

ASSESSMENT OF GROUNDWATER AND SURFACE WATER USE EFFICIENCY (WUE) AND ECONOMIC WATER PRODUCTIVITY ACROSS THAILAND AGRICULTURAL SECTOR THROUGH THE LENS OF SUSTAINABILITY

ÉVALUATION DE L'EFFICACITE DE L'UTILISATION DES EAUX SOUTERRAINES ET DE SURFACE (WUE) ET DE LA PRODUCTIVITE ECONOMIQUE DE L'EAU DANS LE SECTEUR AGRICOLE THAÏLANDAIS A TRAVERS LE PRISME DE LA DURABILITE

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ABSTRACT

Thailand's water and climate adaptation are complex and under challenges from a low-lying delta capital city, combination of intensifying floods and droughts, increasing land subsidence, river and coastal erosion, biodiversity loss and sea-level rise. Thailand's approach to water development and management has always been relying on multiple sector basis without substantial consideration of any interactions between them and institutions and policies are typically flawed, in the long-term leading to inefficient water use and undesirable consequences from development, all are creating an urgent need for sustainable solutions, actions, and practices. As climate change intensifies, growing water scarcity, unpredictability, and vulnerability drive the need for sound baseline economic analyses related to current water use efficiency and water productivity, providing the basis for innovative approaches to allocate water to various sectors and increase the efficient use of existing water supplies with minimal adverse effects to the resource for our next generations, and setting the stage for more sustainable water management. In this study, we assess the water use efficiency (WUE) and economic water productivity across Thailand agricultural sector to focus on the efficient use of limited water resources under water scarcity threat at the basin-scale nation-wide (total of 22 river basins) based on standardized terminologies and formulas from modified version of the FAO's monitoring framework. Meteorological, physical geospatial, Gross Provincial Products (GPP), and historical allocated surface water and groundwater to agricultural sectors in irrigated area data (based on the System of Environmental Economic Accounting for Water approach) are collected and the economic efficiency in agricultural sector expressed as a quantitative ratio between the amount of monetary production (i.e., value added in agricultural sector) per area as resources or efforts made for its realization are investigated. With increasing in water allocated to irrigate crop area in the dry period, slow rising in the economic efficiency of agricultural sector is observed. Change in the economic water productivity defined as a ratio between the amount of monetary production (i.e., value added in agricultural sector) per unit irrigated water resource made to obtain them, is further evaluated. Declining in the economic water productivity (THB/m³) is observed with increasing of dry-season allocated water, suggesting that the economic water activity is complex, requiring specific level of resource consumption to achieve the efficiency, not entirely corresponding to the allocated expenditure. Dry-season water allocation escalates consistently with increase in annual rainfall nation-wide and growing irrigated crop area, but fails to enhance both water economic productivity and sustainability. Greater attention needs to be focused on managing surface water and groundwater for conjunctive use. We need a better understanding of biophysical and socio-economic changes in basins over time and improved measures of basin-level efficiencies before we can determine in a given situation the potential for increasing water productivity through responsive interventions and policies. Decisions on basin-level allocations among sectors cannot be based strictly on economic efficiency but they must involve value judgements as to how best to benefit society inclusively as a whole. This will include setting priorities in the management of water resources to meet objectives such as ensuring sustainability, meeting food-security needs and providing the more vulnerable segments of society with access to water.

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Keywords: agricultural sector; efficiency of agricultural sector; economic water productivity; socio-economic changes; basin-level allocations.

RESUME

La gestion de l'eau et l'adaptation au changement climatique en Thaïlande sont complexes et confrontées à de multiples défis : une capitale située dans un delta de basse altitude, une intensification conjuguée des inondations et des sécheresses, l'affaissement croissants des sols, l'érosion fluviale et côtière, la perte de biodiversité et l'élévation du niveau de la mer. L'approche thaïlandaise en matière de développement et de gestion des ressources en eau a toujours reposé sur une logique multisectorielle, sans prise en compte des interactions tenues entre les secteurs; par ailleurs, les institutions et les politiques présentent souvent des lacunes. À long terme, cela conduit à une utilisation inefficace de l'eau et à des conséquences indésirables liées au développement, créant ainsi un besoin urgent de rechercher des solutions, des actions et des pratiques durables. Comme le changement climatique s'intensifie, la pénurie croissante de l'eau, l'imprévisibilité et la vulnérabilité rendent nécessaire des analyses économiques de base solides liées à l'efficacité actuelle de l'utilisation de l'eau et à la productivité de l'eau. Ces analyses fournissent une base aux approches innovantes pour l'allocation de l'eau à divers secteurs et l'augmentation de l'efficacité de l'utilisation des approvisionnements en eau existants tout en minimisant les effets négatifs sur la ressource pour nos prochaines générations, et ouvrent la voie à une gestion de l'eau plus durable. Dans cette étude, nous évaluons l'efficacité de l'utilisation de l'eau (WUE) et la productivité économique de l'eau dans le secteur agricole thaïlandais afin de nous concentrer sur l'utilisation efficace des ressources en eau limitées face à la menace de la pénurie de l'eau à l'échelle du bassin national (En tout 22 bassins versants) basé sur des terminologies et des formules normalisées issues de la version modifiée du cadre de suivi de la FAO. Les données recueillies comprennent des informations météorologiques, des données géospatiales physiques, le produit intérieur brut provincial (PIB provincial) ainsi que les volumes historiques d'eau de surface et d'eau souterraine alloués au secteur agricole dans les zones irriguées (sur la base de l'approche du Système de comptabilité économique et environnementale pour l'eau). L'efficacité économique du secteur agricole exprimée sous forme d'un rapport quantitatif entre la quantité de production monétaire (c'est-à-dire la valeur ajoutée dans le secteur agricole) par zone, à mesure que les ressources ou les efforts déployés pour sa réalisation sont étudiés. Avec l'augmentation de la quantité d'eau allouée à l'irrigation dans les zones cultivées pendant la période sèche, on observe une lente augmentation de l'efficacité économique du secteur agricole. L'évolution de la productivité économique de l'eau définie comme un rapport entre le montant de la production monétaire (c'est-à-dire la valeur ajoutée dans le secteur agricole) par unité de ressource en eau irriguée réalisée pour l'obtenir, est évaluée plus en détail. Une baisse de la productivité économique de l'eau (THB/m³) est observée avec l'augmentation de l'eau allouée en saison sèche, ce qui suggère que l'activité économique de l'eau est complexe, nécessitant un niveau spécifique de consommation de ressources pour atteindre l'efficacité, ne correspondant pas entièrement aux dépenses allouées. L'allocation de l'eau pendant la saison sèche s'intensifie constamment avec l'augmentation des précipitations annuelles à l'échelle nationale et la croissance des surfaces cultivées irriguées, mais ne parvient pas à améliorer à la fois la productivité économique de l'eau et sa durabilité. Une plus grande attention doit être accordée à la gestion des eaux de surface et souterraines pour une utilisation conjointe. Il est nécessaire de mieux comprendre l'évolution biophysique et socio-économique des bassins au fil du temps et de prendre des mesures améliorées de l'efficacité au niveau du bassin avant de pouvoir déterminer, dans une situation donnée, le potentiel d'augmentation de la productivité de l'eau grâce à des interventions et des politiques réceptives. Les décisions sur les allocations de l'eau entre les secteurs au niveau du bassin ne peuvent pas être basées strictement sur l'efficacité économique, mais elles doivent impliquer des jugements de valeur visant à maximiser les bénéfices pour l'ensemble de la société, dans une perspective inclusive. Il s'agira notamment de mettre en place des priorités dans la gestion des ressources en eau afin d'atteindre des objectifs tels que la durabilité, la sécurité alimentaire et l'accès à l'eau aux segments les plus vulnérables de la société.

Mots-clés : Secteur agricole; Efficacité du secteur agricole; Productivité économique de l'eau; Evolutions socio-économiques; Allocations au niveau du bassin.

Introduction

Water resources are a basic human need and are of vital importance for economic security and the environment. At the same time, water resources are scarce and must therefore be managed in an economically efficient way. Thailand has a long history of climate variability with major droughts punctuated by rapid flooding. The country is considered one of the most drought-affected countries in the Asia-Pacific region, with more than 40 million people have been impacted. Although it experiences the 2nd highest frequency of droughts after Indonesia however, it suffers the most extensive damage. In addition to climate variability and seasonal droughts, water scarcity is worsening due to population growth, climate change, water quality degradation, overexploitation, and growing water demand, significantly affecting people of Thailand across all sectors, i.e., agricultural water consumption, rapid urbanization, industrial growth, and tourism-driven development.

During the past decades, the water scarcity problem has placed vulnerable agricultural production at risk. There has been a continued development of water resources at different scales, from small to large scale projects, concerning both surface water and groundwater, to meet a growing water demand for consumption, farming and industrial uses. However, water availability has come under increasing pressure due to a number of reasons, particularly changing weather patterns, growing demand and competition for limited water supplies between various economic sectors, inefficient management of irrigation systems, political intervention, water use behavior of people and farmers. The recent evidence of water shortage problem in Thailand could be observed as farmers were urged not to plant a second rice crop in order to reduce stress on water supply. Although the problem tends to be only temporary, the situation signalizes that the problem of water shortage should not be ignored, but should become an issue of pressing concern.

Thailand's water and climate adaptation are complex and under challenges from a low-lying delta capital city, combination of intensifying floods and droughts, increasing land subsidence, river and coastal erosion, biodiversity loss and sea-level rise. Thailand's approach to water development and management has always been relying on multiple sector basis without substantial consideration of any interactions between them and institutions and policies are typically flawed, particularly when agricultural sector demands the largest share of water use, approximately at more than 106 billion m³ or 70 percent of total water demand of all sectors (Royal Irrigation Department 2009), irrigation water allocation system may affect the entire allocation structure. In the long-term, leading to inefficient water use and undesirable consequences from development, all are creating an urgent need for sustainable solutions, actions, and practices.

As climate change intensifies, growing water scarcity, unpredictability, and vulnerability drive the need for sound baseline economic analyses related to current water use efficiency and water productivity, providing the basis for innovative approaches to allocate water to various sectors and increase the efficient use of existing water supplies with minimal adverse effects to the resource for our next generations, and setting the stage for more sustainable water management. In this study, analyze the characteristics of water allocation and assess the water use efficiency (WUE) and economic water productivity across Thailand agricultural sector to focus on the efficient use of limited water resources under water scarcity threat at the basin-scale in Chao Phraya river basin. Further discussions, recommendations, and policy implications about an increasing importance in more efficient use of water are addressed.

Materials and Methods

Study Area

The EEC covers 13,285 km² spanning 3 provinces at the country's eastern seaboard: Rayong, Chonburi, and Chachoengsao, as illustrated in **Figure 1**. According to the National Statistical Office (as of December 31, 2019), Chonburi Province is the most populous province in the eastern region, with a population of 1,558,301, followed by Rayong Province with 734,753 people and Chachoengsao

Province with 720,113 people. It is the special economic zone and regional development project designed to boost economic growth and investment and serve as a critical production base for advanced industries including petrochemicals, smart electronics, and electric vehicles, in the eastern part of Thailand and transform Thailand to high-income country. The program was announced by the Thai government in 2017 and was officially established in May 2019 which is considered as a cornerstone of the government's "Thailand 4.0" strategy. The ambitious goal of EEC is to transform the eastern seaboard region into a hub for industry and innovation. Additionally, the region is a source of high-value agricultural exports, and it is also emerging as a prominent destination for tourism, particularly in Chonburi. As part of Thailand 4.0 strategy, the EEC's goal is set to become a world-class smart city and an investment destination for a range of critical sectors, including digital technology, health, smart logistics, and decarbonization. The 4 pillars of this strategy are economic prosperity, social well-being, raising human values and environmental protection. The growth plan envisions the creation of over 200,000 jobs by 2032. To achieve these objectives, EEC needs stable and resilient infrastructure to underpin well-functioning city mechanisms such as sufficient and reliable energy, water, and other public goods supply networks. Above all, water security and disaster risk management are requisites for this ambition to materialize as several water challenges coexist.

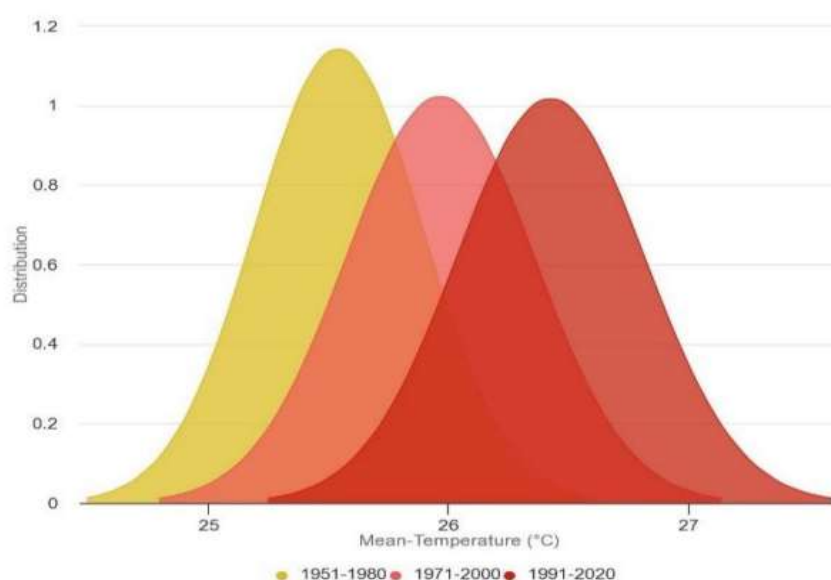


Figure 46: Change in Distribution of mean temperature in Thailand for the periods 1951 to 1980, 1971 to 2000 and 1991 to 2020

Source: World Bank, 2023; Climate Change Knowledge Portal.

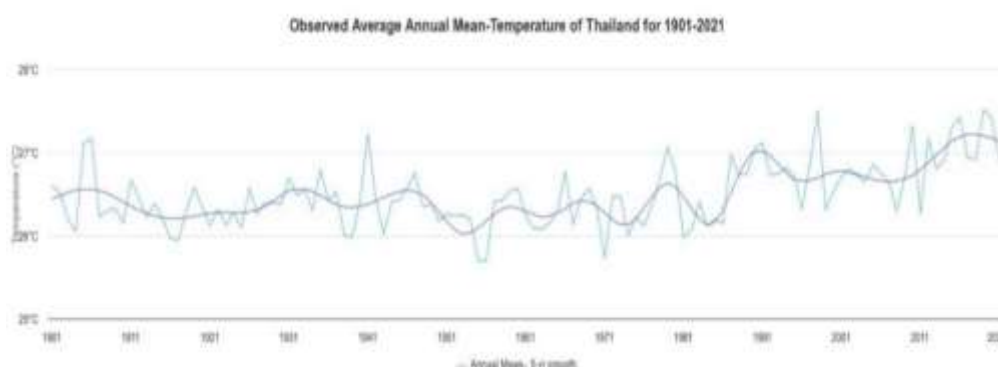


Figure 47: Observed Average Annual Mean Temperature of Thailand for 1901 to 2021



Figure ES 4: Rainfall anomalies in Thailand are rising (1981-2019).
Source: HII, 2019: Thailand Water Situation 2019 (ThaiWater.net)



Figure 1. Study Area: EEC Region.

Desalination Stage and Technologies Review

Desalination, as a complementary strategy within the multi-stage framework, stands out as one of the viable solutions to combat water scarcity challenges, with over 18,500 desalination plants worldwide producing over 90 Mm³/day (Dweiri et al. 2018). With rich technology history dating back to 18th and 19th centuries, with modern advancements leading to its widespread adoption globally, seawater desalination is known as the process of eliminating dissolved minerals and salts to produce drinkable water, producing high quality water in large quantities necessitates a significant energy input, reaching up to 70 kWh/m³ in some processes (Prado de Nicolas et al. 2023). The efficiency of desalination technologies has gradually improved in recent years. Nevertheless, several concerns have increasingly emerged in desalination systems, including waste (concentrated brine) discharging and environmental pollution from feed fossil fuels consumption (Marini et al. 2017). Two main technological approaches for seawater desalination, i.e., thermal and membrane groups are reviewed for the technology pros and cons based on the seawater quality characteristics collected from related governmental agencies and annual environmental monitoring report provided by private companies in the region.

Multi Criteria Decision Analysis (MCDA)

Given the diverse desalination technological advancement that can be powered by different RE sources, ranking, identifying, and selecting the most appropriate technologies for the desalination process among multiple alternatives become necessitate and challenging. Decision-makers and investors need to comprehensively evaluate alternatives integrating relevant aspects, including economic feasibility, environmental impacts, technological efficiency, and social responsibility before making an economically and financially viable investment decision. Therefore, selecting the proper desalination technique is better defined using multidimensional criteria integrative qualitative and quantitative Multi-Criterion Decision-Making (MCDM) methods to rank and prioritize the desalination technologies ensuring a comprehensive assessment of the available desalination system options in Thailand.

MCDM is one of the most used decision methods to perform mathematical optimization in different fields of application. In complex and challenging decision processes, MCDM is a tool that allows decision-makers to make fast, accurate, and efficient decisions by optimizing and sorting multiple criteria to select the best alternative, in this case the desalination technical option based on the evaluation structure shown in **Figure 2** and criteria. The weighted summation method of the MCDA (Ronald et al. 1997) is used, where the utility of each alternative U_j is determined by the summation of weighted numerical values (scores) of each criterion (**Eq. (1)**). The alternative which has the greatest utility is the best alternative, **Eq. (2)**.

$$U_j = \sum_{i=1}^m W_i \times S_{ij} \text{ for all } j \quad (1)$$

$$U_{optimal} = U_j \text{ for all } j \quad (2)$$

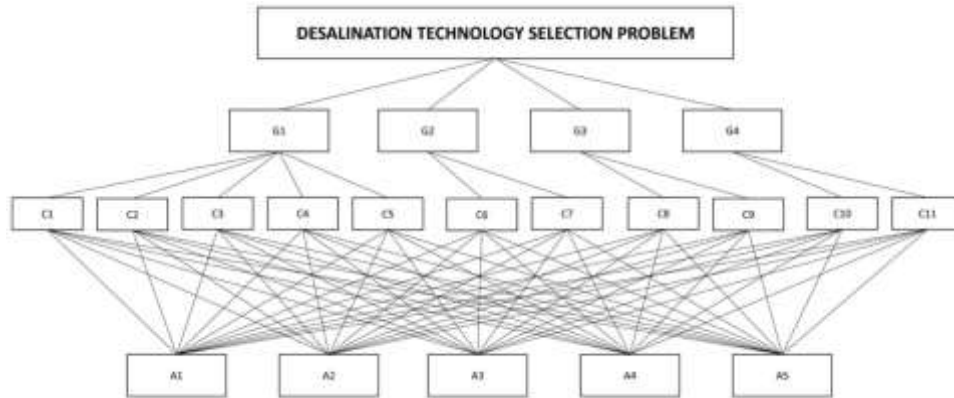


Figure 2. MCDA Evaluation Criteria for Desalination Selection

Qualitative Stakeholders Interview and Questionnaires Survey

In this study, stakeholders from government agencies, non-governmental organizations, water industries, water users, representative local people/residents, and desalination business developers were interviewed for their different prioritizing perspective to foster water security and achieve sustainable water resource management in the EEC. Data collection involved in-depth interviews and questionnaires to gather comprehensive information.

The quantitative questionnaire was designed to investigate the stakeholder's perception on the development of desalination plants. The closed-ended questions were divided into 4 parts. The first part was aimed at surveying the public's views on current and future water resources in the study. The second part examined the public's position on the development and their awareness of desalination systems and related technological advancement. The third part surveyed the public's opinions on the stakeholder perception of desalinated water and their willingness to pay at the local level for improved

water security from the development of desalination systems. Lastly, the fourth part investigated the public's perceptions of the environmental impact and energy consumption caused by the desalination plant. The total quantitative questionnaire samples were approximately 400 sets. The questionnaire data are analyzed using the software Statistical Product and Service Solutions (SPSS) ver. 17.0 for Windows. The overall information on the public's perception and socio-demographic variables is analyzed through descriptive statistics.

Results and Discussion

Regional Hydro-Meteorological Conditions

Monthly average rainfall in the EEC region falls between 5.4-284.2 mm with minimum rainfall in December and maximum rainfall in September - October. Annual average rainfall is approximately 1,308.5 mm (lower than the nation-wide average) with distribution patterns shown in **Figure 3**.

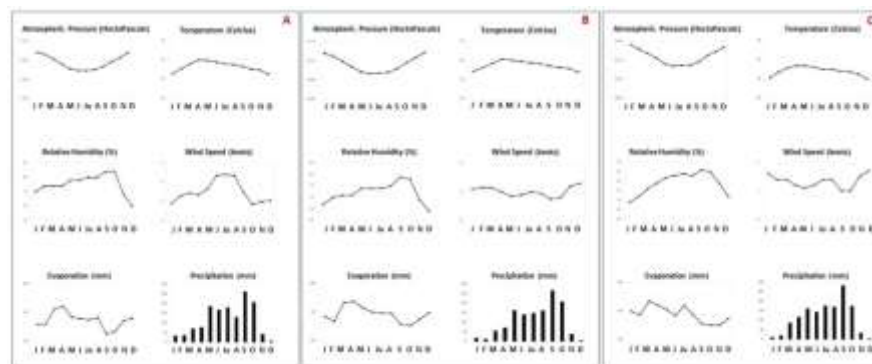


Figure 3. Observed daily climatic data for EEC region for the period from 1987-2017 for (A) Rayong province; (B) Chonburi province; and (C) Chachoengsao province.

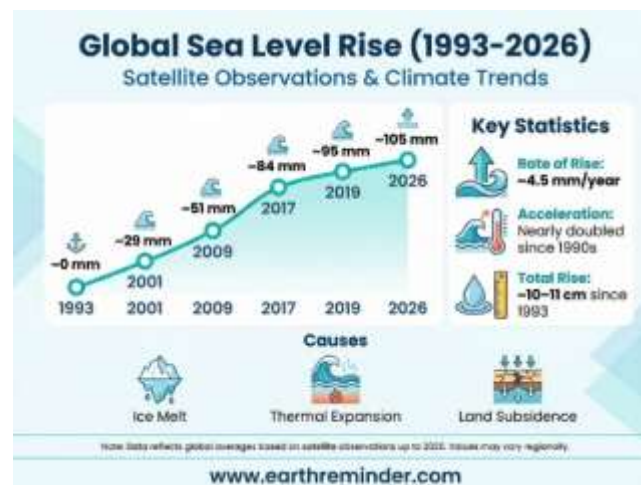


Figure 4. Global Sea Level Rise Record from 1993-2026.

The Intergovernmental Panel on Climate Change reports that global sea level rise associated with climate change is expected to be between 8-16 mm/year in the 21st century with the latest observation of 10.5 mm/year in 2026 illustrated in **Figure 4**. Due to global climate change, sea level in the inner part of the Gulf of Thailand is expected to further increase with the increment in wind speed especially of the monsoons that blow into the Gulf (The World Bank Group 2021).

Water Resources and Management in EEC

Thailand is recognized as highly vulnerable to climate variability and change due to increasing natural hazards including heavy rainfall, floods, drought, and threatening sea level rise along the country's coasts, ranking Thailand the 31st position in National Water Security Index among 49 Asian and Pacific countries mainly due to its low water urban security and high climatological risks (Asian Development Bank 2020). Thailand is one of the 193 member countries that signed the pledge promising to achieve various sustainable development goals (SDGs) by 2030 (United Nations 2015). The Agenda serves as a roadmap for future environmental and development work in line with the United Nations' SDGs, which comprise a total of 17 goals and 169 objectives.

The Royal Thai Government has laid out a 20-Year Strategy for Thailand to achieve high-income status by 2036. The strategy includes a wide range of top-down initiatives, especially in infrastructure and human development, to transform Thailand into a nation that can compete against wealthier, more knowledge-based economies. The EEC Development Plan is set to bring about substantial growth and transformation in Thailand's physical and social infrastructure within the region. Predictions by various agencies suggest that the EEC multi-dimension development projects and the economic growth of the eastern region will lead to urban expansion and an increase in the workforce by 100,000 people annually. This is due to the expansion of the industrial sector in provinces such as Chonburi, Rayong, Chachoengsao, and Chanthaburi, including existing industrial estates and new industrial estates. At this growth rate, it is already affecting on agriculture, services, and large-scale businesses, resulting in an increased demand for water. It is estimated that by the year 2027, the water demand in the entire EEC area will exceed 3,000 million cubic meters per year, and by 2037, this demand will rise more than 3,600 million cubic meters per year as tabulated in **Table 1**. Assuming average water supplies are similar to average actual hydrological conditions in the decade leading up to 2023, it is projected that in 2037 the EEC will face a supply shortfall of almost 40 percent. The situation in dry years will be even more precarious, with the shortfall increasing to 72 percent. The government is aware that, given the current water management situation, EEC's future development cannot be realized without addressing water scarcity challenges and securing additional water supply.

Table 1 Projected Annual Water Demand and Water Balance in the EEC Region (in Million Cubic Meters, MCM).

Area	2024		2027		2037	
	Demand	Deficit	Demand	Deficit	Demand	Deficit
Chachoengsao	1237	-897	1171	-811	1115	-379
Chonburi	794	-412	894	-464	1228	-729
Rayong	924	-170	1047	-139	1272	-292
EEC Total	2955	-1479	3112	-1414	3615	-1400

Source: Water Balance Report for the Eastern Economic Corridor, Office of the Eastern Economic Corridor, August 2024.

Note: Demand and deficit values are based on average water supply scenarios as opposed to dry or wet years and the average scenario assumes water supplies similar to the average actual hydrological situation for the period 2013-2023.

Royal Thai government executed by National Office of Water Resources Thailand (ONWR) has tirelessly initiated the water master plan for the EEC composed of 38 comprehensive water projects to be developed during Year 2020 to 2037 shown in **Figure 5**, bringing additional 872 million m³ freshwater yearly to meet projected demand, ensure water security, and support growth in both the economic and social aspects to the region. While increased variability in precipitation may lead to an increase in the vulnerability of water supplies (Bates et al., 2008; Kundzewicz et al., 2008; Gleick et al., 2014; Jim'enez Cisneros et al., 2014; Delpla et al., 2020), demand management can also play a significant role in managing water supply given that water productivity in Thailand remains low compared with global and regional benchmarks (World Bank Group 2025), in contrast to focusing solely on increasing freshwater supply. Measures to promote more efficiency and circularity in water use can also potentially complement supply augmentation by investment in water demand management of various sectors and circularity via treatments and reuse of wastewater. Currently, more than 60% of EEC wastewater goes untreated, and it is single largest untapped source of new water supplies for the region. Moreover, as the digital infrastructure expands, the influx of water-hungry facilities from recent anticipated massive boom in hyperscale data center investments in the EEC is heavily straining local existing water grids,

with projections indicating that total regional water demand could surge up to 5 million m³ per day, and posing even major sustainability challenge.



Figure 5 Water Development Projects in EEC Year 2020-2037

Desalination Stage and Technology Review

The long-term forecast for the EEC indicates that the area is exposed and vulnerable to climate change. Rising sea levels can also introduce new, or exacerbate existing, saltwater intrusion into freshwater resources, both groundwater and surface water. The water resources supplying from reservoirs and water infrastructure in the area are limited due to the climatic-topographic conditions, making it almost impossible to develop any large scaled *in situ* water reservoirs. For EEC Thailand, there is a need to integrate desalination projects into the existing water management system by shifting from pure supply management towards integrated supply-demand management, allaying investment in non-traditional desalination system, water conveyance grids, along with water reclamation. The necessity for desalination, where and when it is needed remains undeniable, mainly due to economic viability and environmental impacts rather than its operational and technological context. Desalination needs a high energy demand, which has significant costs.

Table 2 Required Energy Use of Distinct Water Sources for 1 m³ of Drinking Water.

Water Supply Alternative	Energy (kWh/m ³)
Conventional treatment of surface water	0.20–0.40
Groundwater	0.48
Wastewater treatment	0.62–0.87
Wastewater reuse	1.00–2.50
Brackish water desalination	1.00–1.50
Seawater desalination	2.58–8.50

Desalination, as a complementary strategy within the multi-stage framework, stands out as one of the viable solutions to combat water scarcity challenges, with over 18,500 desalination plants worldwide producing over 90 Mm³/day (Dweiri et al. 2018). With rich technology history dating back to 18th and 19th centuries, with modern advancements leading to its widespread adoption globally, seawater desalination is known as the process of eliminating dissolved minerals and salts to produce drinkable water, producing high quality water in large quantities necessitates a significant energy input. The extensive literature review demonstrated that desalination technology requires an 8–20 times greater energy intensity than conventional surface water treatment technology in **Table 2**.

The efficiency of desalination technologies has gradually improved in recent years to produce high quality water with total dissolved solids (TDS) of 5 to 50 ppm. However, they have the disadvantage of requiring high energy, resulting in. Nevertheless, several concerns have increasingly emerged in desalination systems, including waste (concentrated brine) discharging and environmental pollution from feed fossil fuels consumption (Marini et al. 2017 and high operational costs (Ghaffour et al. 2013). There are two main technological approaches for seawater desalination summarized in **Figure 6**, i.e., thermal approaches: (i) thermal desalination (relatively traditional); and (ii) membrane approaches. The properties of thermal and membrane techniques are summarized in **Table 3** and **Figure 6**.

Table 3 Overview of Desalination Technologies.

Classification	Thermal	Membrane
Desalination technologies	MED, MSF, MVC, TVC	MF, UF, NF, MB, MD, ED, RO
Separation mechanism	Phase change	Diffusion
Main type of energy requirements	Thermal	Electricity
Driving force	Heat	Pressure/Electricity
Specific energy consumption	High	Low

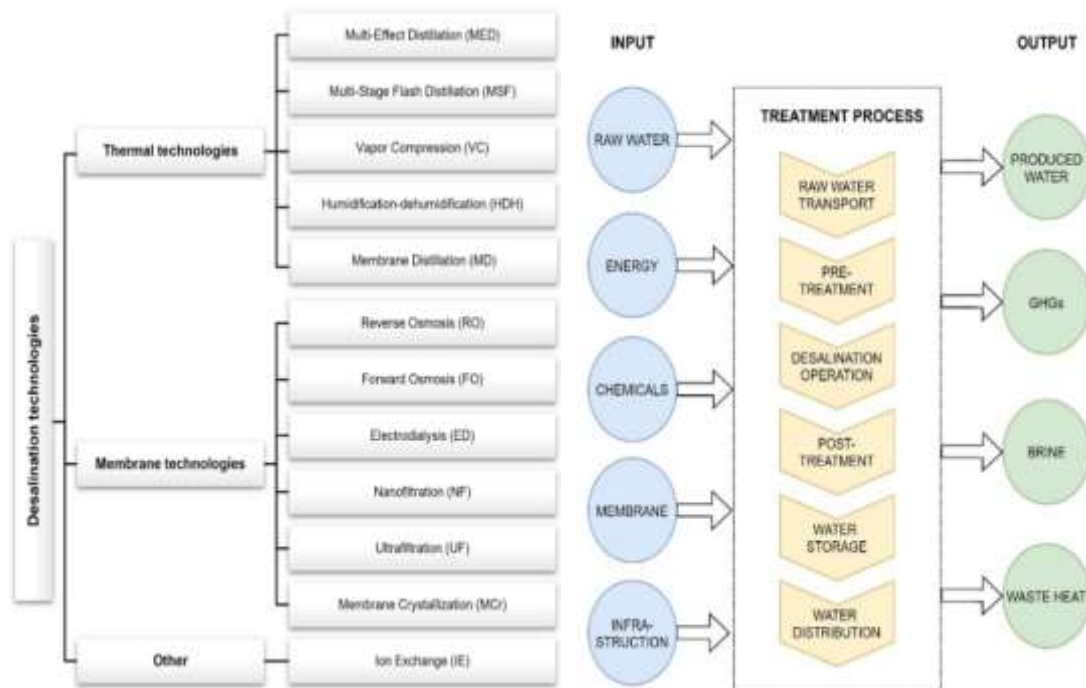


Figure 6 (A) Desalination Technology Classification (B) Desalination Process

The thermal process is a phase-changed method in which the feedwater is heated under an operating temperature and pressure. Water vapor condenses as pure water, leaving behind salts and other non-volatile substances. The thermal technologies include multi-effect distillation (MED, **Figure 7**), mechanical vapor compression (MVC), multi-stage flash distillation (MSF, **Figure 7**), and thermal vapor compression (TVC).

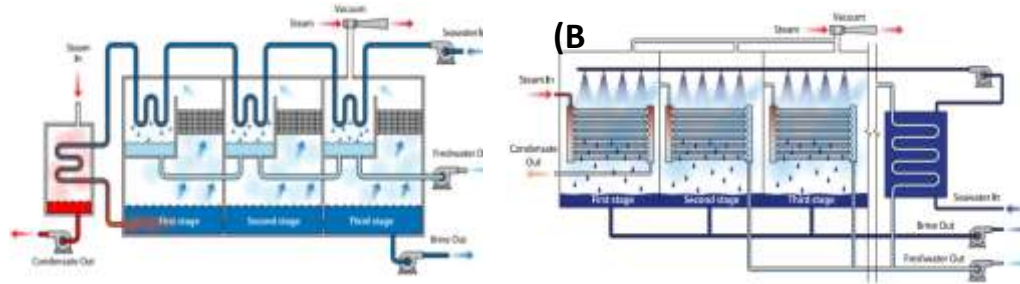


Figure 7 (A) Multi-Stage Flash (MSF) (B) MED Multi-Effect Distillation Desalination System

In contrast to the thermal processes, the membrane technology (e.g., reverse osmosis: RO in **Figure 8**) is not subject to any phase change and therefore requires less energy. The semi-permeable membranes selectively separate water or salt from the feedwater, allowing only pure water to remain in the liquid phase.

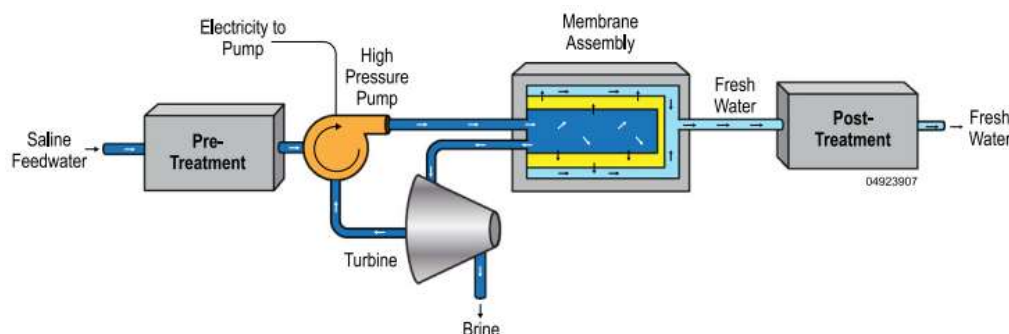


Figure 8. Reverse Osmosis (RO) Desalination System

Table 4. Comparison of Desalination Technologies.

Factors	Desalination Technology		
	Thermal		Membrane
	MSF	MED	RO
Water Type	Seawater or Brackish	Seawater or Brackish	Seawater or Brackish
Operation Temperature (°C)	90-110	70	Ambient
Electrical Energy Consumption (KJ/kg)	4-6	1.5-2.5	5-9
Thermal Energy Consumption (KJ/kg)	190-390	230-390	none
Electrical Equivalent for Thermal Energy (kWh/m ³)	9.5-19.5	5-8.5	none
Total Electric Equivalent (kWh/m ³)	13.5-25.5	6.5-11	5-9
Maximum Value of CO ₂ Emissions (kg CO ₂ /m ³)	24	19.2	8.6
Distillate Quality – TDS (ppm)	~10	~10	<500
Unit Product Cost (USD/m ³)	0.52-1.75	0.52-1.01	0.52-0.56

We reviewed previous studies comparing MED MFC and RO desalination technologies focusing on electrical/thermal/total energy consumption, technology conditions, environmental impacts, product quality, and product cost shown in **Table 4**. In general, membrane technology is optimal based on a combination of both energy consumption and CO₂ emissions. However, the unit cost of products is close to that of thermal technology because of its higher operating and maintenance costs. Currently,

conventional fossil fuels are the energy source for 99% of the desalination process (Washahi and Gopinath 2017)

MCA Desalination Technology

Three desalination technologies were compared and evaluated using MCDA approach based on 4 decision criteria characteristic groups (C1-C4), i.e., technical, energy, environment, and economic with sub-criteria (SC1-SC13) listed in **Table 5**. Some of these criteria need to be maximized and some have to be minimized simultaneously for obtaining a mathematical/scientific index. The criteria selection process was conducted to include only the criteria which are complete, operational, and non-redundant. Analysis from the decision hierarchy of the desalination technology selection in MCDA environment represented in **Figure 2** using relative weights of the individual criteria with respect to each other based on experts' opinion are illustrated in matrix in **Table 5**.

Table 5 Criteria of the Desalination Technology Selection.

Evaluation Criteria Group	Sub-Criteria
Technical (C1)	Complexity Degree (SC1)
	Stability (SC2)
	Effluent Water Quality (SC3)
	Lifetime (SC4)
	Water Recovery Ratio (SC5)
	Scalability (SC6)
	Compatibility with Other Technologies (SC7)
Energy (C2)	Energy Consumption (SC8)
	Compatibility with Renewable Energy (SC9)
Environment (C3)	Waste and Brine Management (SC10)
	Pollution Discharge (SC11)
Economics (C4)	Capital Cost (SC12)
	Operating Cost (SC13)

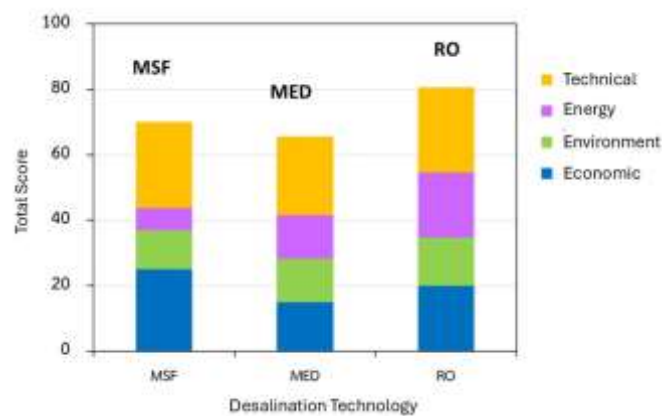
Table 6 MCDA Analysis Matrix for MSF MED and RO Desalination Technology Selection

Evaluation Criteria	Weight	Scale			Weight x Scale		
		MSF	MED	RO	MSF	MED	RO
Technical)C1) / 30	375				330	300	325
SC1 Complexity Degree (SC1)	5	2	2	2	10	10	10
SC2 Stability (SC2)	25	3	3	3	75	75	75
SC3 Effluent Water Quality (SC3)	15	3	3	2	45	45	30
SC4 Lifetime (SC4)	30	3	2	2	90	60	60
SC5 Water Recovery Ratio (SC5)	30	2	2	3	60	60	90
SC6 Scalability (SC6)	10	3	2	3	30	20	30
SC7 Compatibility with Other Technologies (SC7)	10	2	3	3	20	30	30
Energy)C2) / 20	75				25	50	75
SC8 Energy Consumption (SC8)	20	1	2	3	20	40	60
SC9 Compatibility with Renewable Energy (SC9)	5	1	2	3	5	10	15
Environment)C3) / 20	75				45	50	55
SC10 Waste and Brine Management (SC10)	20	2	2	2	40	40	40
SC11 Pollution Discharge (SC11)	5	1	2	3	5	10	15

Evaluation Criteria		Weight	Scale			Weight x Scale		
			MSF	MED	RO	MSF	MED	RO
Economic)C4) / 30		180				150	90	120
SC12	Capital Cost (SC12)	30	2	1	3	60	30	90
SC13	Operating Cost (SC13)	30	3	2	1	90	60	30
Total			550	490	575			

MCDA analysis results based on the 4 evaluation criteria groups in this study indicate that RO is more viable technology (compared to MED and MSF) for the desalination application in EEC Thailand as shown in **Figure 9(A)**. Complex stakeholders' perception for desalination systems was conducted using 400 sets door-to-door questionnaire surveying technique and the results are presented in **Figure 9(B)**. The findings reveal that the community significantly responded more positively to the desalination system installation and operation, even if they have to pay more for water, to strengthen water security and address water scarcity challenges in the region.

(A)



(B)

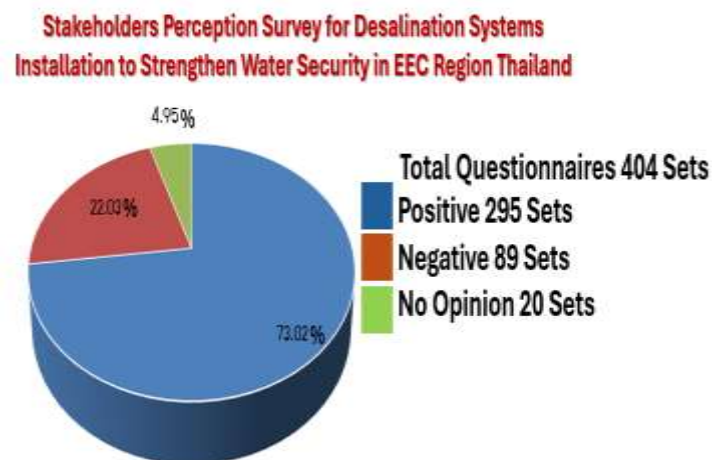


Figure 9 (A) MCDA Analysis Results for MSF MED and RO; (B) Stakeholders' Perception for Desalination Systems Installation and Operation in EEC Thailand.

Conclusions

Current trend is shifting from linear water use to circular systems marks a significant water evolution for longer-term sustainability in Thailand's water management, starting with modern industrial water sector in the eastern economic corridor (EEC) region. The socio-technical and economic analysis of seawater desalination project is conducted to address water scarcity challenges. Various desalination technological performance is investigated and compared using multi criteria decision analysis (MCDA) based on preliminary technology review and feed (sea)water characteristics in EEC region Thailand. MCDA analysis results based on the 4 evaluation criteria groups in this study indicate that Seawater Reverse Osmosis (SWRO) is more viable technology (compared to MED and MSF) for the desalination application in EEC Thailand. Complex stakeholders' perception for desalination systems conducted based on 400 sets door-to-door questionnaire surveying technique revealed that the community significantly valued water security more than water price as they responded more positively to the desalination system installation and operation to strengthen water security and address water scarcity challenges in the region. Findings from this study suggest that integration of desalination to support regional productivity and economic development requires balancing technological, economic, and environmental trade-offs. Modern practical desalination systems for Thailand should be readily designed for (i) high energy efficiency through optimized performance of reverse osmosis (RO) systems; (ii) integration with renewable energy sources; (iii) blending with reclaimed water to reduce overall treatment costs; (iv) water trading mechanisms among water sectors (e.g., trading water between agricultural sector and industrial sector) for economic viability; and (v) government subsidies, shared water infrastructure (e.g., direct pipelines from desalination plants to users), public-private partnerships investment can lead to cost effectiveness for desalination systems. Further analysis provide macro- and micro-level insights to inform policy and strengthen the sustainability of desalination systems in climate-vulnerable coastal regions of Thailand. By combining desalination with reclaimed water, Thailand can build a diversified and resilient water portfolio along the EEC coastline. Future research should examine the environmental impacts of brine disposal and the feasibility of zero-waste desalination systems and integrating remineralization technologies to address health risks from demineralized water. This study offers actionable insights for policymakers and practitioners to strengthen resilient, equitable, and sustainable water supply systems in climate-vulnerable coastal regions, contributing to Sustainable Development Goal 6 (target 6.1). By leveraging innovation, policy support, and international cooperation, desalination can become a sustainable and transformative solution for water security.