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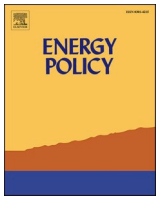

Renewable energy certificate mechanism and markets in Taiwan: The evolution and characteristics

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ABSTRACT

With the world striving to achieve net-zero emissions by 2050, carbon-free energy systems must accelerate. This study examines how Taiwan's renewable energy certificate (T-REC) assists Taiwan-based global enterprises in meeting supply chain requirements and establishing a renewable energy certification and initial market system with reliability and validity. The analysis examines several critical dimensions, including government-led initiatives, the voluntary nature of the program, the design of bundled certificates, and their integration with the national greenhouse gas registry. From an institutional perspective, it can be affirmed that the institutional design of the T-REC aligns with the fundamental purpose of energy attribute certificates in promoting the development and utilization of electricity derived from renewable sources. The reliability of the T-REC can be strengthened through government-led governance. Furthermore, the T-REC tracking system is integrated with the national greenhouse gas registry platform to prevent the double-counting of environmental benefits. From a market perspective, the design of the T-REC shapes the quality and operational regulations of the initial renewable electricity trading market.

1. Introduction

Addressing climate change through energy transitions has become a global priority. At least 120 countries have established energy transition targets (World Economic Forum, 2024). By 2023, 421 companies worldwide had joined the RE100 initiative (RE100, 2023), pledging to meet 100 % of their operational electricity needs with renewable energy by 2050. This commitment seeks to effectively manage greenhouse gas (GHG) emissions, fulfill corporate social responsibilities, meet customer expectations, and establish a new social contract that balances climate protection with resource consumption.

Recognizing the critical need for an energy transition, Taiwan began implementing policies to promote this shift following the inauguration of the Democratic Progressive Party government in 2016. The country is actively encouraging the development of renewable energy, aiming to generate 20 % of its electricity from renewables by 2025 (Ministry of Economic Affairs, n.d.) This commitment marks Taiwan's crucial first move toward reducing carbon emissions. Taiwan established a renewable energy certificate (T-REC) system in 2017 as a part of a series of energy policies, using certificates known as renewable energy identity cards as a trading instrument in Taiwan's renewable energy market to assist Taiwan-based global companies obtain credible renewable energy, while serving as a model for APEC countries. In 2021, President Tsai declared that Taiwan aims to reach net-zero emissions by 2050. To accomplish this goal, Taiwan must ensure that renewable energy accounts for at least 60–70 % of its energy mix, along with energy storage and green hydrogen. These initiatives respond to the growing demand for green supply chains and the pursuit of environmental, social, and governance (ESG) performance to reduce GHG emissions.

Some studies on T-REC (Chuang et al., 2018; Gao et al., 2020; Chou et al., 2022; Senturk and Ozcan, 2023; Chung et al., 2024), with the main emphasis placed on the impact of the T-REC system design on Taiwan's renewable energy market. T-REC as an instrument for fulfilling Taiwan's Renewable Portfolio Standard (RPS) clients' demand, and its contribution to enabling enterprises to reduce carbon emissions while improving their ESG performance. There is an apparent shortage of T-REC developmental history in the existing research.

To elucidate the role of the T-REC system in shaping Taiwan's renewable energy market and its regulatory framework, a comprehensive analysis of its historical development is imperative. Existing

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literature has largely overlooked the critical conditions necessary for establishing a voluntary renewable energy certificate (REC) system and its associated market at the national level, with few studies addressing this gap (Stokes and Breetz, 2018). The primary idea of this paper is to identify the characteristics and evolution of the T-REC mechanism, as well as the critical factors underpinning the establishment of Taiwan's renewable electricity market, alongside its challenges through an in-depth analysis of Taiwan's renewable energy policies. For each component, this study examines the influence of policy agendas, actors, and institutions on their enactment and subsequent development, drawing on insights from Stokes and Breetz (2018).

The remainder of this paper is organized as follows. Section 2 provides an overview of the literature. Section 3 describes the methods. Section 4 examines the promotion of Taiwan's renewable energy policy, employing process-tracing methods to elucidate the causal mechanisms behind policy decisions by focusing on the sequence of events. Section 5 conducts a comparative analysis of the characteristics and market development of T-REC. The aim is to highlight key factors that the government should consider in developing a certification system to enable the future promotion of a high-quality certification system in more countries. Section 6 concludes with a synthesis of research findings and their policy implications.

2. Literature review: the rationale, development, and design of REC mechanism

In previous academic research on REC (Gupta and Purohit, 2013; Hulshof et al., 2019; Chung et al., 2024; Ringel, 2006; Zhang et al., 2018; Aune et al., 2012; Jia et al., 2023), the primary research categories can be summarized as follow: the market operation and performance of REC, the relationship between REC, RPS, and FIT systems, and a comparative analysis of the REC's applicable regions and operation frameworks.

Research findings elucidate the distinctive features of the transition from conventional FIT and RPS frameworks to the emergent REC system. The FIT mechanism has proven effective in fostering the development of renewable energy; however, it often entails a significant financial burden on governmental budgets. In contrast, RPS and REC trading are regarded as mechanisms that mitigate government expenditure on subsidies. Furthermore, REC trading markets serve as instrumental tools in enabling governments to achieve RPS targets. Beyond merely satisfying obligatory RPS requirements, the evolution of RECs has also been propelled by voluntary initiatives. The subsequent analysis will delineate the functionalities, historical development, and operational dynamics of these systems.

2.1. Functions of REC

The key functions of REC can be divided into three aspects. The first is its ability to track the production and use of renewable electricity. Once the energy is generated and disseminated through the grid system, it becomes physically indistinguishable. Consumers of grid-supplied electricity cannot differentiate their consumption from the sources of energy-generation facilities. Thus, RECs are used to assign ownership and track the use of renewable electricity generation (U.S. Environmental Protection Agency, n.d.) and can be sold either bundled or unbundled from their corresponding electricity sources (Center for Resource Solutions, n.d.). Bundled RECs include the underlying electricity (U.S. Environmental Protection Agency, n.d.). The U.S. Environmental Protection Agency defines an unbundled REC as a nonphysical REC separated from physical electricity. If it is unbundled, the electricity and the RECs may be sold to two separate parties (NREL, 2011). Currently, most countries issue unbundled certificates, as seen in Japan, South Korea, China, and Australia. In the U.S., the amount of bundled and unbundled issuance is similar. In recent years, the U.S. has shifted toward integrated energy-and-certificate models, promoting aligned development between renewable energy generation and certification.

The second aspect of REC is a market-based tool that represents ownership rights to the environmental, societal, and other non-energy attributes of renewable electricity production. Additionally, establishing REC markets helps support the scaling of renewable energy capacity and addresses market asymmetry issues. According to the U.S. Environmental Protection Agency (2018), RECs are issued when 1 MW-hour (MWh) of electricity is generated and delivered to the power grid from a renewable energy source. Thus, RECs provide information about the environmental attributes associated with 1 MW-hour (MWh) of renewable electricity (Natural Capital Partners, 2021). These certificates can be seen as identity cards for electricity (EKO Energy, n.d.). In other words, RECs are frequently regarded as the primary instrument for renewable electricity trading, and buyers must hold contractual RECs ownership to claim the green power usage from the renewable electricity procurement project (U.S. EPA, 2024).

The third function of REC is not only to represent the property rights of renewable energy generation but also to serve as a vital tool for electricity consumers to concretely claim their use of renewable energy. The GHG Protocol Scope 2 Guidance classifies the indirect emissions from the generation of purchased electricity, steam, heating, and cooling used by the reporting company as Scope 2 emissions. An Energy Attribute Certificate (EAC) is a type of contractual instrument that represents specific information about the generated renewable energy, allowing for the most precise calculation of emission factors (World Resources Institute [WRI], 2015). REC can be used when calculating GHG equivalencies, for the reason that REC is the most suitable, accurate, precise, and high-quality emission factor.

In summary, RECs provide economic benefits by driving investment and reducing government costs, social benefits by enhancing corporate responsibility and public trust, and environmental ones by facilitating emissions reductions and renewable energy growth. These multifaceted advantages underscore the value of REC as a tool for sustainable development across various dimensions.

2.2. Brief origin of REC

The REC market was established in the 1990s (RECS Energy Certificate Association, n.d.) and includes various instruments known by different names, such as certificates, tags, credits, and generator declarations (WRI, 2015). According to Natural Capital Partners, RECs enable companies to demonstrate their commitment to climate action, impact, and leadership by reaching their renewable energy goals and supporting all grid-connected renewable energy solutions, including power purchase agreements and green tariffs (Natural Capital Partners, 2021).

Early adopters of REC systems came from Western countries. RECs were first introduced during the mid-1990s electricity restructuring debates in the U.S. as tradable environmental commodities and renewable energy policy tools. The California Public Utilities Commission's 1995 discussions on adopting a RPS were among the earliest conversations about RECs (Gillenwater, 2008). In the Netherlands, a voluntary green certificate market called the Green Label was launched in January 1998. Its primary goal was to increase the integration of renewable electricity production into the electricity market by boosting demand (Morthorst, 2000).

Currently, various RECs are in operation worldwide, such as Japan's Green Power Certificate, American Renewable Energy Certificate, Australia's Renewable Energy Certificate, the E.U.'s Guarantee of Origin (GO), Taiwan's Renewable Energy Certification, China's Green Power Certificate, International Renewable Energy Certificate, and the Tradable Instrument for Global Renewables. For example, the REC in the U.S. represents all the environmental characteristics associated with renewable energy production and the prevention of GHG emissions (EnergyTag, 2021). Europe has established several certification systems for energy commodities. The E.U. Directives 2009/28/EC and 2001/77/EC require member nations to establish certificate systems for renewable electricity, known as GOs (Daan et al., 2019). In Australia,

RECs provide a new and innovative way to support renewable energy technologies, allowing the certificate market to be separated from the actual electricity market. These certificates can then be traded nationwide and not just within the electricity grid of the state or territory in which a generator is located. This approach effectively addresses resource constraints due to the varying availability of renewable energy sources across Australia (Andrews, 2001).

Looking at the characteristics of certificate issuers globally, in the United States, certificates are issued through tracking systems managed by individual states. Since each state has its certification system and tracking methods, Green-e serves as a third-party verification mechanism to certify green electricity. This ensures that consumers purchasing REC gain genuine environmental benefits that are neither double-counted nor misrepresented. In Australia, the Clean Energy Regulator, a government department, handles the application, issuance, transfer, and registration of the REC. The European Union (EU) operates its GO certification system through the Association of Issuing Bodies, with members designated by their respective governments as the official issuing authorities.

In Asia, South Korea's REC system is managed by the New & Renewable Energy Center, which operates under the semi-governmental Korea Energy Agency. In Japan, the issuance of Green Electricity Certificates is handled by the Japan Quality Assurance Organization, a private organization. Conversely, official government bodies primarily manage certificate issuance in India and China.

2.3. REC recognized conditions and tracking system

For the RECs framework, it is evident that all RECs have specific scopes of applicability and are not universally suitable for the globe. Currently, there is no internationally unified green electricity trading system not even a widely accepted REC standard, which poses challenges to the global utilization of green electricity and the cross-regional application of REC.

According to the WRI, EACs must be capable of being issued, transferred, and claimed, with the relevant standards recognized by the Carbon Disclosure Project (CDP) quality criteria like RE100, the GHG Protocol, and the CarbonNeutral Protocol. Table 1 proposes specific conditions that must be met for the issuance, transfer, and claiming of EACs, substantiated by the requirements for qualified renewable energy standards as outlined in the International Sustainable Development Assessment. RECs suggest to identify the essential details, such as the origin of the electricity produced, name of the power-production device, energy source, issuance time of the REC, certificate's unique identification number, and location of the generator (RE100, 2016; U.S. EPA, 2018; Becour, n.d. EKO Energy, n.d.).

For RECs, tracking helps consumers identify the renewable characteristics of their purchased energy and verify its origin. These certificates are issued in registries where renewable energy installations are recorded, based on the criteria of the tracking system. Independent and reliable certification of origin allows consumers to claim a specific amount of energy generated (EKO Energy, n.d.). Tracking systems can operate on various chains of custody models, such as book-and-claim or mass-balancing. The book-and-claim method emerged in the early 1990s and was driven by the development of environmental policies in the Netherlands, which created a consumer demand for renewable electricity. End users can use certificates to show their green electricity consumption based on registered data, and these certificates can serve as proof of renewable electricity purchases. The book-and-claim system, primarily used for renewable electricity, allows energy providers to "book" the renewable electricity they have produced in their systems and allows energy consumers to "claim" the energy they have used as renewable. The book-and-claim model does not require proving a physical connection for energy from the production point to the consumption point, indicating that the claim of renewable energy consumption is independent of the physical flow (International Renewable Energy Agency, 2022).

Table 1
REC: Stages and conditions.

Stage	Conditions	Description
Certificates issued	Ensuring accurate generation and attribute information	■ Generators report production data (MWh) to the tracking system, as well as data about energy attributes, which should meet whatever measurement and verification protocols are required by that system (WRI, 2015). ■ Credible generation data (RE100, 2016). ■ Eligible renewable energy source (LEED, 2022).
Certificates transferred	Unique ownership	■ There can be only one owner of a particular MWh and as such, the attributes of this MWh can only be claimed once (Green Power Partnership U.S. EPA, 2017) ■ Entities that wish to participate in the market and trade and own certificates must also register with a tracking system and open one or more accounts. Trading can occur, but each certificate can reside in only one account at a time to avoid double counting (WRI, 2015). ■ Exclusive ownership of renewable energy generation attributes consists of legal enforceability, tracking (exclusive issuance, trading, and retirement), and exclusive sales and delivery (RE100, 2016). ■ Exclusive, unique ownership of generation attributes and attribute certificates (IEEE, 2020).
Certificates claimed	Prevent double counting	■ To the extent that tracking systems prevent double issuance and other forms of double counting, tracking systems alone will not necessarily ensure exclusive claims, i.e., that no other claims are being made on either attributes (including emissions) or electricity as renewable (RE100, 2016). ■ The information in the system can be used to avoid the double counting of attributes (CDP, 2023).

Source: Compiled by the authors

For the mass-balancing model, according to Recital 76 of the Renewable Energy Directive, the mass balance method for verifying compliance establishes a physical connection between the production of biofuels and bioliquids that meet the sustainability criteria and their consumption within the community (European Renewable Gas Registry, 2017). This physical connection between the production and consumption of biomethane in a natural gas network requires a balance between each injected and corresponding drawn consignment. Therefore, the mass balance method links the certificate to the physical delivery of the energy carrier. Sustainability certificates are traded by mass balancing to ensure that the physical delivery of an energy carrier is always accompanied by a certificate.

Through a systematic review of the literature, this article finds that REC's function has precise attribute certificates and market trading tools to calculate Scope 2 greenhouse gas emissions reductions. T-REC system, primarily based on international sustainability guidelines, ensures compliance with standards for certificate issuance, such as the traceability of generation and consumption records and preventing double-

counting of environmental benefits. Furthermore, book-and-claim systems are classified as soft management because they do not consider mass balancing or use sustainability accreditation, and issuers might lack the necessary government authorization, potentially resulting in multiple trading or certificate misuse. Mass balancing is a stringent management strategy. It documents the physical trade, including both injection and submission quantities, and addresses the handling of sustainability-certified deliveries, adherence to E.U. renewable energy directives, and eligibility of registered deliveries for use as sustainable biofuels in importing countries. As electricity is an extremely perishable product, it must be used as soon as it is generated, necessitating a constant balance between production and consumption (Statnett, 2018). This balance ensures a physical connection between power generation and consumption, which must adhere to spatial and temporal concepts.

Regarding the history of REC, originally, REC was designed as regulatory instruments to meet compliance quotas, akin to emission allowances (Li et al., 2022), but they have since evolved into tools for voluntary markets. Countries using REC to fulfill mandatory obligations include the United States, South Korea, the EU, and Australia. In contrast, countries like the Netherlands, Japan, China, and Taiwan have implemented certificate systems to encourage voluntary renewable energy market growth. Notably, Taiwan lacks the RPS for electricity-generating enterprises; thus, its certificate market was initially established as a voluntary market. Allowing businesses to meet international supply chain requirements through certificates. A distinguishing feature in Asian countries is that certificate management is often handled by non-governmental organizations, contrasting with the Western model where official government agencies typically serve as issuing authorities. Taiwan, however, aligns more with the Western approach by designating a government agency to manage certificate issuance and Taiwan has implemented both bundled and unbundled REC.

3. Research methods

This study seeks to systematically analyze the evolution of T-REC and elucidate the underlying political influences that have propelled its evolution, thereby addressing deficiencies in prior research. Leveraging the author's firsthand involvement in the T-REC policy-making process, the research employs a dual methodology comprising an extensive literature review and in-depth interviews with seven experts. These interviewees encompass a diverse group of stakeholders, including policymaking officials, international sustainable development organizations, global brands, and domestic companies (See Table 2).

The literature review draws on primary sources, such as regulatory documents, alongside secondary sources, including prior academic studies and technical reports, to ensure a comprehensive and well-rounded informational base for the analysis.

4. Evolution of renewable energy policy and the T-REC mechanism

4.1. Taiwanese renewable energy policy

Taiwan depends on imports for approximately 98 % of its total energy requirements, with a substantial portion of its energy supply derived from imported fossil fuels. Owing to the global shift toward low-carbon energy, the Taiwanese government has committed to transitioning toward renewable energy sources. In 2009, after the Renewable Energy Development Act was passed, solar photovoltaics (PVs) entered the period of a FIT system, which was calculated based on the installation capacity of power generators, with each tariff corresponding to a different interval (Lin and Lee, 2017). This system provides long-term purchase prices to renewable energy producers, thereby facilitating production in stable and predictable markets. The Ministry of Economic Affairs (MOEA) initiated the "Voluntary Green Electricity Price System Pilot Program" in 2014 to establish a robust framework for regulating renewable energy prices.

The year 2016 was a critical moment in Taiwan's energy transition period. President Tsai comprehensively promoted energy transition, including energy conservation, generation, storage, and the integration of smart systems and aimed to foster a positive cycle in the green energy industry and technological innovation. In October of the same year, the Executive Yuan implemented the "Green Energy Technology Industry Innovation and Promotion Action Plan." This plan aimed to promote the development of renewable energy, with the Ministry of Economic Affairs setting a target of 20 % renewable energy generation by 2025 (Ministry of Economic Affairs, n.d.).

Taiwan amended the Electricity Act in January 2017, a revision with three key implications. First, it enables the trading of renewable electricity. Second, it fosters the development of a new industry—namely, the renewable energy-based electricity retailing industry.[1] Third, it supports Taiwan's progressive reduction of GHG emissions. This milestone in Taiwan's green energy advancement enables users to access renewable electricity via public utilities and private renewable electricity retailing enterprises, establishing an innovative model for renewable energy trading in the region. As Taiwan's industry is primarily export-focused, the adoption of REC as evidence of corporate renewable electricity usage is central to governmental policy. Consequently, the T-REC system was progressively implemented in the same year.

In 2019, the government passed amendments to the "Renewable Energy Development Act" aimed at fostering the advancement of renewable energy, such as diversifying the energy supply, promoting fair usage, and empowering individuals with freedom of choice. This Act also requires energy-intensive industries to set up a specific percentage of renewable energy generation equipment or purchase renewable electricity and certificates to increase the installed capacity of renewable energy. On December 31, 2020, the Bureau of Energy officially announced the "Regulations for the Management of Setting up Renewable Energy Power Generation Equipment of Power Users above a Certain Contract Capacity." This regulation requires power users with a contract capacity of 5000 kW or more to install 10 % green electricity within five years. These mandatory users can meet this obligation by establishing renewable energy generation equipment, setting up energy storage facilities, buying renewable energy and certificates, or providing a monetary substitute. The regulation obligates a certain number of power users to set up renewable energy sources or purchase renewable electricity and certificates. Because of this mandatory regulation, companies have begun to actively understand the significance and operation mode of T-REC.

After the implementation of policies promoting renewable energy development, the installed capacity of renewable energy reached 17,916 MW by 2023 (Energy Administration, Ministry of Economic Affairs, 2024), and the installation capacity increased by at least eight times compared to 2016. The Taiwanese government and private sector are ambitious in promoting and implementing solar PVs and offshore

Table 2
Characteristics of interviewees.

Interviewee	Position
R01	International supply chain manager
R02	government official
R03	government official
R04	local company manager
R05	Researcher (think tank)
R06	Researcher (think tank)
R07	renewable energy consulting firm chief

[1] It refers to any non-public utility that purchases electricity generated from renewable energy for the purpose of reselling to users.

wind power development. Its goal is to achieve an installed capacity of 31 GW for solar PVs and 13.1 GW for offshore wind by 2030 (National Development Council, 2022). This shows that businesses have been given the choice of a power source because of the government's proactive promotion of renewable energy transition policies. This will contribute to protecting the planet's environment and diversifying the development of renewable energy commodities, thereby fostering a new renewable energy economy.

4.2. T-REC mechanism

4.2.1. The origin of T-REC mechanism

In August 2016, the Energy and Carbon Reduction Office of the Executive Yuan proposed the establishment of the T-REC mechanism. This mechanism functions as a unique identifier for renewable electricity, replacing the voluntary green electricity pilot program initiated by the Ministry of Economic Affairs in 2014. The T-REC was developed to address pressure from international brands, such as Google and Apple, which require their supply chains to utilize renewable electricity (Google, 2016).

The T-REC mechanism was established through an inclusive stakeholder consultation process. In May 2017, the BSMI organized an expert consultation involving Taiwan's Environmental Protection Administration, the Bureau of Energy, Taiwan Power Company, potential buyers of renewable electricity, renewable electricity generating enterprises, and environmental organizations to discuss a draft of the REC regulations. In October 2017, REC regulations were enacted, establishing a foundational standard for T-RECs. The same year saw a collaboration between the BSMI and the Taiwan Institute of Economic Research to establish the National Renewable Energy Certificate Center, which was designed to improve third-party verification and international convergence, meeting the needs of international enterprises. In the early stages of system establishment, the BSMI actively partnered with the Center of Resource Solutions in the U.S. The aim was to gain valuable experience in the U.S. renewable energy market, tracking systems, design, and various applications. Moreover, to increase the value of corporate use of renewable electricity and sustainable investment and to enhance the competitiveness of their own ESG indicators, a T-REC can be integrated into the CDP environmental disclosure and reporting system, the Green Electronics Council in the U.S., the Electronic Product Environmental Assessment Tool, the RE100, and the supply chain, such as Apple. Domestically, it can align with the national GHG registration platform, the green procurement of government agencies, Taiwan's corporate governance assessment, green building labels, green factory labels, and corporate social responsibility awards. Companies can use the RECs they have acquired as evidence of renewable electricity use in these initiatives.

Increasingly, both domestic and foreign companies are prioritizing sustainable management and voluntarily joining the RE100. In Taiwan, corporations in sectors such as finance, information retail, and commerce, which typically have fewer production bases and primarily lease commercial buildings, find it difficult to secureRECs. To address this issue, the BSMI initiated the "Multiple Users in Single Customer Number Pilot Project" in November 2020. This project will enable companies located in commercial buildings without independent meters to acquire renewable electricity and certificates (National Renewable Energy Certification Center, 2021). In response to the increasing demand for renewable energy from commercial building tenants, the BSMI launched the "Green Leasing Program" in 2022. This program extended its service from the "Pilot Program of Renewable Energy Certificate Transaction for Multiple Users in Single Electricity Account Number." The advantage of this scheme is that it provides landlords with the flexibility to distribute the green electricity required by their tenants optimally. As a result, tenants can benefit from the services that the landlord offers and buy the precise amount of electricity they need. The first participants in the Green Leasing Program were commercial buildings owned by Cathay Life Insurance Co., Ltd. and the Shin Kong Life Tower owned by Shin Kong Life Insurance Co., Ltd. (National Renewable Energy Certification Center, 2022).

4.2.2. The operation of T-REC

Under the "Implementation Regulations Governing Renewable Energy Certificates (REC regulations)" (Ministry of Economic Affairs, 2020), electricity-generating enterprises,[2] renewable energy-based electricity retailing enterprises, and owners of self-generating equipment qualify to apply for T-REC.[3] The procedures for application, facility inspection, and the administration of issuance, transfer, and claims of T-REC are regulated by these provisions.

In Taiwan, certificate issuance is based on the monthly power consumption curve, power generation curve, and matching results of Taiwan Power Company. Once the BSMI approves the T-REC application, the power generation capacity is metered, and for every 1000 kWh of generated power, the BSMI issues an electronic certificate and registers it on the T-REC Center platform. The transfer of T-REC requires the transferor to submit a transfer application and relevant documents for evaluation. T-REC holders can use T-REC for the current year's GHG emissions inventory or to claim corporate social responsibility; however, once a T-REC is claimed, it cannot be transferred. The aforementioned processes and the T-REC tracking system should ensure that each T-REC represents exclusive and unique ownership of generation attributes and attribute certificates, where applicable.

Given the above practices, international experts emphasized that physical products must be accompanied by certificates to effectively combat greenwashing. While most of T-REC combine electricity and certification, this approach demonstrates a strong commitment to environmental improvement. We hope to conduct a detailed study on the T-REC system to provide an international reference on best practices for avoiding greenwashing.

4.3. T-REC trading market

RECs have become essential tools in renewable electricity markets, as they represent ownership of the environmentally beneficial attributes of renewable energy. Through a generation and usage tracking system, RECs enable power consumers to claim renewable energy usage, providing a concrete, compliance-based structure for renewable energy transactions. For electricity buyers, these certificates serve as tangible proof of their renewable energy use, reflecting both social and environmental benefits. This has led to increased willingness among Taiwanese companies to purchase renewable energy, boosting the renewable energy trading market.

Looking back at the trading history of RECs in Taiwan from 2017 to May 2020, the T-REC trading mode mostly adopted a self-use renewable-energy-based power generation equipment owner model. Subsequently, renewable energy wheeling was initiated (i.e., electric certificate integration mode), and the trading volume gradually expanded. By the end of 2023, a total of 3.5 million T-RECs had been issued, encompassing 2,382,571 for wind energy, 975,755 for solar energy, 65,391 for small hydropower, and additional certificates for various other energy sources (National Renewable Energy Certification Center, 2024). This achievement marks a significant milestone in the renewable energy certification system (see Fig. 1). In addition to large-scale electricity users, industrial users, financial and telecommunications industries, law firms, and brands are actively involved in renewable energy procurement.

Despite the T-REC trade reaching a significant scale, substantial

[2] Electricity Generating Enterprise refers to any non-public utility that operates major power generation equipment and engages in the generation and selling of electricity, including the renewable energy-based electricity generating enterprises.

[3] This excludes participants in the Feed-in Tariff (FIT) and greenhouse gas (GHG) emission reduction programs, primarily to prevent double counting.

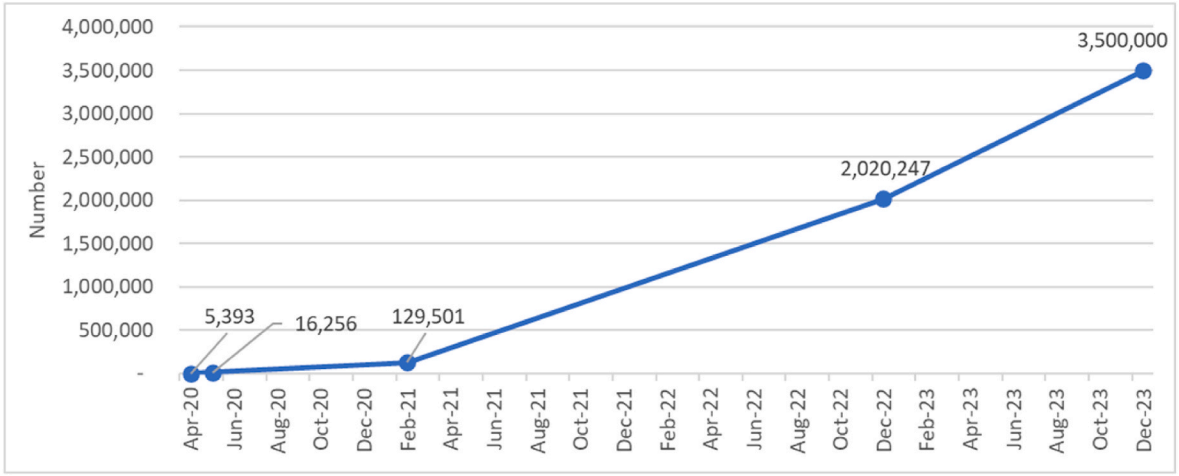

Fig. 1. Number of traded T-RECs in Taiwan.
Source: National Renewable Energy Certification Center (2024); compiled by the authors

efforts are still needed to fully meet buyer demand. For instance, by the end of 2023, approximately 75 % of the T-RECs obtained through the wheeling route were acquired by large-scale companies. Additionally, respondents expressed concerns that T-REC prices are too high, market information is unevenly distributed, and small and medium-sized enterprises encounter difficulties in purchasing them. Despite substantial progress, significant efforts are still required to fully meet demand, as approximately 75 % of T-RECs acquired via wheeling are held by large-scale companies.

This means that it is difficult for small and medium-sized enterprises in Taiwan to obtain renewable energy. First, Taiwan's FIT for solar PV and wind energy remains above international rates; particularly in comparison to Australia and Japan, the FIT mechanism limits market price elasticity. Second, the purchase and sale prices of renewable-energy electricity are considered trade secrets by the parties involved. This lack of transparency complicates buyers' acquisition of renewable electricity at fair prices, and leads to increased transaction costs. Third, small and medium-sized businesses may have less negotiating leverage than larger corporations when establishing terms for buying green electricity. *"The higher cost of renewable energy in Taiwan makes it challenging for suppliers to use green electricity in production. The Taiwanese government must consider phasing out the FIT mechanism to narrow the price gap between green and conventional electricity or adopt a feed-in premium system to* support *the development of renewable energy" (R01) and (R04)*. Recently, the government planned to lease a certain proportion of the installation capacity of solar PV sites of public or state-owned enterprise land into the trading market, making it easier for small- and medium-sized enterprises to obtain renewable energy and allowing the Taiwan Power Company's green power to enter the market to achieve stable prices.

5. Discussion

In analyzing the design of the T-REC system, we find four pivotal characteristics that underpin its quality and shape its market development.

5.1. T-REC operates on a voluntary basis

The REC was initially designed as a regulatory tool for utility companies to demonstrate compliance with minimum renewable electricity purchasing requirements, as seen in the RPS in the United States and South Korea and the Renewable Energy Target in Australia. Beyond these compliance REC, a voluntary REC market has emerged, allowing generators and other electricity consumers to purchase REC independently of regulatory mandates.

> *"As a key partner in the global supply chain, Taiwan has established a voluntary-driven T-REC system to enable Taiwanese companies to meet the sustainability requirements of international brands'' (R03).*

From a mechanistic perspective, our analysis reveals that the prevailing trend of energy transition, coupled with the proactive demands of enterprises, has emerged as the primary catalyst for a nation to institute the REC system. This is particularly salient for leading manufacturing countries, where the REC framework can significantly bolster the advancement of a voluntary renewable energy market and create a new renewable energy industry. Taiwan's experience shows that establishing a voluntary goal-oriented REC system can refine the operational mechanisms of the market and allow companies to obtain RECs through the use of renewable electricity and subsequently improve the competitiveness of their own environmental, social, and governance indicators to reach the ultimate target of integration into the green supply chain.

5.2. Government-supported T-REC

Taiwan adopted a government-issued certificate mechanism by tracking the system of the National Renewable Energy Certificate Center under the BSMI of the MOEA. Taiwan's experience in developing the REC system suggests that government-led frameworks are more likely to gain recognition from international organizations and can effectively support the early development of renewable energy markets. However, such government-led approaches may also introduce challenges related to limited information availability and transparency.

> *"The government has designated an issuing body for T-REC to ensure that it is a reliable certification mechanism that can be readily accepted internationally. Before issuing the T-REC, the renewable electricity generator must be verified, and the power generation accumulation must be confirmed" (R02).*

T-REC approach is in line with the conditions of RECS; that is, in well-regulated markets, issuers are often appointed by the government and are frequently transmission system operators, regulators, or other private parties (RECS, 2023). For example, the U.S. and the EU implement similar practices. In the U.S., RECs are issued by state tracking systems. Then the independent system operators and regional transmission organizations track the generation, retirement, and quality of

the REC. In the EU's GO system, issuers are government-appointed entities that issue standardized certificates within the certification framework (Sustainability Roundtable, Inc., 2012).[4]

5.3. Bundled T-REC as design principle

The unbundled RECs were preferred in 2015 (RE100, 2019), some companies have recently changed their procurement strategy from buying unbundled RECs to directly investing in renewable energy projects or using a combination of procurement mechanisms such as a mix of power purchase agreements and RECs (Li et al., 2022).

> "The development of the T-REC system closely follows the U.S. model, which has matured over many years. Initially, the U.S. primarily issued unbundled RECs. However, since 2016, the U.S. RPS has required obligated parties to fulfill mandates through bundled RECs, reinforcing the role of RECs as evidence of renewable electricity. To keep pace with international trends and support domestic renewable energy goals, the T-REC system adopts a dual approach: bundled RECs, which integrate electricity and certification, serve as the primary mechanism, while unbundled certificates provide a supplementary option to support flexibility in the renewable energy market"(R05).

Fig. 2 shows the current T-REC transfer model. Routes 1 and 2 depict the direct supply and wheeling of renewable electricity, respectively, whereas route 3 shows the renewable electricity retail model. Route 4A indicates the on-site renewable electricity generation and consumption. Routes 1, 2, and 4A make up the bundled T-REC transfer models. Route 4 B represents the transfer model for unbundled RECs for on-site renewable energy generation. Statistics from the T-REC Center reveal that fewer than 0.1 % of certificates are issued under routes 4A and 4B of T-RECs, with most originating from renewable energy generation facilities in institutions such as schools, government agencies, and social welfare organizations. These data suggest that most T-RECs are bundled, assisting companies in reducing their value chain carbon emissions. This strategy not only provides positive social and economic benefits but also encourages environmental enhancements. This system is consistent with several academics to advocate for the use of bundled REC. Acquiring unbundled credit can create the illusion that a company's electricity emissions are zero when, in fact, they are not (S&P Global, 2021).

> "The T-REC tracking system uses smart meters to log the data of generated and consumed electricity, and ensures alignment between power generation and consumption in real-time, thereby achieving a mass balance standard.''(R03).

"A crucial foundation for T-REC's development toward bundled certificates and compliance with Quasi 24/7 Carbon-Free Energy standards.''(R07). 24/7 Carbon-Free Energy means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources at every hour of every day, everywhere (Global Climate Action, 2024). In Taiwan, the issuance of T-REC is primarily conducted through renewable electricity system matching and tracking at a national level, with temporal matching units set at every 15 min, and certificates are issued in a bundled format to ensure physical goods are paired with time-stamped certificates is the most crucial method for achieving deep grid decarbonization.

5.4. T-REC tracking system linked with national GHG registry platform

The GHG Protocol Scope 2 Guidance mandates the use of emission factors from EACs that a company has retained or purchased as the primary option for market-based Scope 2 accounting (CDP, 2023). It is considered best practice to use certificates supported by robust energy tracking and auditing systems. These systems enable a link between energy production at a specific source (with its unique attributes) and its sale through a supplier network until it reaches the end consumer, who claims the unique characteristics of the source (CDP, 2023).

According to Article 8 of the RECs regulations, T-RECs can be used to validate the use of renewable energy in the year of power generation recorded in the certificate and to evaluate the GHG emissions. In other words, T-REC serves as a tool for tracking GHG emission reductions. If a business entity uses T-RECs to conduct a GHG inventory in accordance with regulations, T-RECs can be directly applied to calculate GHG emissions. The National GHG Registry Platform calculates the corresponding GHG emission reduction based on the type of registered renewable energy. Fig. 3 shows the link between the T-REC tracking system and the National GHG Registry Platform, along with the operational procedure flow diagram.

When a T-REC is registered in a GHG inventory, the platform communicates the T-REC serial number to the T-REC tracking system, which then labels it as claimed. This process allows for the use of renewable resources to lower GHG emissions for an environmental benefit declaration to be recorded and monitored through the connection between the T-REC tracking system and the National GHG inventory registry, where the data are comprehensive and digitized. This procedure ensures that the T-REC mechanism aligns with the relevance, completeness, consistency, transparency, and accuracy of GHG inventory standards. By cross-verifying with the regulations and GHG inventory registry system, which can ensure that environmental benefits are transferred exclusively to the reporting entity while simultaneously avoiding double-counting.

6. Conclusion and policy implications

Establishing certificate systems to promote the development of renewable energy is flourishing worldwide. The certificates embody the environmental benefits obtained from producing power from renewable sources; as such, they fit in the category of tradeable permits used for environmental policy (OECD, 2002). This study represents the first international research focused on the evolution of the T-REC system. Findings from our analysis of T-REC development, the primary goal is to help domestic enterprises meet both supply chain requirements and voluntary renewable electricity commitments. Unlike traditional policies that focus on renewable electricity supply, the T-REC system centers on addressing demand. A government-led certificate system enhances its credibility. The bundled certificate issuance ensures the effectiveness of the T-REC and helps the grid to achieve the goal of a 24/7 carbon-free energy purpose. Integrating the certificate tracking system with the GHG platform could enhance T-REC's visibility and credibility among international sustainable advocacy organizations. Finally, strong government policy involvement could affect the transparency of market operations.

Several policy implications emerge from this analysis. The system design of the T-REC effectively aligns with the EAC's role in tracking electricity generation and consumption. This alignment not only fulfills corporate demands but also contributes significantly to the innovation within Taiwan's renewable energy industry and supports the nation's GHG emissions reduction. By implementing a voluntary REC system integrated with a demand based RPS policy framework, corporations can be incentivized and supported in transitioning to renewable electricity. During the nascent stages of Taiwan's renewable energy market, the government bolstered the environmental efficacy, market feasibility, and credibility of the T-REC system by instituting a standardized electricity certification framework, power purchase agreements, and a government-managed certification process. This strategy not only safeguards consumers but also markedly accelerates the expansion of

[4] The European Energy Certification System offers two certification schemes: GO and Independent Certification Schemes (ICS). The prices of GO and ICS certificates vary according to the time of energy production and the energy source.

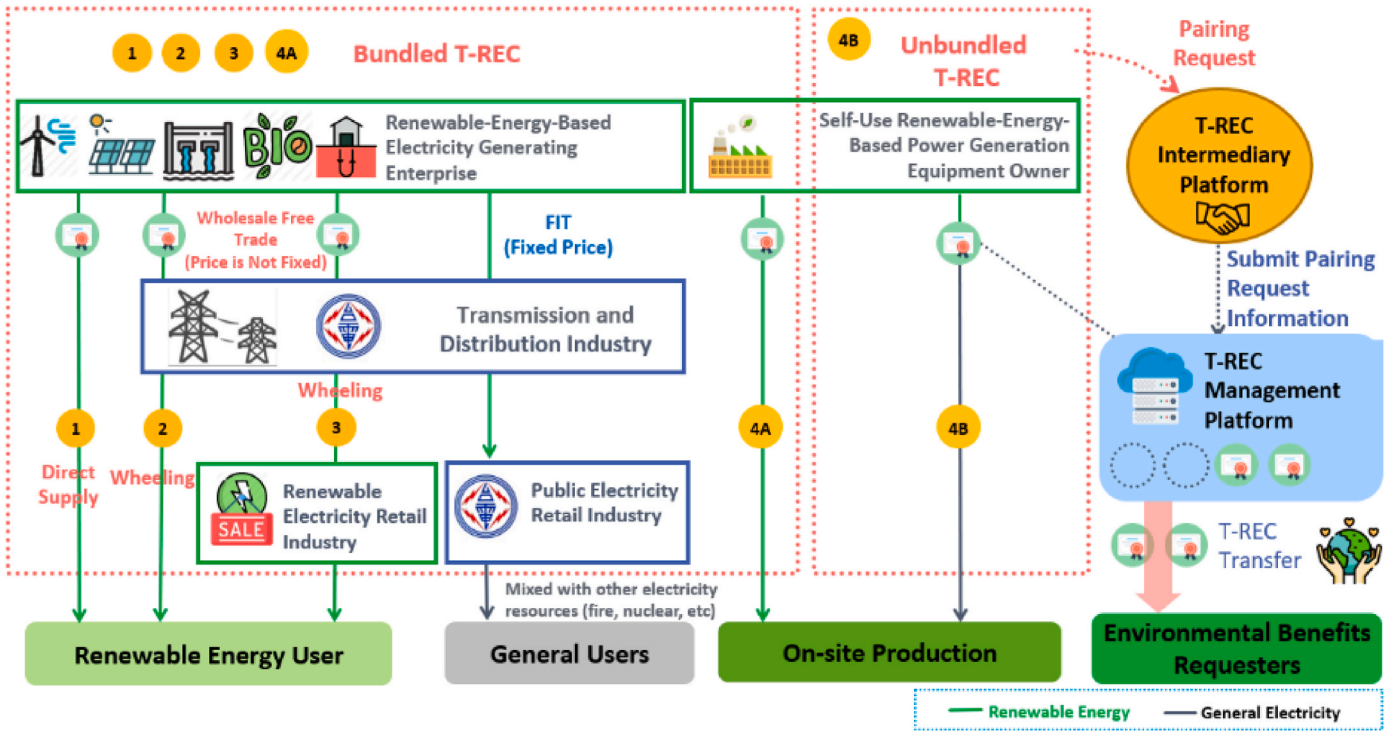

Fig. 2. T-REC transfer model.
Source: National Renewable Energy Certification Center (2018)

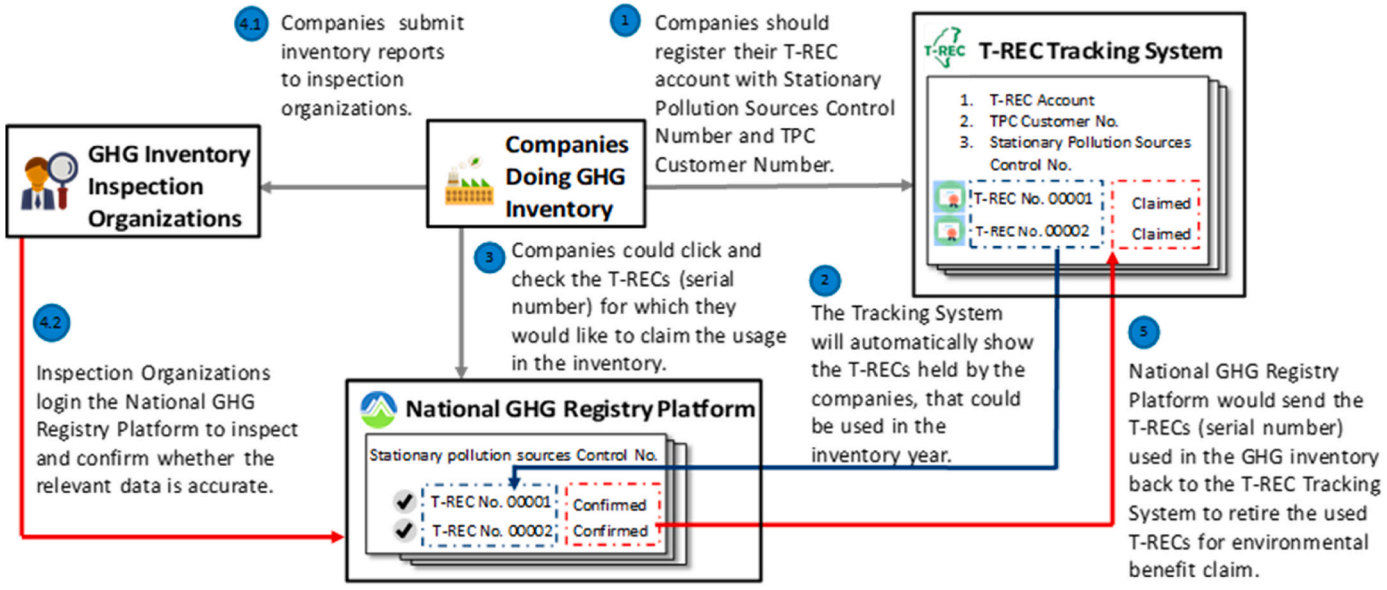

Fig. 3. Linking operation procedure between T-REC Tracking System and National GHG Registry Platform.
Source: National Renewable Energy Certification Center (2019).

renewable energy. Nevertheless, a government-dominated certification system may engender issues such as excessive protectionism or inadequate market transparency. To address these challenges, the Taiwanese government should enhance the framework for renewable electricity trading by, for example, providing incentive mechanisms or developing a comprehensive renewable electricity price index to effectively guide market participants.

Furthermore, given Taiwan's rising demand for and supply of renewable electricity, the government encounters emerging challenges in reconciling the economic costs of renewable energy adoption with the imperative of sustaining a reliable electricity system. Establishing a robust primary renewable electricity market can effectively raise public awareness and enhance consumer choice in electricity use. However, the future may require exploring new forms of renewable energy development, such as offshore energy or geothermal. This would necessitate aligning renewable energy resources, technologies, and market conditions across regions and timeframes, while adopting innovative market models, such as renewable electrcity matching. These strategies could increase the share of renewable energy in Taiwan's energy mix. Globally, there is increasing advocacy for innovative renewable electricity

markets and certification systems, such as time-stamped certificates or carbon-free electricity markets. Taiwan is encouraged to consider these developments to effectively promote energy system decarbonization and achieve its net-zero transition goals.

CRediT authorship contribution statement

Tze-Luen Lin: Writing – original draft. **Kuan-Ting Chen:** Writing – original draft. **Yen-Haw Chen:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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