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# Exploring the Supply and Demand of Renewable Energy Certificate (REC) Market in Taiwan: A Case Study

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# Table of Contents

# List of Figures

## List of Tables

# List of Abbreviations

CD Carbon Dioxide

CDP Carbon Disclosure Project

EAC Energy Attribute Certificate

ETS Emissions Trading System

EU European Union

FiT Feed-in Tariff

GHGP Greenhouse Gas Protocol

GO Guarantee of origin

IEA International Energy Agency

IDB Industrial Development Bureau

IPP Independent Power Producers

KW Kilowatt

KWh Kilowatt per hour

MOEA Ministry of Economic Affairs

MW Megawatt

MWh Megawatt per hour

REDA Renewable Energy Development Act

REC Renewable Energy Certificate

RECC Renewable Energy Certification Center

RE100 Renewable Energy 100

RE Renewable Energy

RSPRC Risk Society and Policy Research Center

T-REC Taiwan Renewable Energy Certificate

Taipower Taiwan Power Company

TWD New Taiwan dollar

TWh Terawatt

TWh Terawatt per hour

UNFCCC United Nations Framework Convention on Climate Change

I-REC International Renewable Energy Certificate

Abstract

This master's thesis embarks on an exploration of the intricate factors underlying Renewable Energy Certificates (RECs) in Taiwan. By situating Taiwan within the global renewable energy landscape, the study underscores its unique position in this dynamic field. Central to this investigation is the examination of the relationship between two types of RECs: international RECs (I-RECs) and Taiwan-specific RECs (T-RECs). The research seeks to unravel the correlations between these two systems and assess the potential impact of introducing T-RECs on I-REC dynamics.

In addition to scrutinizing the I-REC and T-REC interplay, the study ventures into less-explored territories, such as the volumes of REC issuance and cancellation. By delving into these overlooked areas, the research aims to provide a comprehensive understanding of the determinants of REC systems. Employing a blend of qualitative and quantitative methodologies, the investigation endeavors to shed light on the intricate dynamics shaping REC markets in Taiwan and their broader implications for the renewable energy sector.

The research questions outlined serve as guiding pillars for this study. Firstly, the inquiry into the relationship between the electricity and REC markets in Taiwan seeks to uncover correlations between electricity production and REC supply, as well as electricity consumption and REC demand. Additionally, the study aims to discern potential correlations between energy indexes and REC supply and demand.

Furthermore, the investigation scrutinizes the relationship between I-RECs and T-RECs in Taiwan. Hypotheses are formulated to explore the long-term correlations between these two types of RECs and to evaluate their interactions beyond pricing. Through rigorous analysis and empirical inquiry, this research endeavors to provide valuable insights for stakeholders in Taiwan's renewable energy sector, informing policy decisions and fostering sustainable energy practices.

# 1. Introduction

The imperative of transitioning to a renewable-based global energy system is undeniable if we are to stay on track with the 1.5°C-compatible trajectory for our planet. Achieving this goal hinges on our collective commitment to key actions, including the modernization and expansion of infrastructure, adaptation of policies and markets, and development of institutional and human capacities. (IRENA, 2024a)

Renewable energy stands as a cornerstone in the global shift towards low-carbon development, serving multifaceted purposes. It not only aids in mitigating greenhouse gas emissions but also fosters technology diversification, thereby mitigating risks associated with fuel price fluctuations and ensuring a reliable energy supply (Jiang et al., 2010). The imperative transition towards renewable energy sources has long been recognized for its dual benefits, both economic and environmental (Borenstein, 2012). However, the integration of renewable energy into existing energy grids presents challenges due to factors such as intermittency, low marginal costs, and climate variability, leading to market uncertainties (Blazquez et al., 2018). To mitigate these uncertainties and incentivize renewable energy generation, various measures have been introduced, including subsidies, tax rebates, and the innovative instrument of RECs ( Gupta & Purohit, 2013). Among these, RECs have emerged as a notable instrument globally to incentivize renewable electricity generation.

During my internship at Becour[1], a pioneering company dedicated to tracking and bolstering renewable energy production globally, I delved into the vibrant realm of renewable energy markets, honing my focus on International Renewable Energy Certificates (I-RECs). Central to my role was the meticulous analysis of price data spanning various countries, aimed at unraveling the complexities inherent in the I-REC market. This endeavor demanded keen attention to detail as I meticulously gathered, processed, and deciphered data to unveil underlying trends and pricing dynamics. Collaborating closely with my colleagues, I embarked on extensive market research endeavors, seeking to grasp the regulatory frameworks, market participants, and pivotal factors influencing I-REC pricing across diverse regions.

Amidst my internship journey, a fascinating revelation emerged – Taiwan boasted one of the globe's highest I-REC prices, a staggering 20 times greater than those in mainland China. This revelation kindled a profound interest in dissecting the intricacies of Taiwan's I-REC market. Initially intent on probing the drivers behind the lofty I-REC prices, I encountered hurdles due to the scarcity of historical price data, attributable to the private nature of I-REC trading between consumers and energy producers or traders.

Undeterred by obstacles, I embarked on a quest for alternative data sources to propel my research forward. Serendipitously, I stumbled upon a treasure trove of information on I-REC issuance and cancellation via the official I-REC website. This data reservoir provided invaluable insights into the

[1] Becour. https://becour.com/

production year of renewable energy, issuance and cancellation timelines, and the volume of I-RECs issued and canceled – emblematic of renewable energy utilization. Recognizing the potential for supply and demand analysis fueled by this accessible data, my research trajectory pivoted towards scrutinizing the dynamics of I-REC trading.

Moreover, the prevalence of Chinese language in Taiwan proved advantageous for my research endeavors. Many data and information pertinent to my analysis were exclusively available in Chinese, leveraging my native language proficiency to navigate through this invaluable resource pool.

Subsequently, my exploration led me to analogous data concerning Taiwan Renewable Energy Certificates (TRECs), further igniting my curiosity. The prospect of juxtaposing two REC systems within Taiwan's market – the international I-REC system and the local TREC system – proved enthralling. I became intrigued by the potential competition or collaboration between these systems, given their shared objective of validating renewable energy usage.

Certificates were introduced to tackle the issue of information asymmetry in energy markets. This arises because consumers typically cannot discern between consuming renewable and non-renewable energy, and often, production happens in locations distant from consumption. The complication is exacerbated in energy markets with extensive networks, such as electricity and gas, where all energy mixes together(Hulshof et al., 2019). Certification aims to address this informational gap by offering consumers insights into unobservable characteristics, such as the production method, empowering them to make more informed decisions.

This master's thesis embarks on an exploration of the intricate factors underlying Renewable Energy Certificates (RECs) in Taiwan. By situating Taiwan within the global renewable energy landscape, the study underscores its unique position in this dynamic field. Central to this investigation is the examination of the relationship between two types of RECs: international RECs (I-RECs) and Taiwan-specific RECs (T-RECs). The research seeks to unravel the correlations between these two systems and assess the potential impact of introducing T-RECs on I-REC dynamics.

In addition to scrutinizing the I-REC and T-REC interplay, the study ventures into less-explored territories, such as the volumes of REC issuance and cancellation. By delving into these overlooked areas, the research aims to provide a comprehensive understanding of the determinants of REC systems. Employing a blend of qualitative and quantitative methodologies, the investigation endeavors to shed light on the intricate dynamics shaping REC markets in Taiwan and their broader implications for the renewable energy sector.

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Furthermore, the investigation scrutinizes the relationship between I-RECs and T-RECs in Taiwan. Hypotheses are formulated to explore the long-term correlations between these two types of RECs and to evaluate their interactions beyond pricing. Through rigorous analysis and empirical inquiry, this research endeavors to provide valuable insights for stakeholders in Taiwan's renewable energy sector, informing policy decisions and fostering sustainable energy practices.

Except for the introduction part, the structure of this paper is organized as follows: In Section 2, I provide background information, including a discussion on Renewable Energy Certificates (RECs), the energy structure in Taiwan, an overview of the international REC market (I-RECs), and an introduction to Taiwan's REC market, specifically focusing on T-RECs. Section 3 presents a comprehensive literature review, covering relevant research on the Taiwan REC market and REC markets in general, including theoretical and empirical studies, and identifying existing research gaps. Section 4 outlines my research questions and hypotheses, focusing on the relationship between the electricity market and REC market in Taiwan, as well as the relationship between I-RECs and T-RECs. In Section 5, I describe my data sources and methodology, including regression models and the utilization of artificial intelligence. The results and discussions are presented in Section 6, where I analyze electricity production and REC supply, electricity consumption and REC demand, and the relationship between I-RECs and T-RECs. Finally, Section 7 concludes the paper, by summarizing key findings, acknowledging research limitations, and providing avenues for future research.

# 2. Background

## 2.1 REC(Renewable Energy Certificates)

### 2.1.1 Definition

Electricity is a homogenous product. This means that regardless of its source, it has the same characteristics. Once electricity enters the electricity grid, there is no way to trace the origin of that electricity. For renewable electricity producers, this poses a problem. Unless a consumer has a direct powerline to a renewable electricity power plant, the consumer cannot purchase renewable electricity directly from the grid. If you cannot differentiate between renewable and non-renewable electricity, there is no market for renewable electricity.

To address this challenge, the Energy Attribute Certificate (EAC) system was developed. An EAC is a contractual instrument that represents information about the origin of the energy generated. It allows markets to track renewable energy production and permits consumers to make credible claims of renewable energy use. Each certificate acquired and then retired certifies the use of a specific quantity of renewable electricity (typically 1 megawatt-hour, MWh) (IRENA, 2024b). EACs serve as "birth certificates" for electricity, allowing renewable energy producers to generate Renewable Energy Certificates (RECs) for each megawatt-hour of electricity produced. RECs represent the environmental and social attributes of renewable energy generation. When a renewable energy source generates electricity, it produces RECs that can be traded separately from the physical electricity.

The purchase of RECs enables buyers to claim the use of renewable energy, even if the electricity they consume is from non-renewable sources. This system, known as a "book and claim" system, facilitates the separation of renewable energy's environmental benefits from the physical electricity, supporting renewable energy production regardless of the energy source used locally (Velazquez Abad & Dodds, 2020).

### 2.1.2 Different kinds of RECs

Renewable Energy Certificates (RECs) serve as pivotal instruments in affirming the renewable origin of electricity across various regions worldwide. They come in diverse types, reflecting the array of renewable energy sources and their distinct characteristics.

One fundamental classification of RECs lies in their bundling status. Unbundled RECs are certificates sold separately from the physical electricity generated, allowing consumers to purchase renewable attributes independent of the energy itself. This method provides flexibility and enables consumers to support renewable energy without directly purchasing the associated electricity. On the other hand, bundled RECs are paired with the physical electricity they represent. When consumers purchase bundled RECs, they are buying both the renewable attributes and the energy itself, ensuring direct support for renewable energy generation.

Additionally, RECs are categorized based on the source of renewable energy they represent, encompassing solar, wind, hydroelectric, biomass, geothermal, or tidal energy. This segmentation allows consumers to align their REC purchases with specific renewable energy technologies or environmental objectives.

Furthermore, RECs can vary in terms of their geographic scope. While some RECs are specific to a particular region or country, others are international in nature, representing renewable energy generation from various countries or regions. This international dimension enables companies with global operations to support renewable energy projects across different parts of the world and address sustainability goals on a broader scale. Specifically, Guarantees of Origin (GOs) in Europe originated to validate the renewable origin of electricity and are widely utilized across the continent to demonstrate compliance with renewable energy targets. In North America, Renewable Energy Certificates (RECs) emerged in the late 1990s as a market-driven approach to stimulate renewable energy growth and are widely adopted by utilities, corporations, and individuals to advance sustainability objectives. International Renewable Energy Certificates (I-RECs) extend renewable energy certification beyond Europe and North America to regions with emerging renewable energy sectors, facilitating cross-border renewable energy transactions and supporting sustainability commitments. Tradable Instruments for Global Renewables (TIGRs) is another system available for renewable energy use, where RECs, GOs and I-REC are not available(NCP, 2018).

By regulation, REC markets can be divided into compliance and voluntary segments. (Stouhi, 2020) Compliance markets are established through regulatory policies that mandate electricity utilities to generate a specific portion of their electricity from renewable energy sources. These regulations require utilities to produce RECs as proof of compliance with renewable energy targets. In instances where utilities cannot meet their renewable energy obligations internally, they have the option to purchase RECs from other entities to fulfill their compliance requirements. Compliance markets facilitate adherence to regulatory mandates and support the transition towards cleaner energy sources (WRI, 2008). In contrast, voluntary REC markets operate outside of regulatory mandates and are driven by organizations' internal environmental and social objectives. These objectives may include reducing greenhouse gas emissions, advancing sustainability initiatives, and responding to the increasing demand for corporate responsibility from investors and consumers. Organizations voluntarily participate in these markets to demonstrate their commitment to sustainability and support renewable energy projects, even in the absence of regulatory requirements(REN21 et al., 2018). This voluntary approach to REC trading aligns with broader sustainability goals and reflects organizations' proactive efforts to address environmental challenges and promote renewable energy adoption.

### 2.1.3 Debate about the usage of RECs

The impact of the EAC system has been under heavy debate. The main question is whether you are paying for additional renewable energy, or for energy that would be generated anyway. Several studies by Aasen et al., (2010), Herbes et al., (2020) and Mulder & Zomer, (2016) have been dedicated to assessing the impact of the GO system in Europe, with the general conclusion being that the system fails to generate sufficient income for additional investments in renewable energy.

However, it's important to note that the primary objective of the REC system is to facilitate the exchange of information regarding electricity rather than solely promoting increased green electricity production (Wimmers & Madlener, 2024). In this regard, RECs serve a crucial role in protocols related to greenhouse gas emissions, aiding in the development of more accurate inventories, and monitoring carbon footprints. Additionally, RECs contribute significantly to fostering acceptance of renewable electricity and transitioning towards eco-friendly economies, underpinned by reliable information and trust.

Despite potentially low prices, RECs can provide additional revenue streams for producers, particularly in regions where they can be issued alongside financial incentives for renewable energy. A closer examination of REC prices reveals their potential to incentivize greater renewable electricity generation. If REC prices align with financial support provided by governments for renewable energy projects, they could emerge as pivotal tools for project developers and renewable energy producers.

The fluctuating prices of RECs, influenced by factors such as the age of power plants and the technology utilized, along with the fundamental principles of supply and demand, indicate their potential to become potent instruments for driving increased renewable energy production in response to growing demand (Wimmers & Madlener, 2024).

Karestree and Panyagometh's (2023) study on I-RECs in Thailand revealed that I-REC represents a promising mechanism for advancing decarbonization by encouraging the utilization of renewable energy both domestically and internationally. Although I-REC does not directly accelerate renewable energy projects in Thailand, it indirectly promotes renewable energy by encouraging renewable energy corporations to undertake initiatives related to renewable energy. Additionally, it raises awareness about renewable energy and attracts more global investors to Thailand, thereby stimulating the country's economy.

## 2.2 Energy structure in Taiwan

### 2.2.1 In general

Taiwan generates almost none of its own energy, with 97.27% of the total energy consumption depending on imports in 2022. (MOEA, 2023) The majority of imported crude oil, totaling 80%, originates from politically unstable Middle Eastern nations. For instance, 33% is sourced from Saudi Arabia, while Kuwait contributes 19%. Additionally, a significant portion of imported coal is supplied by Australia and Indonesia, comprising 44.9% and 40.4% of the total, respectively. Last, natural gas mainly came from Qatar and Malaysia. (BOE, 2022)

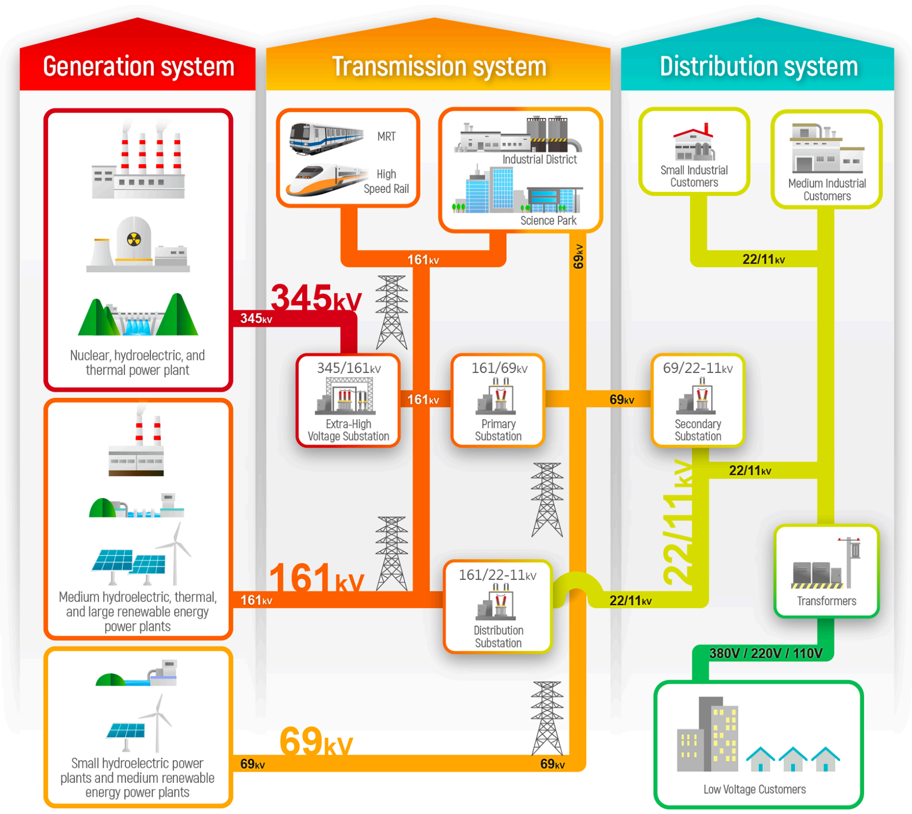

*Figure 1: Electricity system in Taiwan. Source: Taipower*

The analysis provided by Chang and Lee (2016) underscores Taiwan's heavy reliance on imported energy, highlighting the imperative for the nation to transition towards sustainable and independent energy solutions. With Taiwan's contribution to global CO2 emissions reaching 0.8% by the close of 2013, ranking it 22nd globally, the urgency for renewable energy development becomes even more pronounced.

In Taiwan, electrical power is generated from nuclear, hydro, and thermal power plants. Transformers change the voltage from generators to a level suitable for transmission to minimize losses. Through transmission lines, power is delivered to substations. These substations will transport electrical power to industrial, commercial, or residential customers.

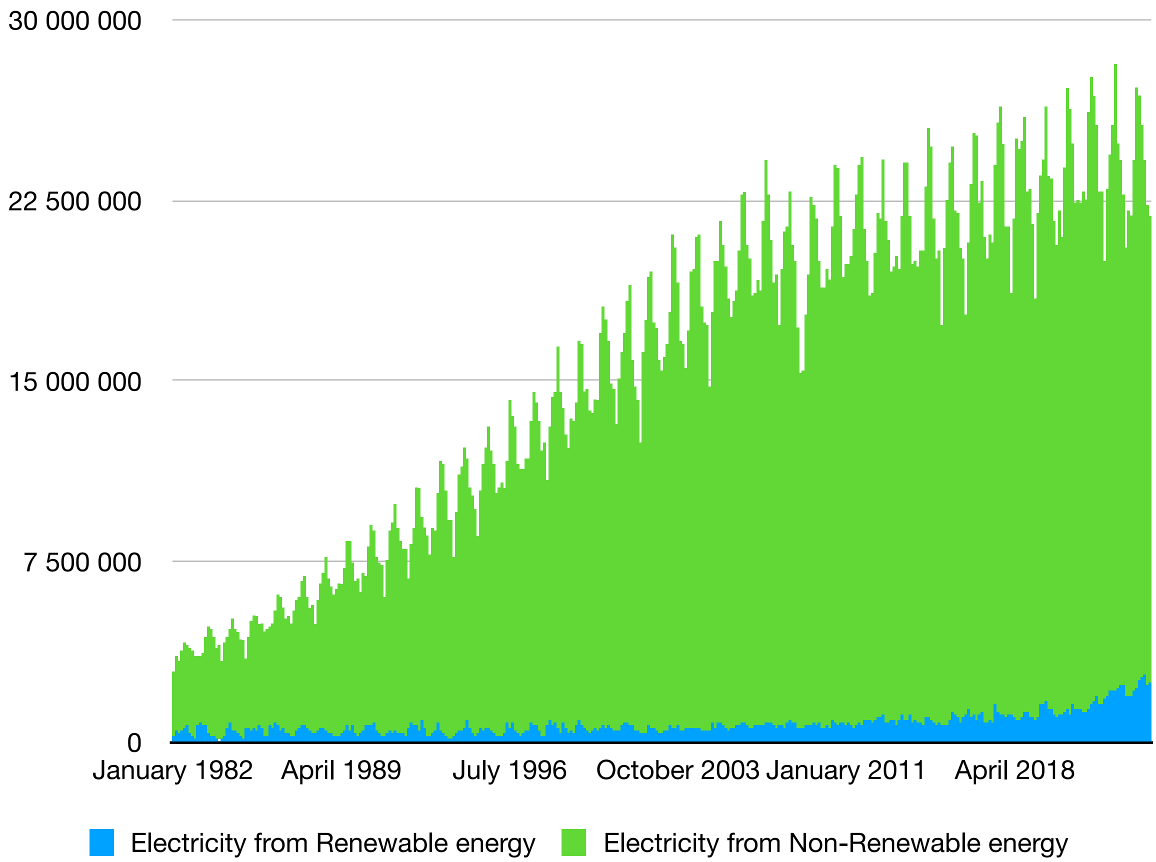


*Figure 2: Electricity production in Taiwan from January 1982 to February 2024(MWh). Source: Taipower*

According to the 2022 Energy Statistical Data Book(MOEA, 2023), electricity production in Taiwan has witnessed a significant increase from January 1982 to February 2024, as indicated by the data in megawatt-hours (MWh). Over this period, there is a noticeable upward trend in electricity generation, reflecting the growing demand for energy in the area. This increase in production is likely driven by various factors such as population growth, industrial development, and technological advancements leading to greater energy consumption. The consistent rise in electricity production underscores the importance of reliable and sustainable energy sources to meet the evolving needs of Taiwan's economy and society.

Despite the overall increase in electricity production, the percentage of renewable energy in Taiwan's energy mix has also been gradually rising but remains relatively low compared to non-renewable sources. While there has been a notable effort to promote renewable energy generation, the proportion of renewable energy in the total electricity production is still far from reaching its desired level. The data indicates a positive trend towards greater reliance on renewable energy sources; however, it underscores the challenges and the long road ahead to achieve Taiwan's renewable energy goals. Continued investment in renewable energy infrastructure, policy support, and public awareness initiatives are crucial to accelerate the transition towards a more sustainable energy future in Taiwan.

### 2.2.2 Renewable energy in Taiwan

Renewable energy in Taiwan has gained increasing attention and significance in recent years as it seeks to transition towards a more sustainable and low-carbon energy future. With ambitious goals and policies in place, Taiwan is actively promoting the development and adoption of renewable energy sources to reduce its reliance on fossil fuels and mitigate environmental impacts.

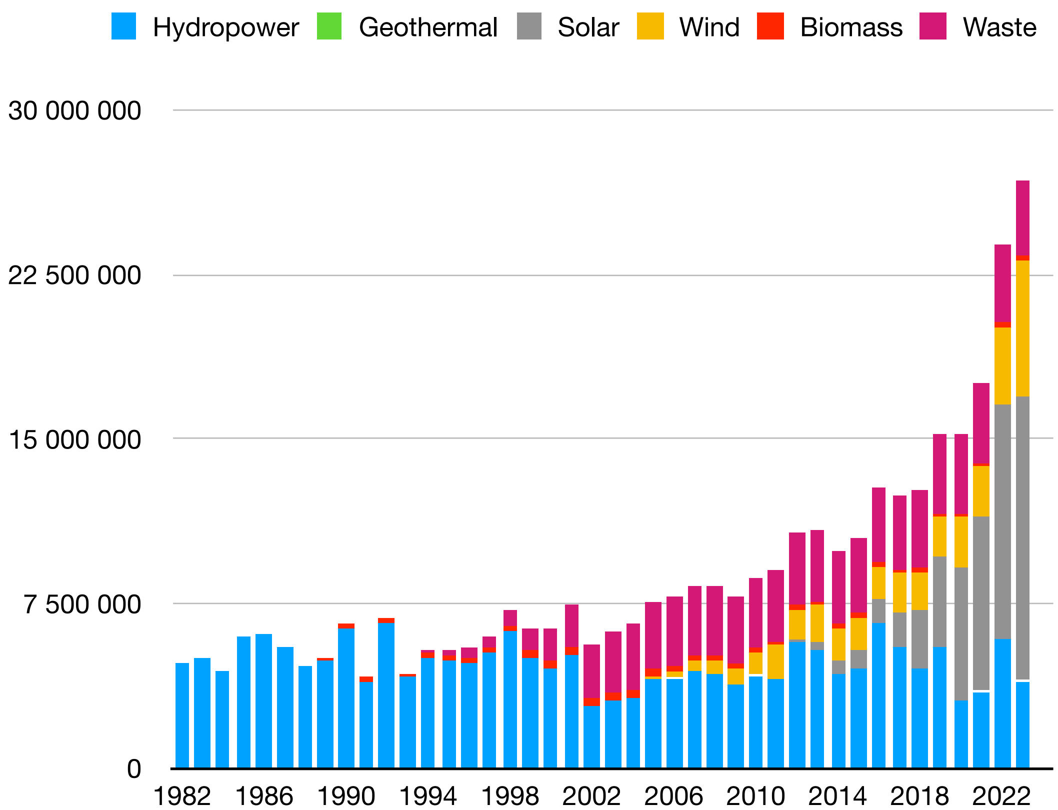


*Figure 3: Renewable energy production in Taiwan.(BOE, 2022)*

Wind energy holds significant promise as a renewable energy source due to the abundant wind resources along Taiwan's west coast, including the influence of Asian monsoons and tropical cyclones in summer and northeast trade winds in winter. However, the development of energy infrastructure projects often faces substantial public resistance, particularly in the case of onshore wind power projects in Taiwan. To navigate these challenges and support the successful growth of green energy, the government is exploring offshore wind power generation. The Ministry of Economic Affairs (MOEA) in Taiwan established the first offshore wind farm in 2015 and by 2030, the goal is to install 600 offshore wind turbines, generating 4,000 MW of power. As a result, the offshore wind market is poised for rapid expansion in Taiwan. (Taipower, 2021)

Solar energy is widely accepted as a major renewable energy source in Taiwan, with no social resistance, unlike wind turbine installations, which have faced protests. (Chang & Lee, 2016) Taiwan boasts excellent solar availability, particularly in southern regions like Tainan and Kaohsiung, with abundant sunshine and high mean annual solar radiation. Additionally, it's the world's second-largest producer of photovoltaic (PV) technology, home to major companies like Neo Solar Power (NSP), MoTech, GinTech, and TSMC Solar. Government support through financial aid and tax incentives further encourages PV production. In 2022, the installed capacity exceeded 2 gigawatts (GW) for the first time in a single year, with a cumulative installed capacity of approximately 9.72 GW by the end of the year, marking a 6.8-fold increase from the 1.25 GW installed in 2016. At the same year, solar energy contributes 44.71% of the total renewable energy electricity output in Taiwan, solidifying its position as the foremost renewable energy source(BOE, 2022).

In addition to solar and wind energy, Taiwan is exploring other renewable energy sources such as hydroelectric, biomass, and geothermal energy. Hydropower, in particular, has been a traditional source of renewable energy in Taiwan, with existing hydropower plants contributing to the country's electricity supply. Biomass energy from agricultural residues and organic waste is also being tapped to generate electricity and heat, further diversifying Taiwan's renewable energy portfolio(Chang & Lee, 2016).

To support the growth of renewable energy in Taiwan, the government has implemented various measures to incentivize investment and facilitate project development. These include financial incentives, tax credits, regulatory support, and streamlined permitting processes. Furthermore, the government has actively promoted research and development initiatives to drive innovation in renewable energy technologies and enhance their efficiency and affordability.

### 2.2.3 RE policies and goals in Taiwan

Taiwan has set ambitious renewable energy (RE) policies and goals aimed at transitioning towards a more sustainable energy landscape. One of the key initiatives is the Taiwan Renewable Energy Development Act, which outlines strategies to achieve a substantial portion of the energy generation from renewable sources. Specifically, the Taiwanese government has targeted to achieve 20% of the total electricity generation from renewable energy sources by the year 2025 (REDA, 2009).

To support the realization of these goals, Taiwan implemented significant reforms in its energy sector. In January 2017, the Amendment of The Electricity Act introduced several mechanisms to facilitate the expansion of renewable energy generation, such as direct supply, wheeling, and a retailer system for renewable energy. One of the notable mechanisms introduced was the establishment of the direct supply and wheeling mechanism. This mechanism enables renewable energy producers to directly supply electricity to end-users or transmit it through the grid to consumers in different locations. It promotes the efficient utilization of renewable energy resources by allowing producers to connect their generation facilities to the grid and deliver electricity to consumers wherever needed. These policy initiatives aim to create a conducive environment for renewable energy investment and deployment while fostering a competitive and sustainable energy market.

### 2.2.4 Regulations about REC in Taiwan

Furthermore, the Amendment of The Electricity Act introduced a retailer system and free trade market for renewable energy. This system allows for the trading of renewable energy among market participants, including producers, retailers, and consumers. It fosters competition and innovation in the renewable energy market while providing consumers with greater choice and access to clean energy options.

Amended in May 1, 2019, Article 12 of the Renewable Energy Development Act outlines requirements for large electricity consumers regarding renewable energy usage and compliance. If the contract capacity exceeds a certain threshold, consumers have two options: either install renewable energy generation equipment and energy storage or purchase a designated amount of renewable energy certificates. Failure to comply will result in monetary substitution to support renewable energy development, with guidelines provided by the central competent authority. This amendment strengthens the regulatory framework for promoting renewable energy adoption among large electricity consumers, aiming to accelerate the transition towards a more sustainable energy sector(REDA, 2019).

Additional details were released in 2020 as part of the Regulations for the Management of Setting up Renewable Energy Power Generation Equipment of Power Users above a Certain Contract Capacity. According to these amendments, large electricity consumers surpassing a capacity of 5000 kW are required to either install renewable energy generation equipment equivalent to 10% of their total capacity or acquire a specified quantity of renewable energy and corresponding certificates(REDA, 2020).

This new regulation imposes a mandatory requirement on companies to either adopt renewable energy sources or purchase Renewable Energy Certificates. This requirement serves as a significant incentive for companies to buy RECs, as it ensures compliance with renewable energy goals. Whether companies opt to install renewable energy infrastructure themselves or procure renewable energy from external sources, possession of RECs is essential to demonstrate adherence to regulatory mandates and fulfillment of renewable energy objectives. It represents a significant step toward promoting renewable energy adoption among major electricity consumers, contributing to the broader goal of transitioning to a more sustainable energy landscape. This law effectively changed Taiwan's REC market, transitioning it from a voluntary to a partially compliant REC market.

## 2.3 I-RECs (The International Renewable Energy Certificates)

### 2.3.1 Definition

The international REC standard (I-REC)[2] expands this concept globally, providing an Energy Attribute Certificate (EAC) for electricity, detailing its production specifics. I-RECs facilitate various voluntary reporting and end-user claims, allowing informed, evidence-based choices for electricity in countries with accredited service providers, supporting global renewable energy adoption.

Headquartered in the Netherlands, the International REC Standard Foundation (I-REC Standard) is a non-profit organization dedicated to establishing a robust standard for attribute tracking systems worldwide, with a particular focus on developing countries. Recognized by leading reporting frameworks like the Greenhouse Gas Protocol (GHGP), Carbon Disclosure Project (CDP), and RE100, the I-REC Standard serves as a dependable foundation for credible and auditable tracking instruments (The I-REC Standard, 2022).

The international Renewable Energy Certificate (I-REC) standard is a globally recognized mechanism for tracking and trading renewable energy attributes. I-REC serves as a standardized certification system, allowing renewable energy producers to create, trade, and retire certificates representing the environmental benefits associated with their renewable energy generation.

### 2.3.2 Details about how I-REC market works

Similar to national-level REC programs, I-REC certifies the environmental attributes of renewable energy generation, such as solar, wind, hydroelectric, biomass, and geothermal power. These certificates provide evidence that a certain amount of electricity has been generated from renewable sources and fed into the grid.

The I-REC certification follows standardized procedures and criteria, ensuring consistency and transparency in the certification process. It provides assurance to buyers and stakeholders that the renewable energy attributes represented by the certificates are genuine and accurately reflect the environmental benefits of renewable energy generation.

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[2] https://www.trackingstandard.org/the-standard/

The geographical scope of the I-REC market is global, allowing for transactions between buyers and sellers across different regions and countries. I-RECs can be claimed internationally if the country generating the electricity is connected to the buyer's country's grid. (Karestree & Mangmeechai, 2023) This global approach enables flexibility in supporting renewable projects worldwide and promotes the international development of renewable energy.

One of the key features of the I-REC market is its geographic scope. Certificates issued in the I-REC market can typically be used across participating countries or regions. This means that renewable energy producers in one country can generate certificates for their renewable energy generation and sell them to consumers or entities in other countries. This international dimension of the I-REC market allows for the seamless transfer of renewable energy attributes across borders and facilitates cross-border renewable energy transactions.

In terms of validity, the duration for which I-REC certificates can be used varies depending on the specific regulations and guidelines of the market or jurisdiction in which they are issued. Generally, I-REC certificates have a finite validity period, after which they may need to be renewed or reissued to remain valid. The validity period ensures that the renewable energy attributes associated with the certificates accurately reflect the renewable energy generation from which they originate and helps maintain the integrity of the I-REC market.

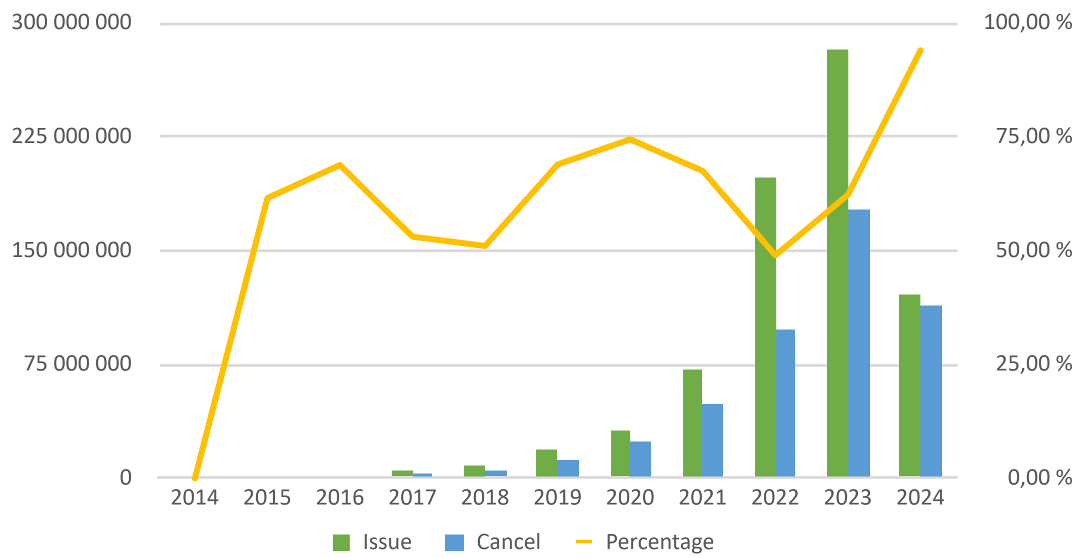



*Figure 4: Issuance and cancellation of I-RECs (Global). Source: I-REC*

In the analysis of renewable energy certificates (RECs), three key dates are typically associated with each certificate: the time of energy generation, the time of issuance, and the time of trade. For analytical purposes, the issuance and cancellation dates are often utilized. This choice is motivated by several factors. Firstly, energy production timestamps usually indicate the year of production rather than the exact date, making monthly data more accessible for the other two dates. Secondly, focusing on issuance and cancellation dates enables a clearer understanding of the behavior of energy producers and REC consumers.

However, it's important to note that there can be a time discrepancy between these dates. In instances where RECs are generated for self-use or have prearranged agreements, it's feasible for energy production, REC issuance, and cancellation to occur on the same day. Yet, in most cases, the issuance occurs subsequent to energy production, and cancellation follows issuance. Consequently, within a self-contained REC market or one isolated from external trades, it's plausible to observe more cancellations than issuances within a specific timeframe, such as one year.

The issuance and redemption of I-RECs began in 2014, marking the inception of this global system for verifying and trading renewable energy attributes. The issuance of I-RECs increased from 121,890 in 2014 to 245,736,921 in 2022, reflecting a substantial rise in global renewable energy generation and certification. Similarly, the redemption of I-RECs surged during this period, reaching 144,368,183 in 2022 before declining to 39,882,487 in 2023. Despite fluctuations, the redemption percentage remained relatively stable, indicating consistent utilization of I-RECs as a mechanism for verifying and trading renewable energy attributes on a global scale.

### 2.3.4 The I-REC market in Taiwan

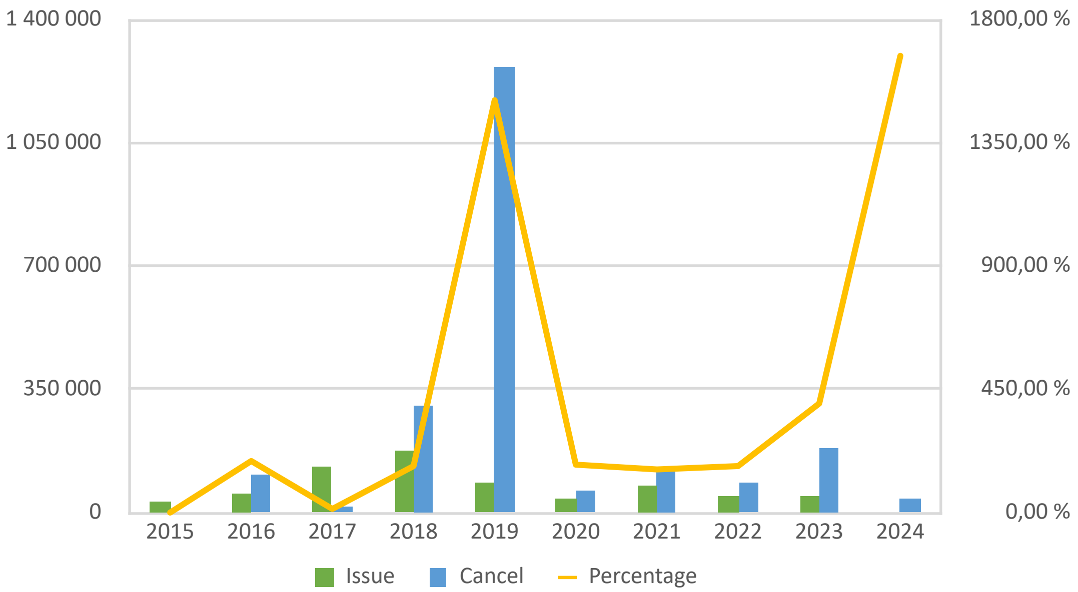



*Figure 5: Issuance and cancellation of I-RECs (Taiwan). Source: I-REC*

The I-REC market in Taiwan has shown dynamic fluctuations over the years, reflecting the evolving landscape of renewable energy adoption. From its inception in 2015, the market demonstrated gradual growth in both issuance and redemption figures. Subsequent years saw varying patterns, with some years experiencing substantial increases in issuance and redemption, while others demonstrated more modest growth or even declines.

Notably, as shown in figure 5, in 2018, the issuance of I-RECs surged to 177,992, marking a significant increase compared to previous years. However, the redemption figure in 2019 skyrocketed to 1,266,643, surpassing the issuance by a considerable margin. The number of canceled I-RECs in Taiwan is 9.87% of the global cancellations, which is incredible for a small market such as Taiwan. Additional information can be found in Appendix A. Primarily, hydropower I-RECs are issued in Taiwan. However, it is noteworthy that various types of I-RECs from other energy sources are canceled in Taiwan, indicating their origin from outside the market.

This phenomenon suggests that more RECs issued outside of Taiwan were canceled within the area, potentially indicating a preference for sourcing renewable energy from international markets. These yearly changes highlight the influence of factors such as policy developments, market incentives, and investment trends on the issuance and redemption of I-RECs in Taiwan.

This increase in redemptions coincides with the implementation of the Renewable Energy Development Act in May 2019. This legislation outlines requirements for large electricity consumers regarding renewable energy usage and compliance, imposing obligations on consumers to either install renewable energy generation equipment or purchase renewable energy certificates. The substantial increase in I-REC cancellations in 2019 is likely correlated with the enforcement of this act, as large consumers sought to meet compliance requirements by redeeming I-RECs. These yearly changes underscore the impact of policy developments on the dynamics of the I-REC market in Taiwan.

## 2.5 T-REC(Taiwan Renewable Energy Certificates)

### 2.5.1 Introduction


*Figure 6: A sample of the Taiwan Renewable Energy Certificate (T-REC). Source: the National Renewable Energy Certification Center*

The Taiwan Renewable Energy Certificates (T-REC) system was initiated in May 2017 with the issuance of the first batch of certificates to eight companies, totaling 268 certificates. Subsequently, in June of the same year, the National Renewable Energy Certification Center (TRECC) was established to oversee certification and accreditation in the renewable energy sector. The TRECC serves as a pivotal institution, setting industry standards and collaborating with stakeholders to develop frameworks for renewable energy development, deployment, and monitoring.

From 2017 to 2023, Taiwan experienced a substantial increase in T-REC issuance, reflecting growing adoption of renewable energy. Solar and wind sources dominated, with issuance peaking in 2022 at over 1.1 million T-REC.

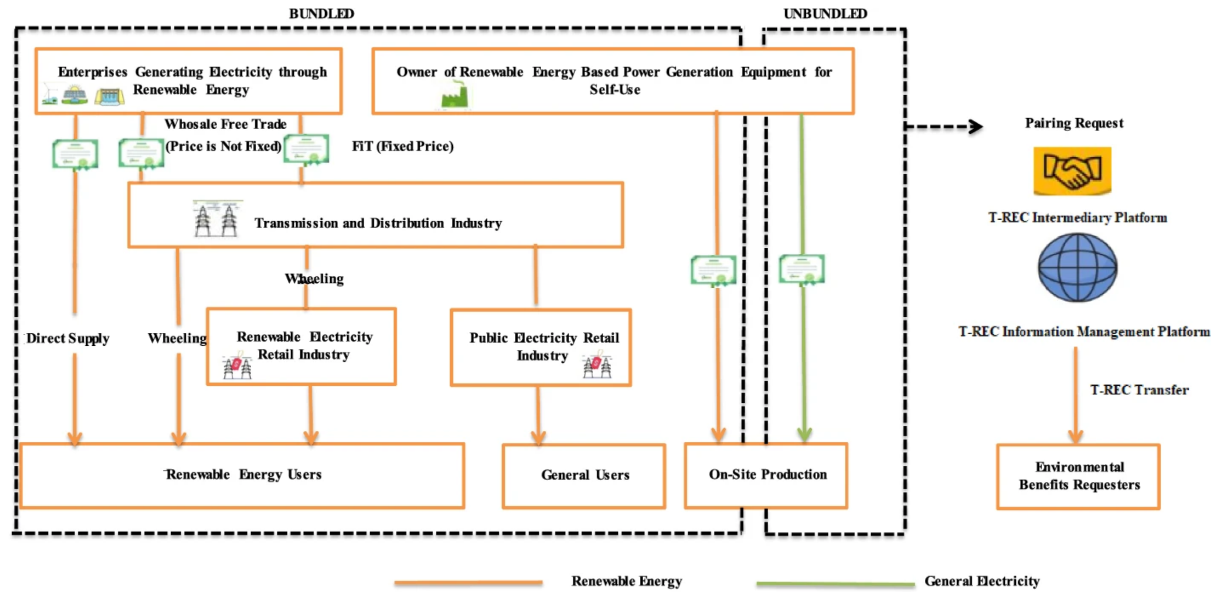



*Figure 7: T-REC mechanism (Chen, 2018)*

Figure 7 depicts the current T-REC transfer models. In the direct supply of renewable energy power model, the power generation company requests T-REC from the REC center, pays the application fee, and subsequently delivers green electricity with T-REC proof. Alternatively, in the wheeling method where users and the electricity industry sign a contract, the power generation company applies for T-REC via the REC center, pays the application fee, and then supplies green electricity with T-REC proof. Lastly, in the renewable power generation equipment for personal consumption model, renewable energy power generated for personal use can apply for T-REC and potentially sell the environmental benefits to those in demand through a T-REC broker.

Chen (2018) also pointed that the demand scenario for the Voluntary Renewable Energy Market in Taiwan indicates that current T-REC applicants predominantly hail from the ICT industry and the finance & insurance sectors. If these sectors, along with public services, escalate their renewable energy usage by 1% annually, projections suggest that by 2027, renewable energy adoption could exceed 10%. Based on this trend, it's estimated that Taiwanese enterprises will incrementally demand an additional 0.5 billion kWh of renewable energy each year, potentially resulting in a yearly increase of 500,000 T-REC issuances.

### 2.5.3 PPA

Power Purchase Agreements (PPAs) have gained traction in Taiwan's renewable energy sector as a means of promoting investment and development. These agreements typically involve a contract between a renewable energy developer and a utility or large consumer, stipulating terms for electricity purchase at agreed-upon rates. In Taiwan, PPAs play a crucial role in facilitating the expansion of renewable energy projects, particularly in solar and wind energy. They provide financial stability and incentivize investment, contributing to the efforts to transition towards a more sustainable and diversified energy mix.

Before introducing T-REC, companies had limited options for purchasing renewable energy, mainly relying on I-RECs or the state-run Taiwan Power Company (Taipower). However, even when purchasing through Taipower, the lack of proper documentation meant that the details of each kWh of green energy couldn't be internationally accredited. This was because the certificates lacked specific information about the source of the renewable energy, making it impossible to verify repeated purchases or identify the originating power plant. With the implementation of the T-REC system, the availability of renewable energy options expanded significantly. Now, users have the flexibility to purchase T-RECs and RECs along with green energy, offering a more comprehensive solution for renewable energy procurement(Senturk & Ozcan, 2023).

### 2.5.4 Development

The TREC system consisted of two types: Self-use and Direct Supply and Wheeling. In the Self-use model, renewable energy producers consumed the energy they generated without connecting it to the grid. This meant that they did not need to rely on grid infrastructure for energy distribution. During the early stages of the TREC system, spanning from 2017 to 2019, only Self-use TRECs were issued. However, during this period, the number of TRECs issued was relatively low, and the cancellation rate consistently reached 100%, indicating a lack of active market participation. Companies primarily utilized TRECs as proof of their renewable energy usage rather than engaging in market transactions.

The actual performance of T-REC did not meet the initial expectations and remained low during the initial years of implementation. This phenomenon can be attributed to several factors. Firstly, the online certificate trading platform was still in its testing phase, which led to a lack of a proper platform for negotiation between certificate sellers and buyers. This inconvenience reduced the incentive for engagement in certificate trading activities. Secondly, due to the absence of a fully operational trading platform, companies generating renewable energy tended to retain their certificates to fulfill their own requirements rather than selling them on the market. Lastly, a significant portion of green electricity, particularly from solar PV sources, was procured by the Taipower Company. The inability of renewable energy generation companies to terminate their contracts with Taipower, as stipulated by Power Purchase Agreements (PPAs), prevented them from selling their green electricity on the open market or providing T-REC certificates. These factors collectively contributed to the low market dealing rate of T-REC during the initial years.

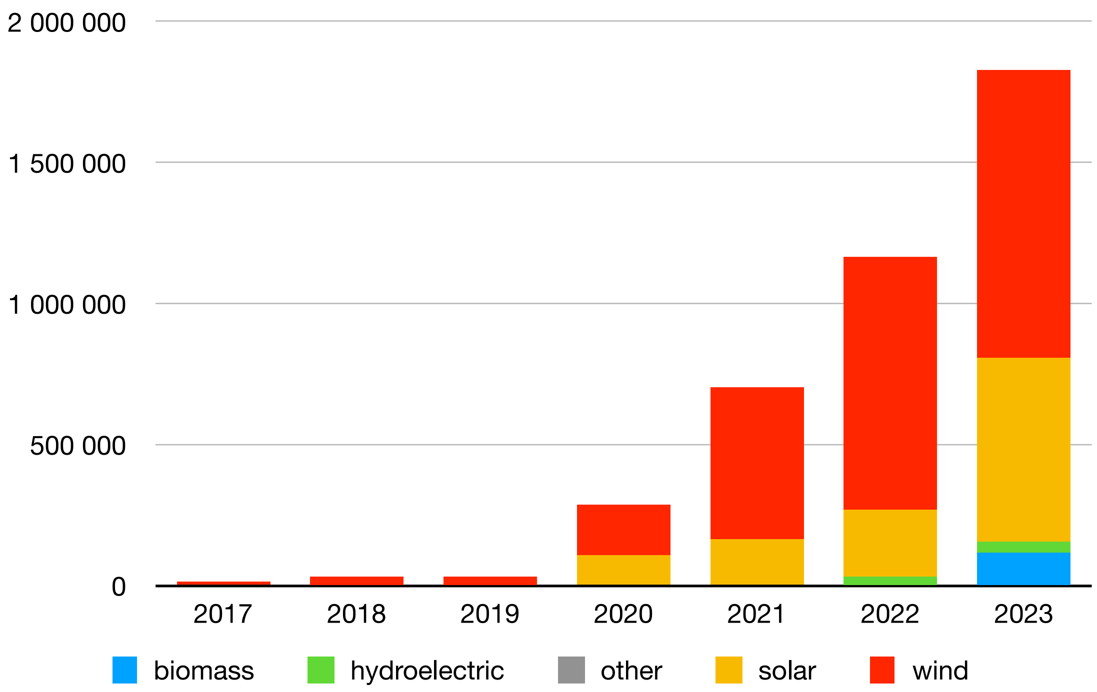



*Figure 8: Issued TRECs from different energy types. Source: the National Renewable Energy Certification Center*

Figure 8 illustrates that the issuance volume of TRECs was notably low, potentially contributing to the high cancellation of I-RECs in 2019. This scenario underscores the absence of alternative solutions to fulfill renewable energy usage requirements aside from procuring from the international market.

Following 2020, there was a notable shift towards Direct Supply and Wheeling, where renewable energy producers connected their energy to the grid for distribution. During this period, TREC consumers had the option to purchase RECs from producers privately or from the official TRECC platform. Despite the continued increase in Self-use RECs year by year, the influx of renewable energy producers applying for RECs resulted in a significant rise in Direct Supply and Wheeling RECs. As a result, the number of Direct Supply and Wheeling RECs surpassed that of Self-use RECs, reflecting a trend towards greater participation in the renewable energy market and a move towards grid-connected energy distribution in Taiwan. Till March 2024, in total 4,580,608 TRECs have been issued. In addition to volume considerations, the predominant types of TRECs are identified to be wind and solar.

The risk of double counting emissions reductions poses a significant challenge to global efforts to combat climate change. This phenomenon occurs when the same reduction in greenhouse gas emissions is counted more than once, leading to an overestimation of actual emission reductions achieved (Schneider et al., 2019). In the context of renewable energy, the issue of double counting arises when energy producers sell International Renewable Energy Certificates (I-RECs) internationally while still claiming the associated renewable energy attributes domestically.

TRECs could offer a local solution to address the problem of double counting. By implementing a jurisdiction-based approach, TRECs ensure that each unit of renewable energy is accounted for only once within Taiwan's energy market. This reduces the risk of double counting by establishing clear boundaries for renewable energy attribution and preventing the same environmental benefit from being claimed multiple times across different jurisdictions.

# 3. Literature review

## 3.1 Relevant research about Taiwan REC market

Limited research has been conducted on the Taiwan REC market, with only a few studies mentioning it as background information. For instance, Chang & Lee (2016), Hung(2020), Chou&Chen (2021), Tsai(2023) mentioned TREC in the study of renewable energy in Taiwan. Hung(2020) uses desk research and interviews to find out how two different renewable energy strategies, T-REC is one of them, influence the expansion of renewable energy in Taiwan. However TREC system has only been introduced to the market in 2017, so it is still in an early stage, and the relevant regulation and trading system have not yet been fully established. The author claims that the current operation and structure in Taiwan's electricity market is in between a "regulated market" and a "deregulated market".

Although the primary focus is on Turkey, Senturk & Ozcan ( 2023) discussed TREC in Taiwan as an example of a national REC mechanism. The study highlights a gradual transition from I-REC to T-REC certificates in Taiwan, indicating evolving user preferences.

Additionally, Chuang et al. (2018) use several simplified scenarios to illustrate the advantage of implementing a trackable REC system to avoid the "free-rider effect" in the electricity market and the proper accounting mechanism for the inclusion of onsite installations of renewable energy to eliminate the "outsider effect". Still, in its early phase of implementing a REC instrument to reach the GHG emission reduction goal, Taiwan has a chance for successful transition from the existing fossil fuel-rich energy portfolio to a low-carbon one, through reforming its energy infrastructure and introducing incentive-driven policies. Therefore, this paper also provides constructive recommendations to the policy-makers on the deployment of the REC system. Other than that, Chuang et al. (2019) conducted a comparative analysis of climate market mechanisms across different regions, including China, Japan, and Taiwan. They highlighted TRECs as a solution to existing loopholes. Previously, the integration of "green" and "traditional" electricity into a unified power grid posed challenges for end users legally obligated to purchase green electricity. These users, connected to Taiwan's power grid, faced difficulties in verifying the amount of green electricity purchased to meet business requirements or regulatory demands. However they noticed by May 2018, a total of 29,339 T-RECs had been issued, while only 448 certificates had been traded, indicating a significant gap between issuance and market activity.

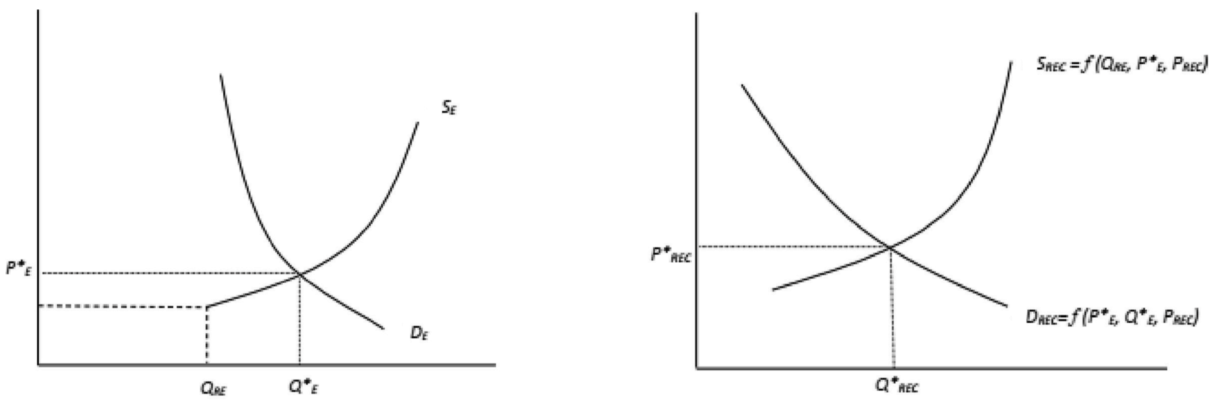
Although the sample size was small and the research was not specifically focused on the REC market itself, the only study I could locate that included REC transaction details in Taiwan was conducted by Chung et al. (2024). They investigated the effect of REC purchases on the stock return and volume of all REC buyers in Taiwan between 2017 and 2021. The sample consisted of 266 REC transactions in the trading market. They found a positive effect of firms' REC purchases on their stock returns in manufacturing but not in the service industry. Moreover, the frequency of REC purchases was an important factor in the relationship between REC purchase and firm value. This study also investigated the underlying mechanisms of these effects. It was found that public attention paid to environmental pollution was the most crucial factor associated with positive stock return and volume of a firm, while ESG disclosure was negatively associated with returns and volume.

In summary, despite the growing importance of renewable energy and the introduction of the Taiwan REC (TREC) system in 2017, comprehensive research solely dedicated to analyzing the dynamics of the REC market in Taiwan is notably scarce. While various studies have referenced T-REC as part of broader investigations into renewable energy adoption, policy impacts, and market mechanisms, there has been a lack of in-depth exploration focused solely on the REC market itself.

## 3.2 Relevant research about REC market in general

### 3.2.1 Theoretical studies

The conventional method of analyzing demand and supply can be utilized to establish the connection between REC and electricity markets.(Jensen & Skytte, 2002)




*Panel A:* Electricity market          *Panel B:* REC market

*Firgure 9:Link between electricity market and REC market. Irfan(2021).*

Panel A illustrates the model for determining the equilibrium wholesale electricity price ($P_{*E}$) in the electricity market. This model showcases how $P_{*E}$ and $Q_{*E}$ (the traded volume of electricity) are established by the intersection of $D_E$ (electricity demand) and $S_E$ (electricity supply) in the market at a given point in time. The addition of electricity generated from renewable resources to the electricity mix is denoted by $Q_{RE}$, contributing to the overall supply.

Panel B demonstrates that the demand for REC ($D_{REC}$) is relatively more elastic than $D_E$, as it depends on factors such as $P_{*E}$, $Q_{*E}$, and the price of REC ($P_{REC}$). (Adamczyk & Graczyk, 2020) Specifically, changes in wholesale electricity prices are expected to affect the demand for REC because higher (lower) $P_{*E}$ discourages (encourages) the purchase of REC. (Lemming, 2003)

An increase (decrease) in $Q_{*E}$ correlates with higher (lower) demand for REC to fulfill the mandatory renewable purchase obligation established by the government. (Goyal & Jha, 2009) The REC price ($P_{REC}$) significantly influences $D_{REC}$, showing an inverse relationship.

The quantity of REC supplied ($S_{REC}$) is impacted by the amount of electricity generated from renewable resources ($Q_{RE}$). While physical electricity is sold in the electricity market, the corresponding REC is traded in the REC market.

The connections between REC and electricity markets imply the potential for a long-run equilibrium or cointegrating relationship between $Q_{*REC}$ and its underlying factors, such as $P_{*E}$, $Q_{*E}$, and $P_{*REC}$(Irfan, 2021). Specifically, disturbances in any of these factors are anticipated to lead to adjustments in the traded volume of REC, nudging it towards its long-term equilibrium position.

### 3.2.2 Empirical studies

Several studies have contributed to understanding the dynamics of renewable energy certificate (REC) markets and their interaction with electricity markets.

Hustveit, et al. (2017) focused on the Swedish-Norwegian electricity certificate market and observed that REC prices are highly responsive to changes in electricity consumption and generation. Similarly, Jensen & Skytte (2002) utilized a static model to analyze both electricity and green certificate markets, revealing that electricity production and prices, along with REC prices, play crucial roles in influencing REC market dynamics.

Girish et al. (2015) examined the performance of REC markets, highlighting the impact of renewable purchase obligations and the long-term REC price on market behavior. In the Indian context, Irfan (2021) conducted an empirical investigation into the integration between electricity and REC markets. Using an autoregressive distributed lag (ARDL) modeling approach, the study found that factors such as the traded volume of electricity, wholesale electricity price, and REC prices significantly influence the traded volume of solar and non-solar RECs in India. The findings suggest avenues for strengthening the REC market in the country.

Additionally, Gupta & Purohit (2013) assessed the effectiveness of the REC mechanism in promoting renewable energy in India. By analyzing various data on renewable energy policy, renewable purchase obligation (RPO) standards, REC market dynamics, and renewable energy development statistics, the study highlighted challenges such as higher REC prices compared to average feed-in tariffs and the concentrated nature of registered capacity in certain states. The study emphasized the importance of refining the functioning of the REC market in India to enhance its effectiveness.

In contrast, Schusser & Jaraite (2018) found that electricity prices have no significant effect on REC prices, suggesting a nuanced relationship between electricity market dynamics and REC pricing.

These studies collectively contribute to a better understanding of REC market dynamics and provide insights into policy measures to enhance the effectiveness of REC mechanisms in promoting renewable energy adoption.

### 3.4 Research gap

This study identifies a multifaceted research gap within the landscape of Taiwan's REC market. Firstly, despite encountering challenges in accessing historical REC price data, alternative avenues such as REC issuance and cancellation volume data have been largely overlooked in existing literature. This presents an opportunity to delve into the often-neglected dynamics of REC volumes and their potential implications for market behavior and policy formulation in the Taiwanese context.

Moreover, an intriguing gap emerges concerning the prevalence of dual REC systems operating within a single geographical area. While Taiwan's situation shares similarities with other markets, such as mainland China or India, where local REC systems coexist alongside international ones due to limited awareness overseas. Investigating the interactions and dynamics between these two systems could offer valuable insights into the functioning of similar setups in global markets, providing a comparative perspective on REC market structures.

Lastly, the influence of different energy sources, business sectors, and energy indexes on REC systems is an underexplored facet. The literature lacks a comprehensive understanding of how various energy sources and sectors interact with REC markets, hindering insights into market dynamics, pricing mechanisms, and the effectiveness of renewable energy policies.

This thesis aims to bridge these gaps by offering empirical insights into REC volume dynamics, exploring the intricacies of Taiwan's dual REC system in a comparative context, and shedding light on the influence of energy sources and sectors on Taiwan's REC markets. Through these explorations, the study aims to contribute substantively to the understanding of Taiwan's REC market dynamics and their broader implications for renewable energy development and sustainability efforts in the region.

## 4. Research questions and hypotheses

My research questions are structured to elucidate key relationships within the electricity and REC markets in Taiwan. Hypotheses formulated under these questions aim to uncover the intricate connections between electricity production and REC supply, as well as between electricity consumption and REC demand. By dissecting these relationships, I seek to gain a deeper understanding of the driving forces behind REC market dynamics in Taiwan.

Furthermore, my investigation extends to exploring the relationship between I-REC and T-REC in Taiwan. I hypothesize that in the long run, I-REC and T-REC are correlated, and that the introduction of T-REC may have a negative effect on I-REC. Through rigorous analysis and empirical inquiry, I endeavor to unravel the complexities of this relationship and its implications for the REC market ecosystem in Taiwan.

### Q1: What's the relationship of the electricity market and REC market in Taiwan?

Hypotheses:

**1.1 Electricity production is correlated to REC supply.**

1.1.1 The total electricity production is correlated to REC supply.

1.1.2 The electricity production from green energy is correlated to REC supply.

1.1.3 The electricity production from certain source of green energy is stronger correlated to REC supply.

1.1.4 The electricity production from non-green energy is correlated to REC supply.

1.1.5 The electricity production from certain source of non-green energy is stronger correlated to REC supply.

**1.2 Electricity consumption is correlated to REC demand.**

1.1.1 The total electricity consumption is correlated to REC demand.

1.1.2 The electricity consumption from certain sector is stronger correlated to REC demand.

1.1.3 The electricity consumption is stronger correlated to REC demand of certain source.

### Q2: What's the relationship of I-REC and T-REC in Taiwan?

Hypotheses:

2.1 In long-run I-REC and T-REC are correlated.

2.2 The introduce of T-REC had negative effect on I-REC.

# 5. Data and methodology

## 5.1 Data

### 5.1.1 Electricity data

Monthly electricity production and consumption data from 1982 January to 2024 February. The data source is Energy Administration, Ministry of Economic Affairs[3] in Taiwan.

### 5.1.2 I-REC data

Monthly I-REC insurance and cancellation data from 2015 to 2024 February. The data source is 2024 I-REC(E) Market Statistics[4].

### 5.1.3 TREC data

Monthly T-REC insurance and cancellation data from 2017 to 2024 February. The data source is the National Renewable Energy Certification Center[5].

## 5.2 Regression models

In this study, regression models will serve as the cornerstone of our analytical approach, allowing us to delve into the intricacies of the REC market dynamics in Taiwan. By employing panel data analysis, we aim to harness the robustness of this method, which is well-suited for handling longitudinal data spanning multiple time periods and entities. This approach enables us to conduct a comprehensive examination of trends over time and across various market segments within the REC landscape.

To capture the potential impact of past volumes on present volumes, I will integrate time lags into our regression models. This innovative approach affords us the opportunity to explore how previous volumes may influence current volumes, providing invaluable insights into the underlying dynamics driving the I-REC and T-REC markets in Taiwan.

[3] Energy Administration, Ministry of Economic Affairs in Taiwan https://www.esist.org.tw/

[4] 2024 I-REC(E) Market Statistics https://www.trackingstandard.org/resource/2024-i-rece-market-statistics-january/

[5] The National Renewable Energy Certification Center https://www.trec.org.tw/en/news

## 5.3 AI utilization

In my thesis, I plan to utilize AI tools, including ChatGPT, for grammar and language accuracy checks. This will aid in ensuring clarity and correctness in my writing.

Utilizing AI tools, particularly ChatGPT, within the framework of my thesis serves a twofold purpose. Firstly, incorporating AI facilitates grammar and language accuracy checks, thereby enhancing the overall quality of the written content. By leveraging ChatGPT's language processing capabilities, I can ensure that my writing maintains a high level of clarity and correctness, crucial aspects in academic discourse.

Moreover, the integration of AI tools such as ChatGPT aligns with contemporary research practices, reflecting a commitment to leveraging cutting-edge technologies to enhance research outcomes. By harnessing the power of AI, I can streamline the editing and proofreading process, freeing up valuable time and resources that can be allocated to other aspects of the research endeavor.

Furthermore, the utilization of AI underscores a forward-thinking approach to scholarly inquiry, embracing innovative methodologies to optimize research productivity and efficacy. By embracing AI tools in the writing process, I aim to not only enhance the quality of my thesis but also contribute to the broader discourse surrounding the intersection of technology and academia.

# 6. Results and discussion

## 6.1 Electricity production & REC supply

This regression analysis explores the relationship between the issuance of TRECs/I-RECs and different sources of electricity generation in Taiwan. The model considers electricity generation from pumped storage hydro, coal, oil, gas, nuclear, hydropower, geothermal, solar, wind, biomass, and waste as predictors of TREC issuance.

### 6.1.1 I-RECs and electricity production

| Predictor | Coefficient | Std. Error | t-value | P-value | 95% Conf. Interval (Lower) | 95% Conf. Interval (Upper) |
|---|---|---|---|---|---|---|
| Pumped Storage Hydroelectricity | -0.0368399 | 0.0907703 | -0.41 | 0.686 | -0.217144 | 0.1434642 |
| Coal Electricity | 0.0009813 | 0.0020157 | 0.49 | 0.628 | -0.0030227 | 0.0049853 |
| Oil Electricity | -0.0110083 | 0.0076445 | -1.44 | 0.153 | -0.0261932 | 0.0041767 |
| Gas Electricity | -0.0012097 | 0.002003 | -0.60 | 0.547 | -0.0051884 | 0.002769 |
| Nuclear Electricity | -0.0118507 | 0.0037462 | -3.16 | 0.002 | -0.0192921 | -0.0044093 |
| Hydropower Electricity | 0.0075126 | 0.0081526 | 0.92 | 0.359 | -0.0086815 | 0.0237067 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Geothermal Electricity | -1.256438 | 3.916179 | -0.32 | 0.749 | -9.035446 | 6.52257 |
| Solar Electricity | -0.0132162 | 0.0111383 | -1.19 | 0.238 | -0.0353411 | 0.0089086 |
| Wind Electricity | -0.0125338 | 0.0139351 | -0.90 | 0.371 | -0.0402142 | 0.0151467 |
| Biomass Electricity | 0.1446754 | 0.3115403 | 0.46 | 0.643 | -0.4741611 | 0.7635118 |
| Waste Electricity | 0.038442 | 0.0630946 | 0.61 | 0.544 | -0.0868877 | 0.1637717 |
| Intercept | 43052.83 | 25336.08 | 1.70 | 0.093 | -7274.182 | 93379.85 |

*Table 1: I-RECs and electricity production*

The findings illuminate the connection between electricity production and the supply of I-RECs in Taiwan, which directly addresses the primary research question (Q1): What's the relationship of the electricity market and REC market in Taiwan?

Specifically, the analysis examines the correlation between electricity production and REC supply, encapsulated within Hypothesis 1.1. The hypothesis posits that electricity production is indeed correlated with REC supply, reflecting the intrinsic link between energy generation and the availability of renewable energy certificates.

The results reveals that the combined electricity generation sources have a modest explanatory power in predicting I-REC issuance, with an overall model that is marginally significant ($F(11, 91) = 1.74$, $p = 0.0762$). However, the coefficient of determination (R-squared) indicates that only approximately 17.4% of the variation in I-REC issuance is explained by the included predictors.

Among the individual predictors, only electricity generation from nuclear emerges as a statistically significant predictor of I-REC issuance, with a negative coefficient of -0.0119 ($p = 0.002$). This suggests that an increase in nuclear-generated electricity is associated with a decrease in I-REC issuance in Taiwan.

Other electricity generation sources, including coal, oil, gas, hydropower, solar, wind, biomass, and waste, do not exhibit statistically significant relationships with I-REC issuance in this model. The coefficients for these predictors are small in magnitude and not statistically different from zero, indicating that they have little influence on I-REC issuance in Taiwan.

The overall fit of the model is relatively weak, with an R-squared value of 0.1741 suggesting that the included predictors explain only a small proportion of the variation in I-REC issuance.

### 6.1.2 TRECs and electricity production

| Predictor | Coefficient | Std. Error | t-value | P-value | 95% Conf. Interval (Lower) | 95% Conf. Interval (Upper) |
|---|---|---|---|---|---|---|
| Pumped Storage Hydroelectricity | 0.1948567 | 0.1880925 | 1.04 | 0.303 | -0.1787659 | 0.5684793 |
| Coal Electricity | 0.0006752 | 0.004177 | 0.16 | 0.872 | -0.0076218 | 0.0089722 |
| Oil Electricity | 0.0415512 | 0.0158409 | 2.62 | 0.010 | 0.0100853 | 0.0730171 |
| Gas Electricity | -0.0100005 | 0.0041505 | -2.41 | 0.018 | -0.018245 | -0.0017559 |
| Nuclear Electricity | -0.0039248 | 0.0077629 | -0.51 | 0.614 | -0.0193448 | 0.0114952 |
| Hydropower Electricity | 0.0265326 | 0.0168936 | 1.57 | 0.120 | -0.0070245 | 0.0600897 |
| Geothermal Electricity | 1.369839 | 8.11503 | 0.17 | 0.866 | -14.74967 | 17.48935 |
| Solar Electricity | 0.1086893 | 0.0230805 | 4.71 | 0.000 | 0.0628426 | 0.154536 |
| Wind Electricity | 0.2291042 | 0.0288761 | 7.93 | 0.000 | 0.1717453 | 0.2864631 |
| Biomass Electricity | -0.1430337 | 0.6455677 | -0.22 | 0.825 | -1.425375 | 1.139307 |
| Waste Electricity | 0.0601371 | 0.1307435 | 0.46 | 0.647 | -0.1995687 | 0.319843 |
| Intercept | -94561.01 | 52500.94 | -1.80 | 0.075 | -198847.7 | 9725.663 |

*Table 2: T-RECs and electricity production*

The findings illuminate the connection between electricity production and the supply of T-RECs in Taiwan, which directly addresses the primary research question (Q1): What's the relationship of the electricity market and REC market in Taiwan?

Specifically, the analysis examines the correlation between electricity production and REC supply, encapsulated within Hypothesis 1.1. The hypothesis posits that electricity production is indeed correlated with REC supply, reflecting the intrinsic link between energy generation and the availability of renewable energy certificates.

The results indicate that the combined electricity generation sources significantly explain the variation in TREC issuance, with a statistically significant F-statistic ($F(11, 91) = 39.82$, $p < 0.0001$) suggesting that the model as a whole is significant. The analysis reveals varying degrees of influence among the different electricity generation sources.

Electricity generation from oil and gas emerges as statistically significant predictors of TREC issuance, with positive coefficients of 0.0416 and 0.0100, respectively. This suggests that an increase in electricity generation from these fossil fuel sources corresponds to a rise in TREC issuance. Conversely, electricity generation from wind and solar stands out as particularly influential factors, with significant positive coefficients of 0.2291 and 0.1087, respectively. This implies that the expansion of wind and solar energy generation significantly drives TREC issuance in Taiwan.

Notably, certain electricity generation sources, such as coal, nuclear, and biomass, do not exhibit statistically significant relationships with TREC issuance in this model. Additionally, the coefficient for electricity generation from geothermal sources, while positive, is not statistically significant. These findings underscore the varied impact of different energy sources on TREC issuance and highlight the growing importance of renewable energy sources like wind and solar in Taiwan's transition towards sustainable energy.

Overall, the regression model demonstrates a strong fit, with an R-squared value of 0.828 indicating that approximately 82.8% of the variation in TREC issuance is explained by the combined electricity generation sources included in the model.

## 6.2 Electricity consumption & REC demand

### 6.2.1 I-RECs and electricity consumption

Regression Model 1: Total Electricity Consumption

| Predictor | Coefficient | Std. Error | t-value | P-value | 95% Conf. Interval (Lower) | 95% Conf. Interval (Upper) |
|---|---|---|---|---|---|---|
| Total Electricity Consumption | -0.0119479 | 0.004178 3 | -2.86 | 0.005 | -0.0202365 | -0.0036593 |
| Intercept | 288617.6 | 94043.81 | 3.07 | 0.003 | 102059.9 | 475175.2 |

*Table 3: I-REC cancellation and total electricity consumption*

Regression Model 2: Breakdown of Electricity Consumption

| Predictor | Coefficient | Std. Error | t-value | P-value | 95% Conf. Interval (Lower) | 95% Conf. Interval (Upper) |
|---|---|---|---|---|---|---|
| Industrial Electricity Consumption | -0.0272353 | 0.0153378 | -1.78 | 0.079 | -0.0576807 | 0.0032101 |
| Residential Electricity Consumption | 0.0195091 | 0.0268071 | 0.73 | 0.469 | -0.0337025 | 0.0727208 |
| Service Industry Electricity Consumption | -0.0782933 | 0.044971 | -1.74 | 0.085 | -0.1675601 | 0.0109734 |
| Transportation Electricity Consumption | 1.020567 | 0.9220927 | 1.11 | 0.271 | -0.8097724 | 2.850907 |
| Energy Sector Self-use Electricity Consumption | 0.1244761 | 0.1196369 | 1.04 | 0.301 | -0.1130013 | 0.3619534 |
| Agricultural Electricity Consumption | -0.0044146 | 0.7910008 | -0.01 | 0.996 | -1.574539 | 1.56571 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Intercept | 255611.1 | 148286.6 | 1.72 | 0.088 | -38735.45 | 549957.6 |

*Table 4: I-REC cancellation and electricity consumption breakdowns*

The results offer insight into the interplay between electricity production and the availability of I-RECs within Taiwan's energy landscape, squarely addressing the central research question (Q1): What's the relationship of the electricity market and REC market in Taiwan?

In particular, the analysis delves into the correlation between electricity consumption and the demand for I-RECs, as outlined in Hypothesis 1.2, which posits that electricity consumption is indeed correlated with REC demand. This examination underscores the intricate relationship between energy consumption patterns and the demand for renewable energy certificates, shedding light on the dynamics of Taiwan's REC market.

In Regression Model 1, where total electricity consumption is considered as a predictor of IREC cancellation, the total electricity consumption variable shows a significant negative relationship with IREC cancellation (p-value = 0.005). This indicates that an increase in total electricity consumption is associated with a decrease in IREC cancellation.

In Regression Model 2, where the breakdown of electricity consumption into different sectors is considered as predictors of IREC cancellation, some individual breakdown variables (e.g., transportation electricity consumption and energy sector self-use electricity consumption) show statistically significant relationships with IREC cancellation, while others (e.g., industrial electricity consumption, residential electricity consumption, service industry electricity consumption, and agricultural electricity consumption) do not. This suggests that the impact of specific sectors on IREC cancellation may vary, with certain sectors having a more significant effect than others.

### 6.2.2 TRECs and electricity consumption

Regression Model 1: Total Electricity Consumption

| Predictor | Coefficient | Std. Error | t-value | P-value | 95% Conf. Interval (Lower) | 95% Conf. Interval (Upper) |
|---|---|---|---|---|---|---|
| Total Electricity Consumption | 0.0037749 | 0.002626 | 1.44 | 0.154 | -0.0014344 | 0.0089842 |
| Intercept | -53712.02 | 59105.3 | -0.91 | 0.366 | -170961 | 63536.98 |

*Table 5: T-REC cancellation and total electricity consumption*

Regression Model 2: Breakdown of Electricity Consumption

| Predictor | Coefficient | Std. Error | t-value | P-value | 95% Conf. Interval (Lower) | 95% Conf. Interval (Upper) |
|---|---|---|---|---|---|---|
| Industrial Electricity Consumption | 0.0207479 | 0.0075532 | 2.75 | 0.007 | 0.005755 | 0.0357409 |
| Residential Electricity Consumption | -0.0007667 | 0.0132013 | -0.06 | 0.954 | -0.026971 | 0.0254376 |
| Service Industry Electricity Consumption | -0.0126136 | 0.0221462 | -0.57 | 0.570 | -0.0565734 | 0.0313462 |
| Transportation Electricity Consumption | 1.664409 | 0.4540886 | 3.67 | 0.000 | 0.7630506 | 2.565768 |
| Energy Sector Self-use Electricity Consumption | -0.0948909 | 0.0589157 | -1.61 | 0.111 | -0.2118376 | 0.0220559 |
| Agricultural Electricity Consumption | -0.1114946 | 0.3895318 | -0.29 | 0.775 | -0.8847091 | 0.6617199 |
| Intercept | -214621.5 | 73024.37 | -2.94 | 0.004 | -359573.7 | -69669.28 |

*Table 6: T-REC cancellation and electricity consumption breakdowns*

The results offer insight into the interplay between electricity production and the availability of T-RECs within Taiwan's energy landscape, squarely addressing the central research question (Q1): What's the relationship of the electricity market and REC market in Taiwan?

In particular, the analysis delves into the correlation between electricity consumption and the demand for T-RECs, as outlined in Hypothesis 1.2, which posits that electricity consumption is indeed correlated with REC demand. This examination underscores the intricate relationship between energy consumption patterns and the demand for renewable energy certificates, shedding light on the dynamics of Taiwan's REC market.

In Regression Model 1, where total electricity consumption is considered as a predictor of TREC cancellation, the total electricity consumption variable does not show a statistically significant relationship with TREC issuance and trading (p-value = 0.364).

In Regression Model 2, where the breakdown of electricity consumption into different sectors is considered as predictors of TREC cancellation, only the industrial electricity consumption and energy sector self-use electricity consumption variables show statistically significant relationships with TREC issuance and trading. The coefficients for transportation electricity consumption and agricultural electricity consumption are also large, indicating potential significant relationships, although their p-values are not statistically significant. The coefficients for residential electricity consumption and service industry electricity consumption are not statistically significant.

## 6.3 I-REC and T-REC

The analysis investigates the relationship between International Renewable Energy Certificates (I-RECs) and Taiwan Renewable Energy Certificates (T-RECs) in Taiwan, addressing the second research question (Q2): What's the relationship of I-RECs and T-RECs in Taiwan?

However the regression results reveal that both TREC issuance and I-REC issuance, as well as TREC cancellation and I-REC cancellation, exhibit p-values higher than 0.05. This suggests that there isn't a significant influence between these variables.

| Variable | Coefficient | Std. Error | t-value | P-value | 95% CI Lower Bound | 95% CI Upper Bound |
|---|---|---|---|---|---|---|
| trecissuetotal_L1 | 0.645426 | 0.1087922 | 5.93 | 0.000 | 0.4290037 | 0.8618483 |
| trecissuetotal_L2 | 0.484374 | 0.1293999 | 3.74 | 0.000 | 0.2269563 | 0.7417917 |
| trecissuetotal_L3 | 0.2555795 | 0.1410193 | 1.81 | 0.074 | -0.0249528 | 0.5361117 |
| trecissuetotal_L4 | -0.4990894 | 0.1435838 | -3.48 | 0.001 | -0.7847233 | -0.2134555 |
| trecissuetotal_L5 | -0.1293405 | 0.1545541 | -0.84 | 0.405 | -0.4367978 | 0.1781169 |
| trecissuetotal_L6 | 0.0783579 | 0.1574392 | 0.50 | 0.620 | -0.2348388 | 0.3915546 |
| trecissuetotal_L7 | 0.1733379 | 0.1519424 | 1.14 | 0.257 | -0.128924 | 0.4755998 |
| trecissuetotal_L8 | -0.0580504 | 0.1499942 | -0.39 | 0.700 | -0.3564366 | 0.2403358 |
| trecissuetotal_L9 | -0.2190538 | 0.139449 | -1.57 | 0.120 | -0.4964623 | 0.0583547 |
| trecissuetotal_L10 | 0.3247432 | 0.1222515 | 2.66 | 0.009 | 0.0815461 | 0.5679404 |
| _cons | 2388.617 | 2081.747 | 1.15 | 0.255 | -1752.642 | 6529.875 |

*Table 7: T-REC issuance and its time lags*

This regression analysis investigates the relationship between lagged trecissuetotal values and current trecissuetotal values. The coefficients represent the change in trecissuetotal for a one-unit change in the respective lagged variable, holding other variables constant.

From the results, we observe that the lagged values of trecissuetotal are statistically significant predictors of current trecissuetotal values. Specifically, trecissuetotal_L1, trecissuetotal_L2, trecissuetotal_L4, and trecissuetotal_L10 have statistically significant coefficients at the 0.05 significance level, indicating that they have a significant impact on the current trecissuetotal.

The overall model is statistically significant ($F(10, 82) = 122.04$, $p < 0.001$) and explains approximately 93.7% of the variation in trecissuetotal. However, caution should be exercised in interpreting the coefficients, as multicollinearity and other statistical assumptions should be considered.

| Variable | Coefficient | Std. Error | t-value | P-value | 95% CI Lower Bound | 95% CI Upper Bound |
|---|---|---|---|---|---|---|
| irecissuetotal_L1 | -0.0972574 | 0.1102903 | -0.88 | 0.380 | -0.31666 | 0.1221452 |
| irecissuetotal_L2 | 0.1503359 | 0.1098191 | 1.37 | 0.175 | -0.0681292 | 0.368801 |
| irecissuetotal_L3 | 0.1511419 | 0.1110626 | 1.36 | 0.177 | -0.0697971 | 0.3720809 |
| irecissuetotal_L4 | -0.1359821 | 0.110259 | -1.23 | 0.221 | -0.3553224 | 0.0833582 |
| irecissuetotal_L5 | -0.1304071 | 0.1107243 | -1.18 | 0.242 | -0.350673 | 0.0898587 |
| irecissuetotal_L6 | 0.0269223 | 0.1111937 | 0.24 | 0.809 | -0.1942774 | 0.248122 |
| irecissuetotal_L7 | -0.0381168 | 0.1095962 | -0.35 | 0.729 | -0.2561385 | 0.1799049 |
| irecissuetotal_L8 | -0.0389593 | 0.1089116 | -0.36 | 0.721 | -0.2556192 | 0.1777006 |
| irecissuetotal_L9 | -0.0948504 | 0.1110904 | -0.85 | 0.396 | -0.3158446 | 0.1261437 |
| irecissuetotal_L10 | 0.0260233 | 0.1095865 | 0.24 | 0.813 | -0.1919792 | 0.2440259 |
| _cons | 7829.245 | 2893.709 | 2.71 | 0.008 | 2072.736 | 13585.75 |

*Table 8: I-REC issuance and its time lags*

The regression model for irecissuetotal does not exhibit statistically significant relationships between the lagged variables and current irecissuetotal values. None of the coefficients for the lagged variables are statistically significant at the conventional significance level of 0.05. Additionally, the overall model is not statistically significant ($F(10, 82) = 0.77$, $p = 0.6545$), and the coefficient of determination (R-squared) suggests that the included predictors explain only a small proportion of the variation in irecissuetotal (R-squared = 0.0861).

# 7. Conclusion

## 7.1 Key findings of the research

This thesis provides a comprehensive examination of the dynamics between International Renewable Energy Certificates (I-RECs) and Taiwan Renewable Energy Certificates (TRECs), as well as their relationship with the electricity market. The study reveals several key insights that shed light on the intricacies of renewable energy markets and policy interactions.

Firstly, both I-RECs and TRECs are highly responsive to renewable energy policies. The surge in I-REC cancellations coincided with the implementation of Article 12 of the Renewable Energy

Development Act in May 2019, highlighting the regulatory influence on market behavior. Conversely, TREC issuance experienced rapid growth following regulatory changes, indicating the market's adaptability to policy shifts. Despite these efforts, Taiwan's progress toward its renewable energy targets remains below expectations, underscoring the need for further policy interventions to incentivize renewable energy adoption.

The interaction between I-RECs and TRECs reveals nuanced patterns. While a direct correlation between the two markets was not observed, noteworthy trends emerged. Taiwanese companies often turn to I-RECs as alternative options when demand for RECs fluctuates due to policy changes or market dynamics. The high cancellation rate in the Taiwan REC market contributes to elevated REC prices, signaling challenges in achieving market stability. Additionally, the analysis highlights the dominance of hydropower in I-REC issuance, contrasting with the prevalence of wind and solar sources in TRECs. However, other energy types such as biomass also contribute to the diversity of available REC sources.

Furthermore, the study delves into the drivers of I-REC and TREC issuance. While nuclear energy generation significantly influences I-REC issuance, other sources like oil, gas, wind, and solar power play pivotal roles in driving TREC issuance. Notably, coal, nuclear, and biomass exhibit limited relationships with TREC issuance, suggesting the need for targeted policy interventions to promote renewable energy diversification.

Regarding REC cancellation, a negative correlation between total electricity consumption and I-REC cancellation implies that higher consumption levels are associated with lower cancellation rates. However, specific sectors, particularly industrial and energy sector self-use, show significant relationships with TREC cancellation, underscoring the importance of sector-specific policy considerations.

## 7.2 Limitation of the research

The primary limitation of this study revolves around the unavailability of comprehensive price data for RECs, posing a significant challenge to conducting a detailed analysis of pricing dynamics within the market. Without access to robust price data, the study's ability to explore the factors influencing REC prices in depth is compromised, potentially leading to limitations in the accuracy and reliability of the research findings.

Furthermore, the relatively young nature of the REC market introduces another layer of complexity due to the inherent volatility or randomness often associated with emerging markets. This volatility in the available data may impact the robustness of the study's findings, raising concerns about the reliability and generalizability of the results obtained.

Given the evolving nature of the REC market and the limitations inherent in available data, there arises a need for future validation of the study's results. Conducting follow-up studies in subsequent years could help validate the findings obtained in this research, ensuring their continued relevance and reliability over time.

Additionally, challenges related to the connectivity and integration of REC data with other relevant datasets further compound the limitations of the research. The inability to seamlessly integrate REC data with other pertinent information sources may restrict the depth of analysis and comprehensive understanding of market trends, potentially limiting the insights gained from the study.

In conclusion, it is imperative to acknowledge and address these limitations when interpreting the findings of the research. Future studies should aim to mitigate these challenges to enhance the reliability, applicability, and overall quality of research outcomes in the field of REC market analysis.

# Appendix

## Appendix A: Details of the issuance and cancellation of I-RECs (Taiwan). Source: I-REC

iRECs in Taiwan

| Energy | Bioenergy | | Hydroelectric | | Solar | | Wind | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Issuance | Cancellation | Issuance | Cancellation | Issuance | Cancellation | Issuance | Cancellation | Issuance | Cancellation | Cancel rate |
| 2015 | 0 | 0 | 32267 | 10 | 0 | 0 | 0 | 0 | 32267 | 10 | 0 % |
| 2016 | 0 | 0 | 56460 | 99834 | 0 | 0 | 0 | 6442 | 56460 | 106276 | 188 % |
| 2017 | 0 | 2426 | 128070 | 14725 | 0 | 0 | 0 | 0 | 128070 | 17151 | 13 % |
| 2018 | 0 | 1036 | 177992 | 62283 | 0 | 380 | 0 | 238088 | 177992 | 301787 | 170 % |
| 2019 | 0 | 0 | 84183 | 29551 | 0 | 1135 | 0 | 1235957 | 84183 | 1266643 | 1505 % |
| 2020 | 0 | 0 | 36405 | 49705 | 0 | 0 | 0 | 13956 | 36405 | 63661 | 175 % |
| 2021 | 0 | 0 | 77400 | 87131 | 454 | 14393 | 0 | 21105 | 77854 | 122629 | 158 % |
| 2022 | 0 | 299 | 49073,8 | 78255 | 0 | 100 | 0 | 4624 | 49073,8 | 83278 | 170 % |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2023 | 0 | 0 | 45093,987 | 150947 | 0 | 5269 | 0 | 23290 | 45093,987 | 179506 | 398 % |
| 2024 | 0 | 0 | 2184 | 21149 | 0 | 4499 | 0 | 10755 | 2184 | 36403 | 1667 % |
| Total | 0 | 3761 | 689128,787 | 593590 | 454 | 25776 | 0 | 1554217 | 689582,787 | 2177344 | 316 % |

## Appendix B: Key findings of literature

| Study | Sample | Methodology | Major Findings |
|---|---|---|---|
| Lemming(2003) | NA | Theoretical analysis | A negative correlation between price and volume of non-solar REC is evident |
| Jensen(2002) | EU | Static models | Electricity production, prices of electricity and REC influence REC market |
| Goyal & Jha (2009) | India | Case study | The framework to promote renewable energy through a framework which puts into place Renewable Purchase Obligation (RPO) mechanism |
| Hulshof (2019) | GOs in European countries | Econometric | This paper analyses the performance of GO certificate markets and the relationship between two design characteristics of certificate systems and market performance in twenty European countries over 2001–2016 |
| Adamczyk(2020) | Poland | Summary of history data | The article presents the model of the renewable energy production support system in force in Poland |
| Girish(2015) | India | Summary of history data | There's a general trend of increase in the trading volume of RECs, and there was more demand for solar RECs than non-solar RECs |
| Irfan(2021) | India | Econometric | Both electricity and REC markets are interlinked |
| Senturk(2023) | Turkey | Case study | National REC mechanisms of Taiwan, Japan and China have been scrutinized and these mechanisms have been compared in terms of design and operation with the Renewable Energy Guarantees of Origin (YEK-G), which is the national renewable energy certification system of Turkey |

| | | | |
|---|---|---|---|
| Stouhi (2020) | Lebanon | Qualitative method | To introduce a novel mechanism(iREC) to the Lebanese market to support energy transition while contributing to the country's international environmental commitments |
| Karestre(2023) | Tailand | Qualitative method | Study iREC's role in decarbonization in Thailand and its ecosystem by the qualitative method through in-depth interviews |
| Schusser(2018) | Nordic-Baltic Nord Pool | Vector autoregressive model | Electricity price has no significant effect on the price of REC |
| Wimmers(2024) | EU | Trend study | WTP percentages' have the highest influence on GO prices |

## Appendix C: DO file of the codes

```
* Open data

import delimited "/Users/shanshanliang/Documents/Thesis/Data/REC data 022024.csv", clear

describe

summarize


*format date

rename month date

gen StataDate = date(date, "DMY")

format StataDate %td

rename StataDate Date

label variable Date "Date"

drop date

summarize


*regress of electricity production and iREC issue

regress irecissuetotal totalelectricityproduction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electricityfromsolar electricityfromwind electricityfrombiomass electricityfromwaste



regress irecissuetotal totalelectricityproductio electricityfrompumpedstoragehydr electricityfromcoal
electricityfromoil electricityfromgas electricityfromnuclear electricityfromhydropower
electricityfromgeothermal electricityfromsolar electricityfromwind electricityfrombiomass
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regress irecissuetotal electricityfromrenewableenergy


*regress of electricity production and TREC issue

gen trecissueother=trecissuetradedother + trecissueremainingother

gen trecissuesolar = trecissuetradedsolar + trecissueremainingsolar

gen trecissuehydro = trecissuetradedhydroelectric + trecissueremaininghydroelectric

gen trecissuebiomass = trecissuetradedbiomass + trecissueremainingbiomass

gen trecissuewind = trecissuetradedwind + trecissueremainingwind

gen trecissuetotal = trecissuetradedtotal + trecissueremainingtotal



label variable trecissueother "trec issue other"

label variable trecissuesolar "trec issue solar"

label variable trecissuehydro "trec issue hydro"

label variable trecissuebiomass "trec issue biomass"

label variable trecissuewind "trec issue wind"

label variable trecissuetotal "trec issue total"


regress trecissuetotal totalelectricityproduction

regress trecissuetotal electricityfrompumpedstoragehydr electricityfromcoal electricityfromoil
electricityfromgas electricityfromnuclear electricityfromhydropower electricityfromgeothermal
electricityfromsolar electricityfromwind electricityfrombiomass electricityfromwaste


regress trecissuetotal electricityfromrenewableenergy


*regress of electricity production and REC issue

gen recissuetotal = trecissuetotal + irecissuetotal

label variable recissuetotal "rec issue total"
```

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regress recissuetotal totalelectricityproduction

regress recissuetotal electricityfrompumpedstoragehydr electricityfromcoal electricityfromoil electricityfromgas electricityfromnuclear electricityfromhydropower electricityfromgeothermal electricityfromsolar electricityfromwind electricityfrombiomass electricityfromwaste

regress recissuetotal electricityfromrenewableenergy


*regress of electricity comsumption and iREC cancelation

regress ireccanceltotal totalelectricityconsumption

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*regress of electricity comsumption and TREC cancelation

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*regress of electricity comsumption and REC cancelation

gen reccanceltotal = treccanceltotal + ireccanceltotal

label variable reccanceltotal "rec cancel total"

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*regress of iREC and TREC issue

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*ARDL model irecissuetotal

gen irecissuetotal_L1 = irecissuetotal[_n-1]

gen irecissuetotal_L2 = irecissuetotal[_n-2]

gen irecissuetotal_L3 = irecissuetotal[_n-3]

gen irecissuetotal_L4 = irecissuetotal[_n-4]

gen irecissuetotal_L5 = irecissuetotal[_n-5]

gen irecissuetotal_L6 = irecissuetotal[_n-6]

gen irecissuetotal_L7 = irecissuetotal[_n-7]

gen irecissuetotal_L8 = irecissuetotal[_n-8]

gen irecissuetotal_L9 = irecissuetotal[_n-9]

gen irecissuetotal_L10 = irecissuetotal[_n-10]
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gen irecissuetotal_L11 = irecissuetotal[_n-11]

gen irecissuetotal_L12 = irecissuetotal[_n-12]

gen irecissuetotal_L13 = irecissuetotal[_n-13]

gen irecissuetotal_L14 = irecissuetotal[_n-14]

gen irecissuetotal_L15 = irecissuetotal[_n-15]



label variable  irecissuetotal_L1 "irecissuetotal lag1"

label variable  irecissuetotal_L2 "irecissuetotal lag2"

label variable  irecissuetotal_L3 "irecissuetotal lag3"

label variable  irecissuetotal_L4 "irecissuetotal lag4"

label variable  irecissuetotal_L5 "irecissuetotal lag5"

label variable  irecissuetotal_L6 "irecissuetotal lag6"

label variable  irecissuetotal_L7 "irecissuetotal lag7"

label variable  irecissuetotal_L8 "irecissuetotal lag8"

label variable  irecissuetotal_L9 "irecissuetotal lag9"

label variable  irecissuetotal_L10 "irecissuetotal lag10"

label variable irecissuetotal_L11 "irecissuetotal lag11"

label variable irecissuetotal_L12 "irecissuetotal lag12"

label variable irecissuetotal_L13 "irecissuetotal lag13"

label variable irecissuetotal_L14 "irecissuetotal lag14"

label variable irecissuetotal_L15 "irecissuetotal lag15"



regress irecissuetotal irecissuetotal_L1 irecissuetotal_L2 irecissuetotal_L3 irecissuetotal_L4
irecissuetotal_L5 irecissuetotal_L6 irecissuetotal_L7 irecissuetotal_L8 irecissuetotal_L9
irecissuetotal_L10 irecissuetotal_L11 irecissuetotal_L12 irecissuetotal_L13 irecissuetotal_L14
irecissuetotal_L15
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regress irecissuetotal trecissuetotal_L1 trecissuetotal_L2 trecissuetotal_L3 trecissuetotal_L4
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trecissuetotal_L15 irecissuetotal_L1 irecissuetotal_L2 irecissuetotal_L3 irecissuetotal_L4
irecissuetotal_L5 irecissuetotal_L6 irecissuetotal_L7 irecissuetotal_L8 irecissuetotal_L9
irecissuetotal_L10 irecissuetotal_L11 irecissuetotal_L12 irecissuetotal_L13 irecissuetotal_L14
irecissuetotal_L15

*ARDL model trecissuetotal

gen trecissuetotal_L1 = trecissuetotal[_n-1]
gen trecissuetotal_L2 = trecissuetotal[_n-2]
gen trecissuetotal_L3 = trecissuetotal[_n-3]
gen trecissuetotal_L4 = trecissuetotal[_n-4]
gen trecissuetotal_L5 = trecissuetotal[_n-5]
gen trecissuetotal_L6 = trecissuetotal[_n-6]
gen trecissuetotal_L7 = trecissuetotal[_n-7]
gen trecissuetotal_L8 = trecissuetotal[_n-8]
gen trecissuetotal_L9 = trecissuetotal[_n-9]
gen trecissuetotal_L10 = trecissuetotal[_n-10]
gen trecissuetotal_L11 = trecissuetotal[_n-11]
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gen trecissuetotal_L14 = trecissuetotal[_n-14]
gen trecissuetotal_L15 = trecissuetotal[_n-15]
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label variable trecissuetotal_L2 "trecissuetotal lag2"

label variable trecissuetotal_L3 "trecissuetotal lag3"

label variable trecissuetotal_L4 "trecissuetotal lag4"

label variable trecissuetotal_L5 "trecissuetotal lag5"

label variable trecissuetotal_L6 "trecissuetotal lag6"

label variable trecissuetotal_L7 "trecissuetotal lag7"

label variable trecissuetotal_L8 "trecissuetotal lag8"

label variable trecissuetotal_L9 "trecissuetotal lag9"

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label variable trecissuetotal_L11 "trecissuetotal lag11"

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trecissuetotal_L5 trecissuetotal_L6 trecissuetotal_L7 trecissuetotal_L8 trecissuetotal_L9
trecissuetotal_L10 trecissuetotal_L11 trecissuetotal_L12 trecissuetotal_L13 trecissuetotal_L14
trecissuetotal_L15



regress trecissuetotal trecissuetotal_L1 trecissuetotal_L2 trecissuetotal_L3 trecissuetotal_L4
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irecissuetotal_L10 irecissuetotal_L11 irecissuetotal_L12 irecissuetotal_L13 irecissuetotal_L14 irecissuetotal_L15

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