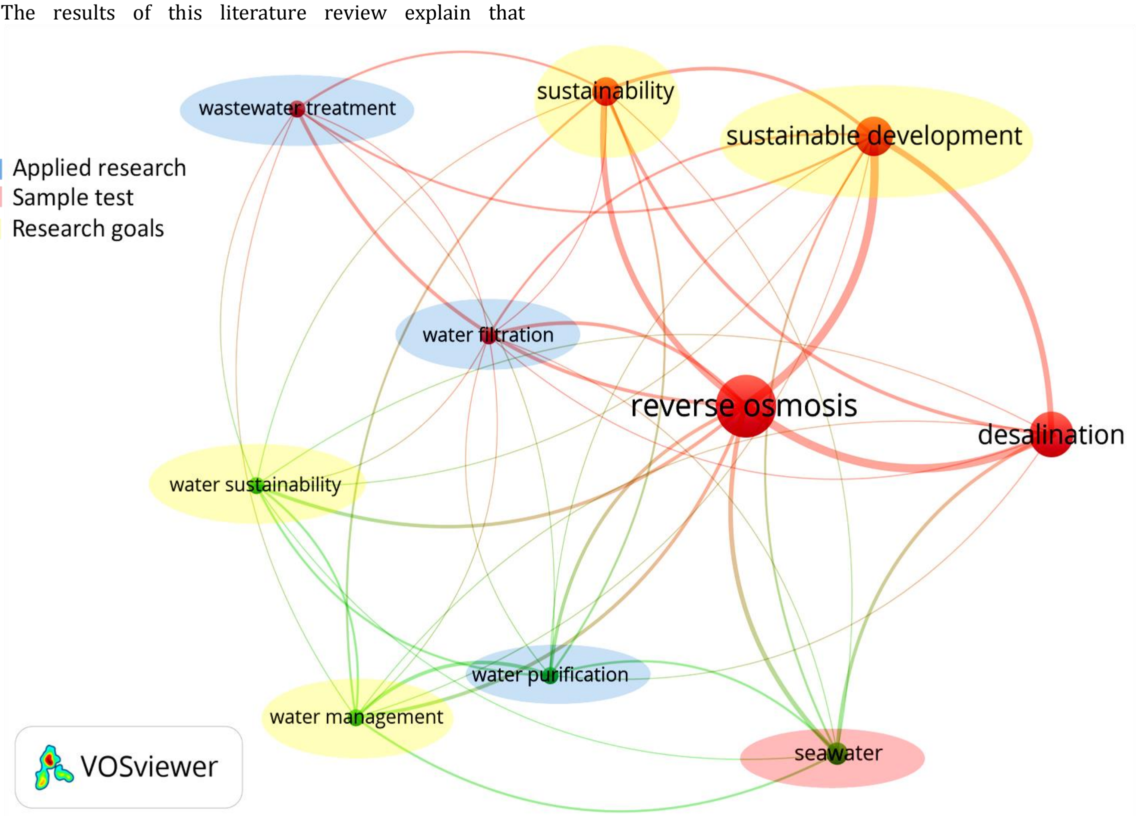


Figure 11. Network visualisation of desalination technology and sustainable development

Figures 10 and 11 have similarities in the design flow of further research that is closely related to titanium dioxide → reverse osmosis → sustainable development. Based on the existing literature, it can be stated that TiO_2 membrane desalination technology has the potential to solve the problem of clean water crisis and contribute to the achievement of sustainable development goals. When research is developed towards the application of desalination technology using TiO_2 membranes, it can provide the latest studies to advance efficient and environmentally friendly desalination technology. Sustainable development goals are not only determined by making technology, but also by the social acceptance of society (socio-economic factors) (Liu et al., 2022). Therefore, the novelty in this study is building a TiO_2-based sustainable desalination technology and assessing people's perceptions to identify the correlation between sustainable technology development and people's socioeconomic acceptance.

Research reviewed by Frederiks et al. and Shokri & Fard state that studying community behaviour requires research on the social acceptability of desalination technology in the context of sociodemographics and socioeconomics (Frederiks et al., 2015;Shokri and Fard, 2022). However, after reviewing the keywords "desalination" and "social" (Figure 12b), the researchers observed that only socioeconomic impacts have a major influence on the acceptability of the technology (Figure 12a). Researchers also reported that society plays an important role in the application of the technology to simulate the relationship of research on the economic aspects of technology application in society (Figure 12a) (Aznar-Sánchez et al., 2017; Mondal et al., 2023). When the keyword "desalination" is entered into the search system on Web Scopus (Figure 12b), it shows research links with three main keywords: Firstly, fundamental research such as "reverse osmosis" and "desalination". Meanwhile, "water production" and "desalination plant" represent applied research, and social research consists of "water supply", "social aspects", and "marine biology". Based on Figure 12b, we can conclude that TiO_2-based desalination research can be directed towards "sustainable development", "renewable resources", "water management", and "water resources". However, researchers have reviewed several journal papers that often focus on research boundaries including fundamental studies, development studies, and social studies. When assessing the applicability of TiO_2-based desalination technology in the environment it is important to consider costs (Figure 12a) and social aspects to determine its acceptability (Figure 12b). These variables serve as benchmarks for community acceptance of the desalination technology.

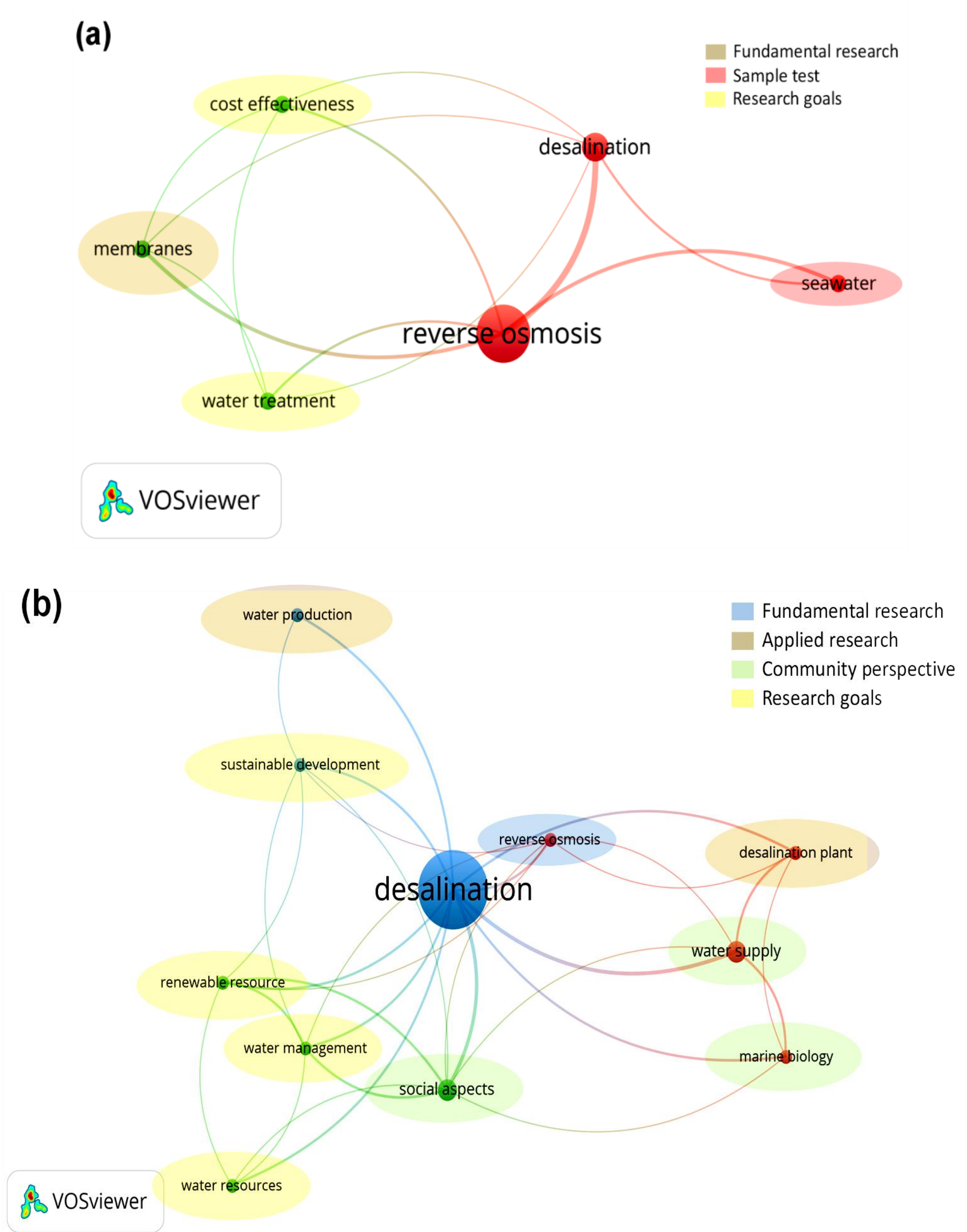
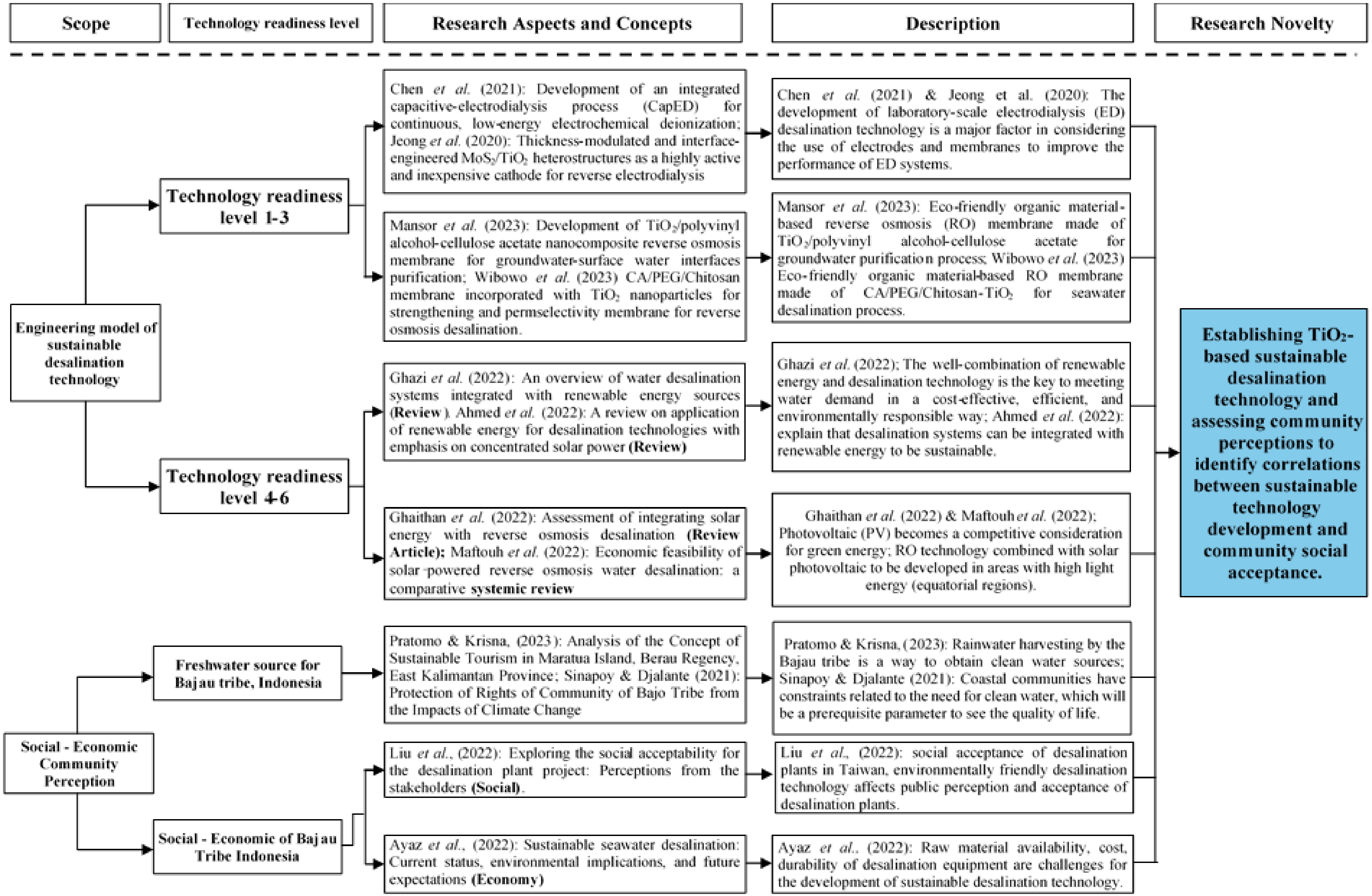


Figure 12. Visualisation of desalination research networks and societal perspectives, (a) applied desalination technology, and (b) societal perspectives

Based on the previous review, we observed a gap between fundamental, applied and utilisation research. It can be seen from the research we made from the flow chart (Figure 13) that researchers only focus on the respective technology readiness levels 1-3, 4-6, or socio-economic impact studies. Therefore, the novelty value of membrane desalination technology research should be directed towards achieving targets for technology application and looking at aspects of community acceptance from a social and economic perspective, especially for coastal communities and small islands. Some points that can be considered include the effectiveness of the technology, socio-economic aspects such as social impact and technology cost analysis, availability of local resources, and partnership collaboration in supporting funding and maintenance. Integrating these aspects can make a significant contribution in ensuring the success and acceptance of membrane desalination technology at the community level.


Scope
Technology readiness level
Research Aspects and Concepts
Description
Research Novelty
Engineering model of sustainable desalination technology
Technology readiness level 1-3
Technology readiness level 4-6
Chen et al. (2021): Development of an integrated capacitive-electrodialysis process (CapED) for continuous, low-energy electrochemical deionization; Jeong et al. (2020): Thickness-modulated and interface-engineered MoS_2/TiO_2 heterostructures as a highly active and inexpensive cathode for reverse electrodialysis
Chen et al. (2021) & Jeong et al. (2020): The development of laboratory-scale electrodialysis (ED) desalination technology is a major factor in considering the use of electrodes and membranes to improve the performance of ED systems.
Mansor et al. (2023): Development of TiO_2/polyvinyl alcohol-cellulose acetate nanocomposite reverse osmosis membrane for groundwater-surface water interfaces purification; Wibowo et al. (2023) CA/PEG/Chitosan membrane incorporated with TiO_2 nanoparticles for strengthening and permselectivity membrane for reverse osmosis desalination.
Mansor et al. (2023): Eco-friendly organic material-based reverse osmosis (RO) membrane made of TiO_2/polyvinyl alcohol-cellulose acetate for groundwater purification process; Wibowo et al. (2023) Eco-friendly organic material-based RO membrane made of CA/PEG/Chitosan-TiO_2 for seawater desalination process.
Ghazi et al. (2022): An overview of water desalination systems integrated with renewable energy sources (Review). Ahmed et al. (2022): A review on application of renewable energy for desalination technologies with emphasis on concentrated solar power (Review)
Ghazi et al. (2022); The well-combination of renewable energy and desalination technology is the key to meeting water demand in a cost-effective, efficient, and environmentally responsible way; Ahmed et al. (2022): explain that desalination systems can be integrated with renewable energy to be sustainable.
Ghaithan et al. (2022): Assessment of integrating solar energy with reverse osmosis desalination (Review Article); Maftouh et al. (2022): Economic feasibility of solar-powered reverse osmosis water desalination: a comparative systemic review
Ghaithan et al. (2022) & Maftouh et al. (2022); Photovoltaic (PV) becomes a competitive consideration for green energy; RO technology combined with solar photovoltaic to be developed in areas with high light energy (equatorial regions).
Establishing TiO_2-based sustainable desalination technology and assessing community perceptions to identify correlations between sustainable technology development and community social acceptance.
Social - Economic Community Perception
Freshwater source for Bajau tribe, Indonesia
Social - Economic of Bajau Tribe Indonesia
Pratomo & Krisna, (2023): Analysis of the Concept of Sustainable Tourism in Maratua Island, Berau Regency, East Kalimantan Province; Sinapoy & Djalante (2021): Protection of Rights of Community of Bajo Tribe from the Impacts of Climate Change
Pratomo & Krisna, (2023): Rainwater harvesting by the Bajau tribe is a way to obtain clean water sources; Sinapoy & Djalante (2021): Coastal communities have constraints related to the need for clean water, which will be a prerequisite parameter to see the quality of life.
Liu et al., (2022): Exploring the social acceptability for the desalination plant project: Perceptions from the stakeholders (Social).
Liu et al., (2022): social acceptance of desalination plants in Taiwan, environmentally friendly desalination technology affects public perception and acceptance of desalination plants.
Ayaz et al., (2022): Sustainable seawater desalination: Current status, environmental implications, and future expectations (Economy)
Ayaz et al., (2022): Raw material availability, cost, durability of desalination equipment are challenges for the development of sustainable desalination technology.

4. Conclusion

The desalination process provides a good direction to helpfully coastal and small-islands communities by utilising seawater as the main resource of freshwater supply. There is a need for desalination technology that is cheap, environmentally friendly, and easy to operate so that local communities can manage it well. The trending desalination technologies that are automated, cheap, and easy are based on RO and ED membrane technologies. Utilisation in coastal areas or small islands that are not supplied with electrical energy can utilise solar panels (PV) to synergise to improve the performance of RO and ED technology. Electrodialysis uses safe and corrosion-resistant electrodes such as precious metals, thus enabling good conductivity and oxidation performance. On the other hand, RO semipermeable membranes should also be considered to improve the seawater desalination process so that combining these two techniques can contribute effectively. TiO_2-based membranes are very promising for development towards application because they are environmentally friendly, low cost, and have photocatalyst benefits. Of course, in its application to the community, it must look at several aspects, such as economic and social, because this technology will be applied to coastal communities (Pasikuta Village), the majority of which are Bajau tribes. Therefore, it is necessary to socialise the use of tools, the benefits of use, and the actual impact for the community to manage desalination equipment. In the application of this desalination technology in Pasikuta Village, of course, the community's perception is needed whether this model is acceptable or unacceptable. If the assumption of this model is acceptable, it can be a new thing for the Bajau tribe regarding the application of technology and fulfil the rules of environmental sustainability insight. However, if it is unacceptable, desalination technology as a device model that supports the community in obtaining freshwater. Hopefully, this desalination technology will provide real benefits for coastal communities and small islands to improve living standards and environmental sustainability development.

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