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Effectiveness and efficiency of support schemes in promoting renewable energy sources in the Spanish electricity market

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ABSTRACT

This research paper delves into the central mechanisms implemented in Spain to foster the adoption of clean energy projects. The study scrutinizes various mechanisms established from 2005 onwards, evaluating their efficacy in achieving the desired outcome of supporting clean energy project implementation. The aim is to comprehensively assess the associated costs, effectiveness, and attainment of renewable energy objectives stemming from implementing diverse support schemes. This paper explores the effectiveness of feed-in tariffs and feed-in premium mechanisms in promoting the integration of new renewable energy generation into the power system. However, the Spanish experience suggests that exhaustive planning control is imperative to prevent excessive support costs that could jeopardize the entire market and cause a significant rise in final energy costs. The research studies the support schemes and associated market distortion and presents the roadmap from regulated tariffs to a "total market" for wind and solar energy. The findings demonstrate that, under proper supervision and planning, a transitional retribution scheme effectively promotes renewable energy plant integration. Finally, the analysis examines the need to regulate the excess benefits that non-emitting power sources receive in a marginal price market, as this can lead to market imbalances and a substantial increase in final costs. These plans serve as a crucial tool in achieving the decarbonization objectives of the European Power System.

1. Introduction

The electricity sector is currently the largest source of CO_2 emissions globally, making renewable energy sources (RES) indispensable for achieving emission reduction goals [1]. The European Union (EU) has recognized the critical role of RES in meeting its ambitious climate targets, including a 55 % reduction in net greenhouse gas (GHG) emissions by 2030 and achieving net-zero emissions by 2050 [2]. The EU has successfully met its three climate and energy targets for 2020, which included reducing GHG emissions by 20 % compared to 1990 levels, increasing the share of RES to 20 %, and achieving a 20 % reduction in energy consumption [3]. Reaching the 2030 target of a 55 % reduction in net GHG emissions will require additional efforts, including adopting and implementing new policies [3]. Spain aligns with the EU's commitment to decarbonizing the electricity sector. Spain has witnessed a significant increase in electricity generation from RES between 1999 and 2022 [4]. In line with its Integrated National Energy and Climate Plan 2021–2030 [5], the Spanish government has set an ambitious target of generating 74 % of the country's electricity from renewable sources by 2030 [4].

This research paper will focus on the promotion of three renewable energy sources through public financial support: (i) wind energy, (ii) solar photovoltaic (PV), and (iii) solar thermal (TE), raising the following research question: *How have various support schemes (RESS) impacted the adoption of RES in the Spanish electricity market?*

In Spain, wind energy production was commanding among RES from 1999 to 2022 [9]. For example, in 2021, wind energy's output more than double the combined production of solar PV and TE [9]. Spain experienced a steady growth in wind power production between 1999 and 2013, with a peak of 54.34 TWh in 2013 [9]. However, wind power generation slowed in 2014 and 2015 [9]. This decline coincided with the introduction of Royal Decree-Law 9/2013 and the proposed royal decree on renewables [10]. The Spanish Wind Energy Association criticized these reforms as "*retroactive, discriminatory, and arbitrary*" [10]. In 2014, the Spanish government confirmed the wide *ex post facto* cutback to RES

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Nomenclature

AET	average electricity tariff
AIC	annual installed capacity
CNMC	*National Markets and Competition Authority*
DET	domestic electricity tariff
DSO	distribution system operators
EU	*European Union*
FIP	feed-in premium
FIT	feed-in tariff
GHG	greenhouse gas emissions
KPI	key performance indicator
NEP	National Energy Plan
PFS	public financial support
PPA	power purchase agreement
PV	photovoltaic
RD	Royal Decree
RE	renewable energy
REP	renewable energy producers
RES	renewable energy sources
RSS	renewable support schemes
SR	special regime
SRR	specific remuneration regime
TE	thermoelectric
TSO	Transmission System Operators

capacity, raising concerns among wind operators about loan defaults [11]. Spain's National Energy and Climate Plan, formulated within the 2018/2001 Directive framework, established the strategic roadmap for expanding renewable energy sources, emphasizing adopting energy generated from RES [12].

In 2011, the Spanish Parliament enacted legislation that retroactively reduced tariffs for the Spanish PV sector by 30 % [13]. This policy shift profoundly impacted solar PV development in Spain, leading to stagnation between 2011 and 2018. After implementing the new Integrated National Energy and Climate Plan [5], solar PV production in Spain has witnessed a remarkable surge in recent years, rising from 7.38 TWh in 2018 to 25.47 TWh in 2022. This growth can be attributed to the more favorable policy environment and technological advancements that have lowered the cost of solar PV installations. The deployment scenario outlined in Spain's Integrated National Energy and Climate Plan 2021–2030 [5] envisioned a substantial rise in RES production compared to the 2018 scenario [11]. Under this ambitious plan, Spain emerged as the EU country with the highest wind capacity installed in 2019, accounting for 15 % of the EU's total capacity [12].

The research is structured as follows: Section 1 provides a concise overview of the historical context and fundamental principles of support schemes in fostering renewable energy sources within the Spanish electricity market. Section 2 reviews the related literature on the promotion of renewable energy, includes a detailed analysis of each support scheme for both capacity markets, and focuses specifically on renewable energy (RE). Section 3 establishes the historical background of the Spanish electricity market. Section 4 presents a comprehensive analysis of the effectiveness and efficiency of RESS in promoting RES in the Spanish electricity market. Finally, section 5 concludes and outlines future research directions. This structured approach ensures a clear and logical presentation of the research, guiding the reader through the various aspects of the study.

2. Literature review

Before describing some of the more relevant and recent scientific literature, it is helpful to briefly outline the economic process leading to the definition of wholesale prices in most electricity markets. Typically, the electricity wholesale markets are organized by sequential auctions. That happens in the day-ahead market, the most relevant wholesale market in electricity.[1] Then, the market operator aggregates supply and demand bids to find the equilibrium market price and the quantity each firm will produce. The various technologies are required to generate increasing bid orders regardless of their investment or fixed costs. Hence, those technologies, with varying marginal and fixed costs, are dispatched to satisfy the demand. Renewable energy is ideally dispatched first due to its low marginal costs. The residual demand is satisfied by conventional power plants, as their marginal costs depend on their efficiency rate and the price at which they buy fossil fuels. Therefore, typically, the conventional generation firms have significantly higher costs than the renewable firms (Fabra [14], Fabra, N. & Llobet, G. [15]).[2] The subsections below analyze the mechanisms for both power capacity support and renewable energy support in the EU.

The EU establishes one of its key principles, the use of and the development of renewable energy, and to achieve this objective, different approaches can be considered. Theoretically, the development of these systems should rely directly on the market rules [16,17], and the exposition of the market competition and trade rules should enhance the achievement of the most efficient and cost-effective technology [18,19]. As a consequence, and directly related to the fact that RE is not always the most cost-effective solution, especially in the first deployment phases [20], it has been necessary to design some mechanisms and schemes to promote the installation of RE capacity and ensure that the RE share objectives are achieved [21]. Therefore, this fact can be called market imperfection and failure [22,23,24], and EU regulators and governments have aimed to establish rectification failure strategies [25,26]. These mechanisms can be classified into two main categories: capacity mechanisms, which aim to enhance and promote the installation of RE generation capacity, incenting long-term power capacity investment in situations when the market self-regulation fails [27,28,29], and, secondly, support schemes, whose main objective is to reduce the competitive gap between conventional energy systems and RES [21,30]. This general framework can be applied in several places and provides a detailed framework for analyzing similar case studies worldwide, focusing on the EU. Section 2.1 studies the capacity mechanisms; section 2.2 analyzes the RES support schemes; section 2.3 reviews the historical background of promotion schemes in the EU that helps frame the specific issues and consequences of the Spanish Market and introduces the scope and framework of this research.

2.1. Overview of capacity mechanisms for renewable energy

To promote renewable energy development, especially in the initial development phases, it can be necessary to deploy support schemes that help introduce RES to the market [31]. In particular, capacity mechanisms aim to enhance and promote RE long-term generation capacity investment installation when market self-regulation fails [32,33]. The

[1] Quoting Fabra [15], "The day-ahead market is organized as a uniform-price auction, in which generators submit 'price-quantity' bids specifying the minimum prices at which they are willing to produce the corresponding quantities. Similarly, consumers submit the maximum prices at which they are willing to buy the various quantities".

[2] For further details on the generation tariff definition and mathematical models on this issue, see, for instance, Fabra [15] and the references therein.

background in most EU countries focuses on two main quantity-based mechanisms, as shown in Figs. 1 and 2 (note that in Spain and Portugal, price-based mechanisms have been implemented). These mechanisms are:

(1) Strategic reserves are plants that the government selects and declares as critical. They do not participate in the regular market but are available for power generation if the operator requires it [34].
(2) Capacity markets are the most complex but most commonly used option and are based on the direct application of market forces. [21]. Many approaches to promote RE capacity deployment can be applied as the most common capacity option [35] and capacity obligation [21].
   - The first mechanism is based on capacity auctions [36], and
   - the second, capacity obligations, is a more complex scheme based on the application of decentralized capacity schemes [37,38]. Under this scenario, all the market participants must operate the required power capacity to ensure that they can provide the required energy supply that they have compromised [39,40,41].
   - Finally, the reliability option is the most complex [42] and novel [21] approach. This mechanism promotes investment in new power plants [21] (in this case, RE plants) based on call options that represent the option (not a contractual obligation) to install the capacity option [33,43,44]. It is a mechanism aiming to avoid high market prices using the definition of ceiling prices for capacity installation [28,45,46].

Direct capacity payment schemes (see Fig. 1) ensure the RE operators an economic flow per installed capacity during the plant life cycle if they keep operating normally [37]. Therefore, it reduces uncertainty and promotes installing available power capacity [37]. As shown in Fig. 2, and for the specific case of Spain and Portugal, price-based mechanisms (in particular, capacity payments) are the capacity mechanisms used.

Eight EU members have operational capacity mechanisms as of 2023: Ireland, Italy, Poland, Belgium, Finland, France, Germany, and Sweden [47]. Finland, Germany, and Sweden are the only three with strategic reserves, whereas the remaining five Member States employ market-wide capacity techniques. Although targeted capacity payments under long-term legacy contracts are still in effect, Spain and Portugal do not currently have an active capacity mechanism [47]. A supplementary program involving capacity auctions aimed at demand response has existed in France since 2018. In Portugal, a targeted capacity mechanism was implemented in 2017 and repealed in 2018. However, certain capacity payments are still awarded to some hydropower projects owing to “legacy” contracts. In Spain, the capacity mechanism consisted of “investment incentives” and “availability payments” [47]. June 2018 saw the end of the availability payments, and as of right now, investment incentive payments are limited to the produced capacity that was developed before 2016 [47].

Although gas and nuclear power plants dominate capacity remuneration schemes in the EU, battery energy storage solutions are gaining traction. Market-wide capacity payment mechanisms in Italy, France, Ireland, and the United Kingdom have supported battery energy storage system development, with large quantities recently contracted [48]. Furthermore, the general situation is changing, as some nations have recently implemented or revised capacity payment schemes while others are planning changes shortly. As a result, the overall image is quite heterogeneous [28].

To some extent, the various capacity compensation models reflect diverse situations and structural patterns in their separate national power systems. In places with minimal resource adequacy issues, “energy-only” markets tend to prevail, not least because of substantial existing (depreciated) generating capacity, typically with considerable hydropower shares in the portfolio, such as Norway and Austria. Other places face substantial resource adequacy issues in the medium term since considerable quantities of generation capacity are set to be decommissioned in the following decade. For example, Germany intends to phase down nuclear power output by 2022, while France expects to decommission nuclear power reactors on a considerable scale by 2030 [28].

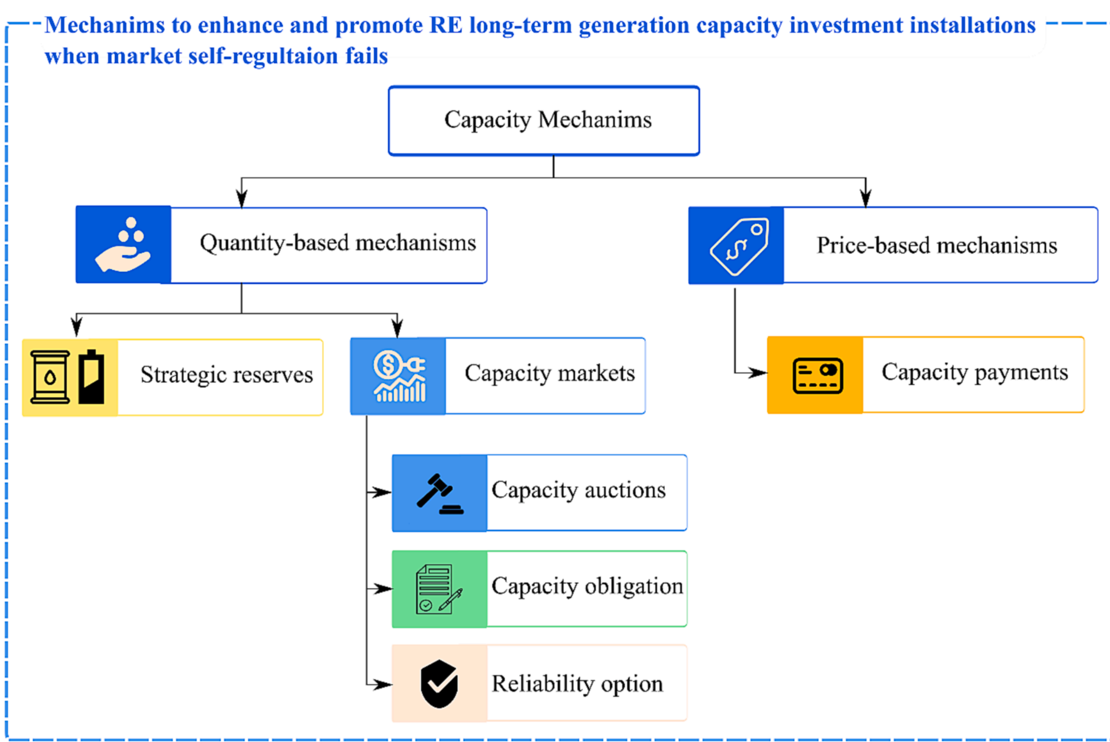

Fig. 1. Overview of the leading capacity mechanisms. Source: Adapted from [28].

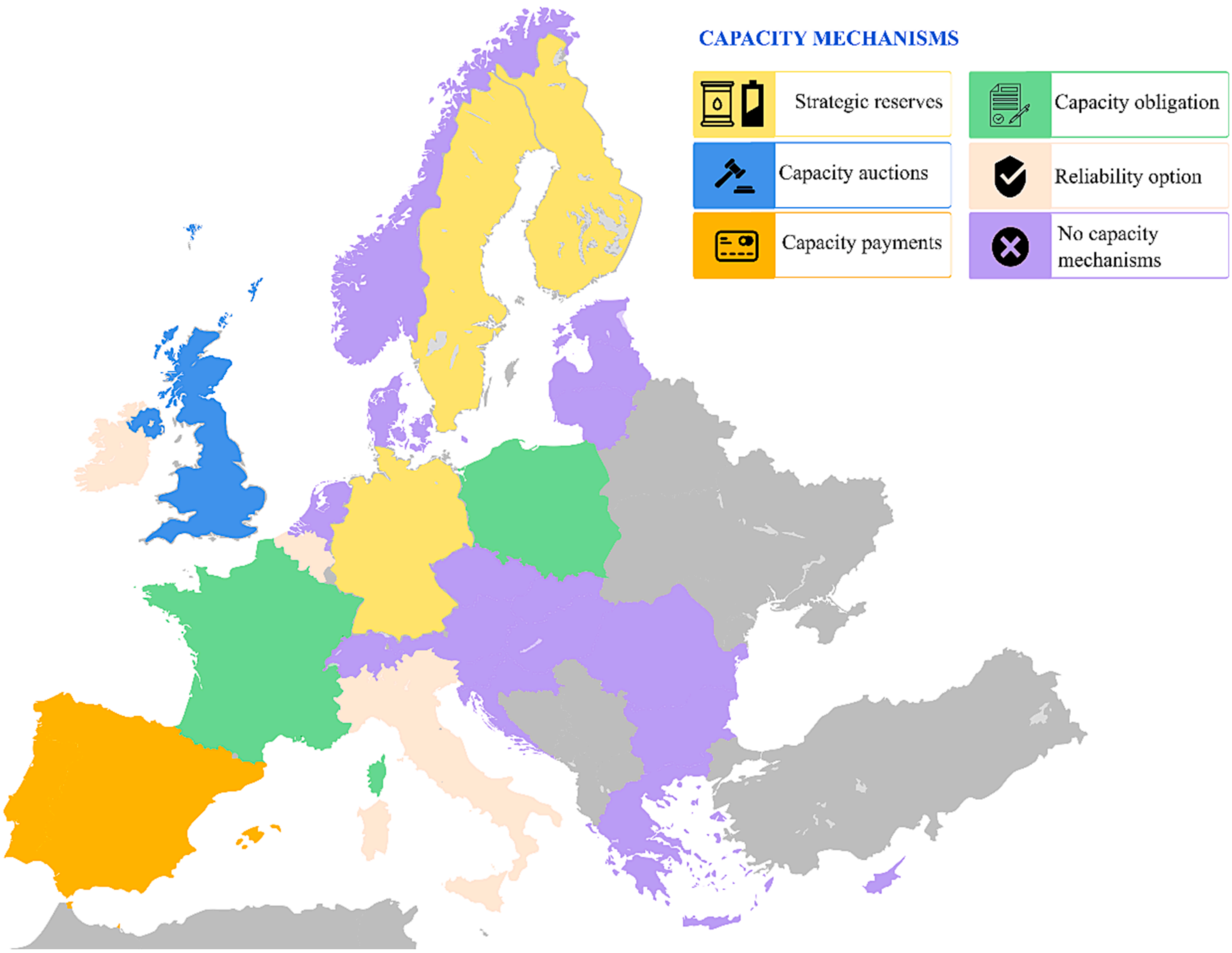

Fig. 2. Status of capacity mechanisms in the EU – 2023. Source: Adapted from [47].

In other countries, like Spain, the issue is more about economics than the lack of generation capacity. Low wholesale energy market prices are insufficient to depreciate new generating capacity. Thus, generation firms argue that capacity mechanisms are required to boost the profitability of existing power facilities, especially relatively new gas-fired production [28].

In addition to the strategic reserves for generating capacity, the sector inquiry identified seven countries—France, Germany, Ireland, Italy, Portugal, and Spain—that run particular demand response programs (usually for large industrial users) and that seem to match the indicators for identifying a capacity mechanism [49]. As a result, recipients of these "interruptibility programs" are placed on hold until the TSO needs them. These initiatives might thus be seen as a form of strategic reserve [49]. It is important to note that the strategic reserve capacity cannot be used until the trigger condition is enabled [49]. This is a significant divergence from the reliability options method and a cause of inefficiency [50].

Several writers have proposed that the adequacy issue can be handled by proactively procuring dependability alternatives, also known as capacity options. These instruments function similarly to call options. When the wholesale spot market price surpasses a predetermined reference price (the "strike price"), the contracted capacity supplier must pay the excess to the option owner. There are three benefits to this capacity choice method [51].

- Capacity suppliers profit from constant and predictable income streams.
- The capacity supplier has a strong incentive to make its resource(s) available during times of scarcity. If the resource is unavailable, the supplier will be forced to make payments under the capacity option contract without receiving market revenue during high market prices.
- Purchasers of capacity options effectively place a ceiling on their energy purchase price at the strike price; any increase in market price above this point will be "reimbursed" by the capacity supplier through the option contract, shielding the buyer from the risk of spot market price fluctuations. Capacity options can take many forms, contingent on whether the scheme is purely financial or imposes an obligation to have and make capacity available when the option is exercised (or suffers a penalty). The latter responsibility ensures that reliability is supported. In this scenario, the capacity option is analogous to a plan based on capacity obligations. In any scenario, the capacity option can be priced via a forward auction, similar to what regional transmission organizations now use.

Reliability Options are capacity remuneration techniques designed to improve the security of supply in electrical networks [52]. The advantage of reliability options is that they keep generators motivated to produce electricity during scarcity periods by setting the strike price above the marginal cost of the most expensive generation unit [53]. As a result, every generator that produces power at the strike price will make a profit [53]. As with an option contract, a generator is liable to pay the difference between the spot and strike price whenever the strike price is exceeded. Failing to generate in such an event can result in considerable losses, providing a strong incentive to deliver full capacity during shortages [53].

Portugal and Spain use a direct capacity payment model, with the capacity to be compensated chosen through auctions [26]. Spain conducts renewable energy capacity auctions and pays renewables per capacity installed [26]. However, the decision to stage each auction is taken independently, and the overall number of renewables to be picked is centrally determined [26]. After ending its feed-in tariff assistance for renewables in 2012, Portugal introduced capacity auctions for such electricity generation [26]. However, the absence of precise guidelines for renewable energy sources has prevented renewables from participating in the auctions [26]. In general, capacity payments have various problems, including the difficulty of determining the appropriate level of payment and the impact of the payments, as well as the mechanism's inability to protect against price spikes or market dominance [37]. Another significant disadvantage is that capacity payments are imprecise; it is unclear what customers pay for and receive in return [37]. To address this issue, the Spanish government considered implementing a new capacity mechanism based on concerns about ensuring adequate flexible gas-fired generation by EU law (a public consultation on the subject was launched in September 2020) [54]. Spain and Portugal have implemented what is known as the "Iberian Mechanism" or "Iberian Exception," which is based on a "gas price cap" (from 15 June 2022 and extended until the end of 2023, following EU approval) that limits the operating costs passed on to the wholesale electricity market by gas-fired power plants [55]. According to government estimates, decoupling the energy and gas markets has helped Spain lower power rates by 15 % to 20 % [55]. As a result, the European policy debate on capacity mechanisms is ongoing [56].

2.2. Support mechanisms for renewable energy deployment

The most relevant object of support mechanisms for RE is to reduce the competitive gap between conventional energy systems and RES [21,57,58]. There are plenty of financial and economic schemes, but the most relevant and applied for RE support in the EU and Spain are listed in Table 1 below. Support strategies can rely on one particular scheme in a combination of some. It is also common for a country or market to adopt one scheme for each project typology or market sector, for example, a specific support mechanism for household RE systems. The feed-in tariffs are the most relevant mechanism in the Spanish market analysis developed in this research paper. A centralized and fixed extra payment is applied for RE generation in this case. If this premium is calculated under an auction scheme, it is called a competitive mechanism.

One key aspect of RE deployment is a direct relationship and interaction between these schemes and the capacity support measures [21]. This relationship can be quite complex and must be analyzed for each market, energy mix, and scenario. However, from a general approach, if RE support schemes are applied and their objectives are achieved, the RE share in the final mix should be increased. Because of the intermittent nature of the most relevant sources, wind and solar, it is required that conventional plants supply the required power at certain models. Still, the reduction in profitability (because of the reduction of equivalent operating hours) can cause conventional plants to enter a shutdown process. Under a marginal cost fixed price mechanism, the most common worldwide and particularly the type used in Spain and the EU, the higher market cost for each hour fixes the final payment [59]. It causes those conventional plants with higher marginal costs, such as natural gas-fired plants, to fix the final price [60,61]. This usually causes a price distortion that governments aim to tackle by fixing a price cap, which results in a reduction of conventional plant benefits that, combined with the reduction of operating hours and the existence of an RE support mechanism, disincentive the investment in conventional plant capacity and increases the profitability of RE sources [62,63]. This factor combination under a Feed-in-Tariff scheme was relevant for RE development in Spain and is deeply analyzed in this research. The most important findings can be applied to similar scenarios worldwide and represent a best practices approach to avoid similar problems.

Table 1
Renewable energy support mechanisms. Source: Own Elaboration.

Regulation typology	Application	Specific schemes
Non-regulatory policies	Projects for all sizes	Voluntary programs Fiscal and financial incentives
Regulatory and pricing policies	Distributed generation	Net meteringNet billing Administrative set pricing instruments
	Large scale plants	Competitive set pricing instruments Administrative set pricing instruments
	Decentralized renewable energy plants to promote electricity access	Pricing policies Legal provisions Grid arrival policies
	All stakeholders	Certificates and quotas

2.3. Review of historical renewable energy promotion schemes in the EU

There is a vast scientific literature on promoting renewable energy investments in the European Union. García et al. [64] empirically evaluated feed-in tariff (FiT) and renewable portfolio standard policies applied to onshore wind power in the EU-28 from 2000 to 2014. García et al. [64] concluded that FiT results are better than renewable portfolio standard policies regarding installed wind capacity. Also, García et al. [64] results enhance the importance of the contact duration and tariff price definitions when FiT is applied. These conclusions are coherent with the previous work of Menanteau et al. [65], Wüstenhagen and Bilharz [66], and Patlitzianas and Karagounis [67], who also analyze European countries. With a broader sample of 25 OECD countries from 1978 to 2003, Johnstone et al. [68] found the positive effects of FiT on innovation in renewable energy technologies.

Oosthuizen et al. [69] examine the influence of policy flexibility on renewable energy adoption in 20 EU countries from 2002 to 2018. Based on a text analysis of the National Energy and Climate Plans, Oosthuizen et al. [69] found that policy adjustments toward a renewable energy goal stimulate renewable energy uptake. Iskandarova et al. [70] investigate the financing of renewable energy technologies, including wind and solar power. Iskandarova et al. [70] look at wind and solar finance growth and subsidies in Poland, the Netherlands, and the United Kingdom, including grants, prizes, crowdfunding, community bonds, ventures, and social investment. Iskandarova et al. [70] concluded that the diversity of financing instruments is positively related to higher investments in renewable energy.

Andor and Voss [71] take a different approach, arguing that renewable energy policies can be distinguished by whether they focus on capacity (for example, investment tax cuts) or electricity generation (for example, FiT, quota systems, or renewable portfolio standards). Andor and Voss [71] use a mathematical model to calculate the appropriate subsidies for energy-producing technologies, considering external advantages such as capacity and power generation. Then, applying the model to the German electricity market, Andor & Voss [71] conclude that some of the most popular promotion instruments, such as FiT, may cause welfare losses.

Also, with a mathematical approach, Mir-Artigues & Río [72] developed a financial model to analyze the impact on the promotion of renewable energy using the FiT combined with other instruments, such as investment subsidies and soft loans. Mir-Artigues & Río [72] conclude that the policy costs of combining different instruments are not significantly different from the FiT as the only option.

The scientific literature offers a rich collection of research papers exploring strategies for promoting and financing renewable energy investments in the European Union. Notable examples include the studies conducted by García et al. [64], Oosthuizen et al. [69], Iskandarova et al. [70], and Andor & Voss [71]. Despite this extensive body of research, a comprehensive assessment of the major RESS implemented in Spain to encourage investments in wind, solar PV, and solar TE projects remains lacking. To address this gap, this paper delves into a thorough analysis of the various RESS introduced in Spain, providing insights into their effectiveness and potential for improvement. A comprehensive review of grey and peer-reviewed literature on the topic [73–78] revealed that while diverse approaches to renewable energy promotion and financing exist, this paper contributes to the existing knowledge base by offering a focused examination of RESS specifically tailored to the Spanish context.

3. Historical background

3.1. Overview

The Secretary of State for Energy in Spain leads the government department responsible for energy affairs [79]. The National Markets and Competition Authority (CNMC) has served as the national regulatory authority since October 2013, overseeing competition law enforcement, regulation, market supervision, and dispute resolution in specific markets and sectors, including the electricity sector [80]. Notably, the CNMC introduced the first compensation scheme for the system operation activity through Circular 4/2019, establishing the payment procedure for the TSO (Transmission System Operators) [81]. Additionally, the CNMC monitors the deregulated market's efficiency and competition in wholesale and retail markets [82].

The Spanish electricity sector has profoundly transformed since 1998 [83]. Before Electricity Law 54/1997, the sector was characterized by a vertically integrated structure, with a handful of companies controlling both generation and distribution [84–86]. Electricity liberalization in Spain commenced in 1998, following a phased approach based on consumption volume and supply voltage [85]. This process was completed on January 1, 2003, when the market was fully liberalized, allowing all consumers to choose their suppliers and negotiate their supply terms freely [87]. Similar roadmaps will occur in power markets suffering a deregulation transition process, and the analyzed experiences presented in this research can be of interest to designing the most optimal strategy and avoiding potential market distortions.

Following the market liberalization enabled by Law 54/1997 (subsequently superseded by Law 24/2013), the electricity sector has been reorganized into four distinct activities: generation, transmission, distribution, and supply [79]. Law 24/2013 repealed most of the previous electricity sector law [88] and served as the foundational regulation governing the current structure and operation of the electricity sector in Spain. In alignment with the objectives of European Directive 2009/72/EC, one of the primary goals of Law 24/2013 is to foster an adequate level of competition within the electricity sector [89]. Fig. 3 illustrates the phases of the support system for renewable energies in Spain from 1999 to 2022. Fig. 4 shows the remarkable surge in electricity generation from RES in Spain during this period.

Fig. 5 shows Spain's cumulative installed capacity of wind energy, solar PV, and solar TE technologies from 2010 to 2021.

As shown in Fig. 6, wind production was predominant in the rest of the RES from 1999 to 2022. With an output of 59.2 TWh in 2021, wind production more than doubled that of solar PV and solar TE combined (25.2 TWh). In Spain, wind power production kept growing between 1999 and 2013, a year in which it peaked at 54.34 TWh. In 2014 and 2015, wind power generation in Spain declined. As shown in Fig. 6, following the Integrated National Energy and Climate Plan 2021–2030 [5], solar PV production in Spain has increased considerably in recent years, from 7.38 TWh in 2018 to 25.47 TWh in 2022.

The rest of this section describes every scheme with a higher degree of granularity and provides evidence of their ability to produce the desired result concerning installed RES.

3.2. Legislation in first stages of renewable energy promotion

The initial genuine effort to promote the adoption of RES through financial incentives was Law 82/1980 on Energy Conservation [96,97]. This law, enacted during the second oil crisis [98], aimed to enhance energy efficiency and reduce reliance on foreign energy sources [99,100]. It marked the beginning of a process to introduce and refine fundamental legal safeguards, including guaranteed access, price guarantees, and purchase contracts with electricity companies [101]. Under this legislation, electricity companies were obligated to purchase electricity generated by small-scale producers with domestic installations, paying them a domestic electricity tariff (DET), which is a fixed feed-in tariff (FiT) [102]. However, despite implementing various RES strategies since the mid-1980 s, the wind energy sector in Spain did not experience a true breakthrough until the mid-1990 s [103]. A previous Spanish National Energy Plan (NEP) for 1991–2000 introduced an incentive scheme for cogeneration and renewable energy production, aiming to achieve a 10 % share of Spanish power generation by 2000, up from 4.5 % in 1990 [104]. Within this timeframe, Law 40/1994 established the concept of the Special Regime, and RD 2366/1994 further defined its principles [96,104].

1998 Royal Decree 2818/1998 established the regulatory framework

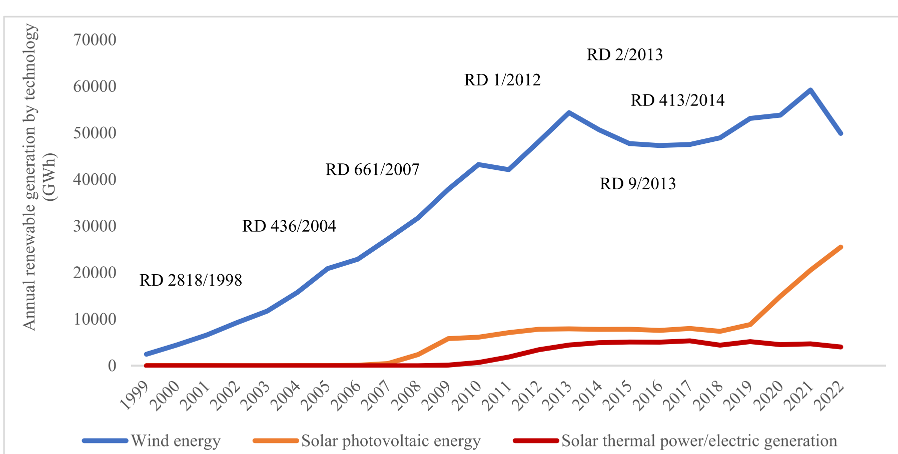

Fig. 3. Phases of the support system for renewable energies in Spain comparing renewable generation by technology and dates of the main Royal Decrees. Source: Adapted from: [8,89–95].

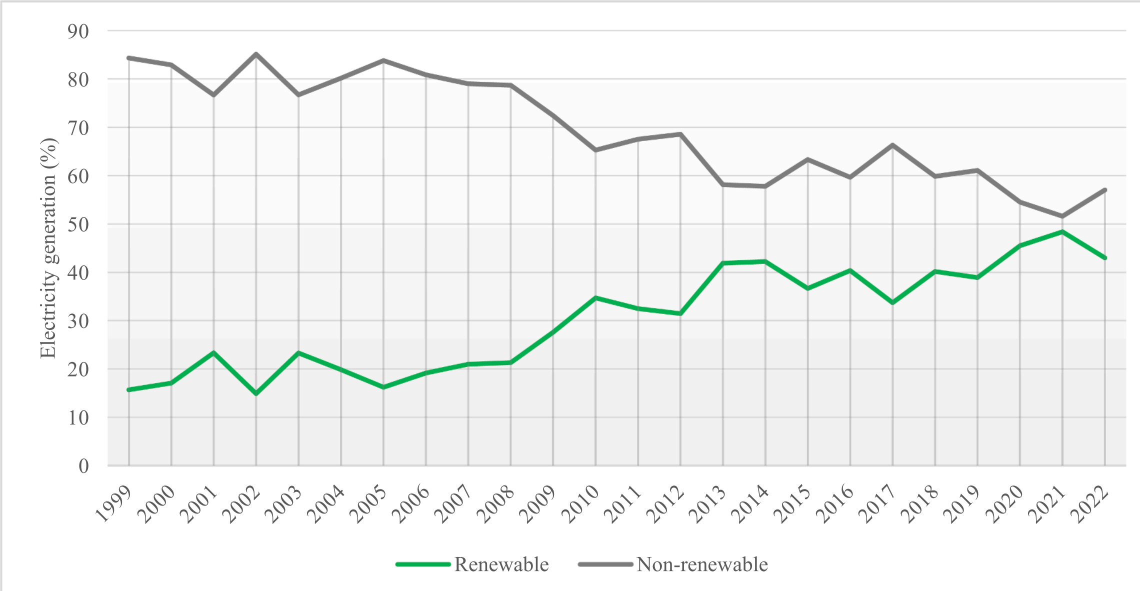

Fig. 4. Evolution of renewable and non-renewable electricity generation for the Spanish mainland power system (renewable energy includes hydro, hydro-wind, wind, solar PV, solar thermal, other renewables, and renewable waste). Source: Adapted from [4].

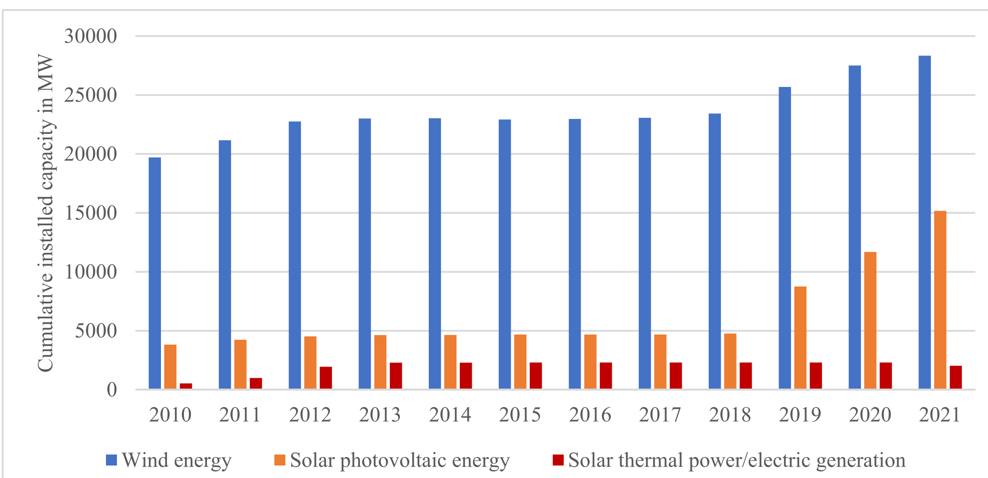

Fig. 5. Cumulative installed capacity of onshore wind, solar photovoltaic, and solar thermal in Spain from 2010 to 2021. Source: Adapted from [4,6,7].

for participation in the Special Regime (SR) [105–107]. This decree allowed generators to either sell their entire output to distribution system operators (DSOs) at a fixed rate, known as a FiT, or to sell their electricity on the market and receive a premium above the market price [108–111]. The FiT provided a stable revenue stream regardless of market fluctuations [112]. Under RD 2818/1998, renewable energy plants had the option, but not the obligation, to offer their energy on the market [113]. While Spain's wind energy industry thrived under these initial schemes, the solar industry did not achieve comparable success until 2007 [114].

Six years later, RD 436/2004 superseded RD 2818/1998 to revise the existing system of subsidies, prices, incentives, and methodologies [115]. RD 436/2004 stated its objective of establishing a "sustainable economic regime based on an objective and transparent methodology for the calculation of remuneration" [116]. However, just three years later, Royal Decree 661/2007 replaced RD 436/2004, introducing new tariffs and premiums for different types of installations [117]. 2012 Royal Decree 1/2012 temporarily suspended support instruments for new RES projects [118]. A year later 2013, Royal Decree-Law 2/2013 introduced regulatory changes affecting special regime installations (renewables and cogeneration) to correct the tariff deficit and strengthen financial stability [119].

Fig. 3 shows the evolution of the cumulative installed capacity of wind, solar PV, and solar TE in the special regime from 1998 until its abolition in 2012. As can be seen in Fig. 3, onshore wind benefited most from the SR, with annual generation increasing from 2474 GWh in 1999 to 48,156 GWh in 2012. During this period, annual generation from solar PV sources increased to 7,830 GWh in 2012 (from 21,652 GWh in 1999), while solar thermal generation reached 3,447 GWh by the end of 2012 (from 0 GWh in 1999).

Having established the historical framework for the research, the following subsections will examine the special and specific remuneration regimes, their modifications, and their effectiveness from 2005 (the date on which Royal Decree 436/2004 came into force) to date.

The first modification to the SR was introduced in 2004 through Royal Decree 436/2004 [120]. This decree provided incentives for new RES projects in two ways, which are enclosed in the support mechanism presented in section 1:

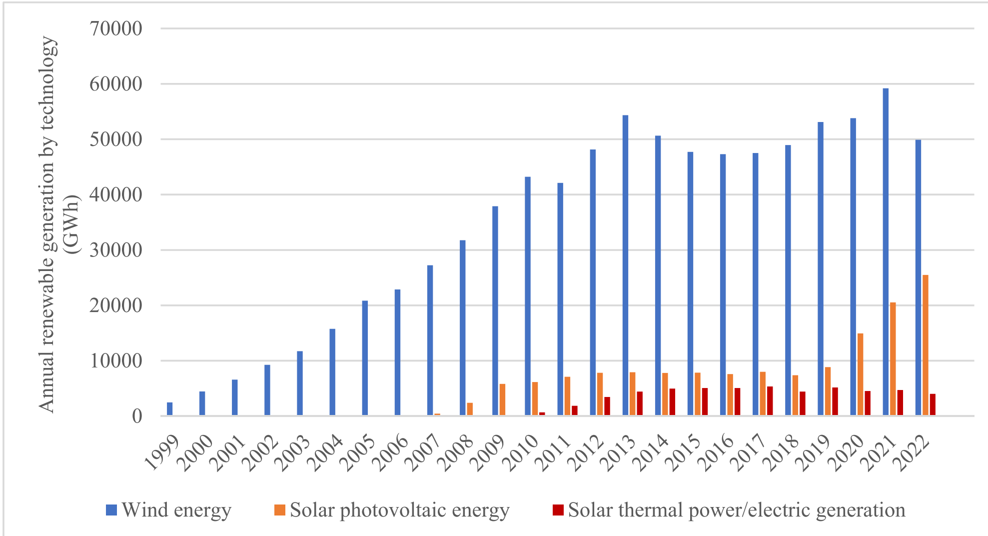

Fig. 6. Annual wind, solar PV, and solar TE generation in Spain from 1999 to 2022. Source: Adapted from [8].

(1) FiT scheme: Generators selling their electricity to a DSO received a fixed rate per kWh of electricity, expressed as a proportion of a reference tariff (the proportion varied depending on the technology).
(2) Feed-in premium (FiP) scheme: Generators selling their electricity on the open market received the market price of electricity, a participation incentive, and a premium if they met certain requirements.

Royal Decree 436/2004 introduced a key feature to encourage participation in the electricity market: RES producers who opted to sell their electricity on the market would receive a "market incentive" (in addition to the market price and premium) [120]. This incentive amounted to ten percent of the average electricity tariff [120].

When RD 436/2004 came into effect, the average or reference electricity tariff for 2004 was 7.2072c€/kWh [121]. This average tariff was updated annually by the Ministry of Economy [121]. The decree stipulated that tariffs, premiums, and incentives would be reviewed every four years starting from 2006, and these reviews would only apply to new installations [121].

For PV facilities up to 100 kW, a remuneration of 575 % of the average electricity tariff (AET) was granted for the first years and then 80 % of that amount for the facility's lifespan [121]. These conditions would remain in place until 150 MW of PV capacity was installed in Spain [114]. RD 436/2004 stated its objective of providing a stable, impartial, and transparent framework to encourage investment in the renewable energy sector [122], providing security for lenders [122]. The new remuneration scheme for the SR was intended to incentivize investment in renewable energy plants [123].

Table 2 summarizes the incentives for RES electricity generation provided under RD 436/2004. Although feed-in tariffs and feed-in premiums were allocated for the lifetime of the plants, Table 2 shows that they were designed to decline after a fixed period. As seen in Table 2, for the first 25 years, solar PV and solar thermal technologies were entitled to receive a proportion of the average electricity tariff equivalent to 575 % and 300 %, respectively. This differed significantly from the support provided to onshore wind technology, which was entitled to receive 90 % of the average electricity tariff for the first five years. The new scheme provided more favorable conditions for large-scale and small-scale solar PV technologies [105]. However, it did not incorporate feed-in tariff best practices, such as a declining feed-in tariff [105]. This was a key aspect for the future increase in solar PV energy during the next years [105].

Table 2
Incentives for electricity generation from RES provided for in RD 436/2004. Source: [124,125].

Renewable Energy Source	Regulated tariff (FIT) (% average electricity tariff)	Premium (FIP) (% average electricity tariff)	Incentive (% average electricity tariff)
Solar			
PV < 100 kW	575 % first 25 years 460 % onwards	–	–
PV > 100 kW	300 % first 25 years 240 % onwards	250 % first 25 years 200 % onwards	10 %
Thermoelectric	300 % first 25 years 240 % onwards	250 % first 25 years 200 % onwards	10 %
Wind			
Onshore < 5 MW	90 % first five years 80 % onwards	40 %	10 %
Onshore > 5 MW	90 % first five years 85 % 6–15 80 % onwards	40 %	10 %

Fig. 7 presents the average price of the total remuneration received by renewable energy producers under Royal Decree 436/2004, categorized by energy sale option (FiT or FiP), technology (solar PV or wind), and year of implementation. It is important to note that until 2010, the installed capacity of solar thermal energy for electricity generation was negligible, hence its absence in Fig. 7. Additionally, Royal Decree 436/2004 remained in effect until June 1, 2007, when it was superseded by Royal Decree 661/2007 [105,127–131]. The significant surge in installed capacity for solar PV and wind power is primarily attributed to this regulatory change implemented on June 1, 2007.

Despite relatively attractive average electricity tariffs under FiT and FiP schemes (Fig. 7), wind power continued to thrive under Royal Decree 436/2004. Figs. 3 and 5 show that annual wind power generation nearly doubled from 11,720 GWh in 2003 to 22,880 GWh in 2006, the last year under Royal Decree 436/2004. Unlike onshore wind, which benefited from both FiT and FiP schemes, solar PV technology solely relied on FiT schemes during the implementation of Royal Decree 436/2004. This was particularly advantageous for facilities below 100 kW, making FiT schemes a more attractive option than participating in the

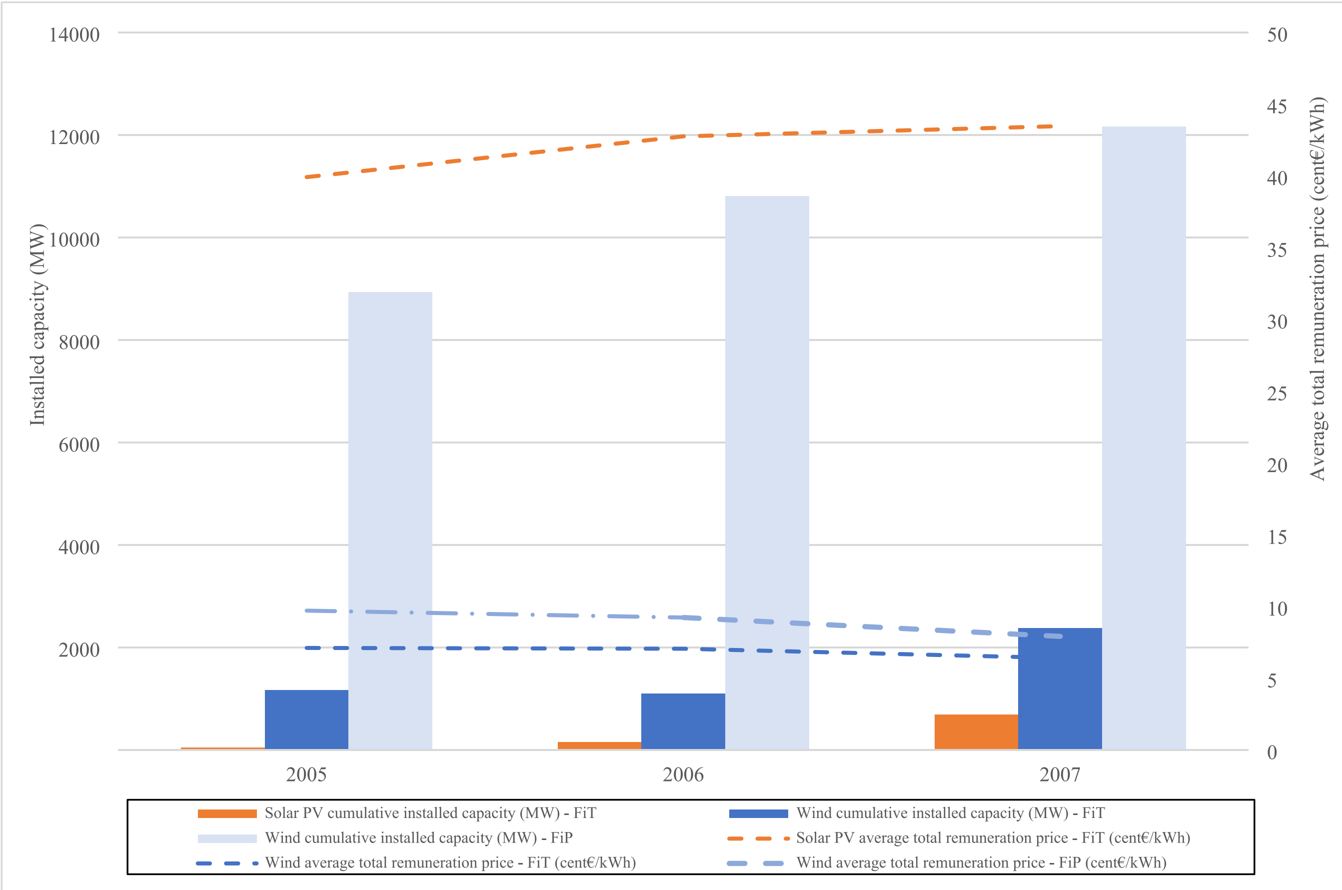

Fig. 7. Average price of total remuneration (cents €/kWh) according to the energy sale option, technology, and year during the period of application of Royal Decree 436/2004 (it should be noted that RD 436/2004 was in force until 1 June 2007, when RD 661/2007 came into force). Source: Adapted from [126].

market and receiving lower FiP premiums for electricity generation (Table 2). While Royal Decree 436/2004's FiT calculation method allowed installations under 100 kW to receive higher tariffs, the rate of growth in uptake remained insignificant until the introduction of Royal Decree 661/2007 in June 2007.

3.3. Impact of Royal Decree 661/2007

In 2004, a significant overhaul of the Spanish FiT regime was widely regarded as a success in enhancing its effectiveness [131]. However, within just three years, it became apparent that additional measures were necessary to address three emerging challenges: (i) the potential threat to electricity supply security, (ii) the escalating system costs, and (iii) the lower-than-anticipated uptake of the market premium alternative by renewable energy producers (REPs) [131]. Consequently, in 2007, following over a year of intensive deliberations, Spain enacted Royal Decree 661/2007 [131]. This decree introduced several crucial modifications to the FiT system [131]. While the growth of cumulative solar PV capacity installed under Royal Decree 436/2004 was deemed satisfactory, Royal Decree 661/2007 mandated a further restructuring of the economic support scheme [132]. This redesigned framework eliminated the market premium option for all solar PV installations [132]. This decision effectively reduced the uncertainty associated with the compensation scheme for solar PV, as support levels were no longer directly linked to electricity market prices [132]. Royal Decree 661/2007 also implemented a 93 % increase in the FiT for facilities in the 100 kW to 10 MW range [132].

This over-incentivization of solar PV plants (which almost doubled the percentage of the feed-in tariff for facilities ranging from 100 kW to 10 MW [105]) unnecessarily increased the financial burden on end consumers [132]. In promoting further competition within the solar PV sector, the inflated compensation was seen as potentially detrimental to competition and cost reduction, ultimately discouraging scientific research in this technology area [132].

Spain experienced an unparalleled solar PV boost between 2007 and 2008 [72] under Royal Decree 661/2007 [133]. In August 2007, i.e., three months after the commencement of Royal Decree 661/2007, 85 % of the installed PV capacity objective for 2010 was surpassed [132]. In particular, by May 2008, 1,000 MW of installed PV capacity had been satisfied [132]. At that time, more than 70 % of all European PV installations connected to the grid were in Spain, the largest solar PV market [132]. As shown in Fig. 5 and Fig. 6, annual solar PV generation in Spain rose from 102 GWh in 2006 to 7830 GWh in 2012.

The rapid growth of solar PV in 2007 and 2008, much higher than expected, made it necessary to draft a new Royal Decree, RD 1578/2008 [134]. The main objective of Royal Decree 1578/2008 was to rationalize remuneration, and to this end, it modified the economic regime applicable to PV installations downwards [127]. Royal Decree 1578/2008 on PV compensation established changing premiums subject to the location of the facility (ground or rooftop) with a ceiling AIC [121]. RD 1578/2008 moderated the installation of new PV plants in Spain after it entered into force [121]. In 2009 and 2010, just 19 MW and 420 MW were installed, respectively, and in 2011, 354 MW were installed [121]. By the "reductionist" tendency of the tariffs ratified in RD 1578/2008, the tariffs for every solar energy subgroup shrunk compared to Royal Decree 436/2004 [135]. The financial situation in Spain (2008–2012) caused an extensive drop in the FiT for solar PV generation, which led to a stagnation in the expansion of this market [136]. As can be seen from

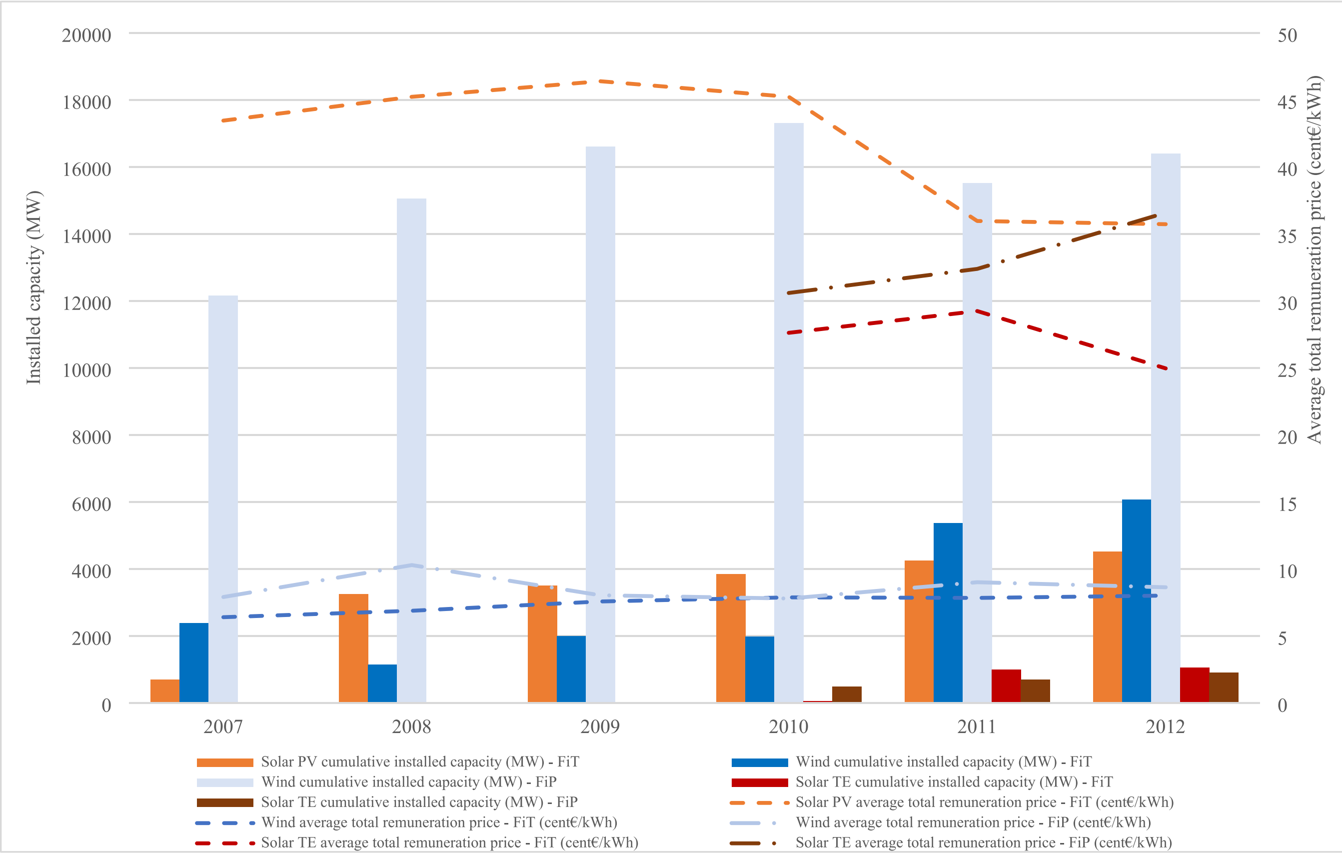

Fig. 8. Average price of total remuneration (cents €/kWh) according to the energy sale option, technology, and year during the period of application of Royal Decree 661/2007 (it should be noted that Royal Decree 661/2007 came into force on 1st June 2007). Source: Adapted from [126].

Fig. 8, the FiT for wind and solar thermal did not decrease significantly after 2008. As a consequence (as seen in Figs. 5, 6, and 8), in contrast to solar PV, onshore wind and solar thermal did show adequate development under Royal Decree 1578/2008.

Under Royal Decree 661/2007, the remuneration was not fixed as a percentage of the average electricity tariff [137]. In particular, there was a floor on the compensation for the feed-in premium alternative (which diminished investors' uncertainty and promoted project financing) and also a cap (which relieved the burden on consumers) [137]. Besides, support levels were very appealing for wind [137] and solar TE. For solar PV, PV installations could no longer elect between a FiP and a FiT [138], as this Royal Decree eliminated the feed-in premium alternative for every PV installation (therefore, it decreased the uncertainty linked to the PV compensation scheme, as PV support levels were not associated to electricity prices) [132].

Despite the various regulatory measures put in place to contain the tariff deficit, the expansion of RES in 2010 (especially solar TE and solar PV) surpassed the installed capacity objective of the 2005–2010 NEP [79]. This considerably heightened the tariff deficit [79]. Specifically, after more than a decade of mismatch between regulated prices and energy costs (which the State guaranteed) [138], at the end of 2012, the electricity system in Spain accumulated a deficit of more than 30 billion euros [139]. Article 4(1) of Regulation (EC) 1228/2003 states that access tariffs shall "reflect actual costs incurred insofar as they correspond to those of an efficient and structurally comparable network operator" [140]. Despite this, access tariffs in Spain continued to be regulated below costs, leading to large tariff deficits in both 2008 and 2009 [113]. Royal Decree 661/2007 certainly contributed to the creation of a structural issue about the financial viability of the Spanish electricity system [96]. In 2009, Spain became increasingly concerned about its tariff deficit (the difference between the cost of subsidies to REP and incomes from electricity sales to end users) [141]. As a result, Spain began to modify the regulatory framework [141]. In December 2010, Royal Decree 14/2010 "on the establishment of urgent measures for the correction of the tariff deficit in the electricity sector" [142] entered into force. Among other measures, this Royal Decree i) included an annual limit on the number of operating hours for which a PV installation would receive the FiT established in RD 661/2007 [142] and ii) required all electricity producers, both under the Ordinary Regime and the Special Regime, to pay a toll to use the transmission and distribution networks [143]. In July 2013, Spain began reorganizing the electricity market to ensure the economic sustainability of the Spanish electricity system [144]. This will be discussed in the following subsection.

3.4. Royal Decree-Law 9/2013 and Royal Decree 413/2014 (Specific remuneration regime)

During the 2000–2010 decade, the Spanish electricity system presented a tariff deficit [145]. This deficit was caused by the expenses inherent in the regulated activities and the operation of the electricity system, which were above the tariffs established by the government and paid by end users [145]. To amend this deficit, urgent measures were adopted to impact costs and revenues in the electricity sector [97]. Despite the legislative measures approved since 2009, aimed at resolving the tariff deficit issue, the (i) contraction in demand (with the consequent curtailment in access fee incomes) and the (ii) higher number of operating hours of the facilities entitled to the feed-in tariff regime concerning the scenarios initially envisaged [145,146] led to the approval of Royal Decree 9/2013 in July 2013 [136]. In Spain, the central support scheme called "Régimen Especial" (Royal Decree 661/2007) operated until the end of 2011 and was suspended at the beginning of 2012 [147] (even for power plants in operation at the time the new law comes into force) [148].

The reform was initiated with the enactment of Royal Decree-Law 9/2013 of 12 July, eliminating the FiT scheme (which remunerated the quantity of electricity produced via premiums) in favor of a compensation system to cover the expenses needed by renewable plants to compete in the market on equivalent terms with other technologies [149]. Until the commencement of Royal Decree-Law 9/2013, RES installations were entitled to receive regulated compensation linked to their energy production [150]. With the approval of Royal Decree-Law 9/2013, the economic regime for renewable energy, cogeneration, and waste facilities was extensively altered, eliminating the feed-in tariff and implementing a new support scheme: compensating REP based on a "reasonable" rate of return specified by the Spanish government [150].

Royal Decree 9/2013 suppressed the economic framework established with Royal Decree 661/2007 and Royal Decree 1578/2008 and introduced the new regulatory framework [96,129]. The new regime was based on producers obtaining their incomes due to their participation in the market and (where appropriate) revenues to compensate for venture costs that a productive and well-managed business could not return from the market [151]. This entailed an incentive system of FiP, supplemented by additional premiums to ensure a reasonable return [151]. Royal Decree 9/2013 approved urgent actions to ensure the economic viability of the electricity system when the EU was pursuing Spain to control the deficit mentioned above, but without discontinuing the grant of incentives to RES [152]. The aim of RD 9/2013 was to follow several measures to guarantee the viability of the Spanish electricity system, mainly affecting transmission and distribution activities and RES electricity generation facilities [153]. The approach of Royal Decree 9/2013 was fundamentally different from previous regimes [154]. Under Royal Decree 9/2013, renewable projects were reimbursed based on a "reasonable profitability" calculated based on their investment cost in installed capacity and their operating and management costs, and not based on their production (provided that a certain minimum number of operating hours is reached) [154]. Under the new scheme, renewable energy operators are guaranteed a "reasonable" rate of return [155] consisting of the 10-year government bond plus a spread, which is presently set at 300 basis points [156,157]. This return can be reviewed every six years [158,159]. During the regulatory period between 2020 and 2025, this "reasonable" rate of return will be 7.09 % [160,161]. Royal Decree 9/2013 was incomplete in that it left the specifics of the new compensation regime for subsequent enactments [143].

In June 2014, Royal Decree 413/2014 was published, which set out the precise terms of the new regime [143]. The main changes introduced by Royal Decree 9/2013 aimed to provide the sector with a homogeneous, transparent, and solid regulatory framework, give economic and financial sustainability to the electricity system, and avoid generating tariff deficits [162]. This Royal Decree was a milestone in the reform of the electricity sector [163]. It ended the previous regime, in which the cost problem was indirectly addressed by adding a series of concurrent savings measures [164]. Consequently, Royal Decree 9/2013 laid the foundations for a new closed-loop control scheme where the electricity system cost was the controlled variable [132].

Royal Decree 9/2013 was applied retroactively to all renewable plants [154]. Therefore, some existing renewable projects did not receive any remuneration besides the amounts collected for selling electricity on the market [154]. The reason is that the Government considered that the amounts collected in the past had already provided such projects with a reasonable return on their investments [154]. However, any amounts already collected through the existing regulatory regimes did not have to be repaid—even if the project's remuneration under the existing regulatory regime exceeded the reasonable return to which the project was entitled under Royal Decree 9/2013 [154].

Royal Decree 9/2013 introduced a new system based on competitive auctions [165]. The significant change with the preceding scheme is that under Royal Decree 9/2013, the compensation regime is set through a competitive tender in which participants bid the concrete value of the investment (€/MW) based on which the remuneration parameters are calculated [165]. Although institutions such as the Spanish Wind Energy Association considered the Reform to be "retroactive, discriminatory and arbitrary" [9], in 2015, the Spanish Supreme Court confirmed that the principles of legal certainty and legitimate expectations had not been violated with Royal Decree 9/2013 [161].

Fig. 9 displays the progression of the annual added and cumulative installed capacity from 2013 to 2022 under the SRR. As seen in Fig. 9, and especially from 2018 onwards, the expansion of installed wind and solar PV capacity in Spain has been considerable. Solar TE's total accumulated capacity has remained unchanged from 2013 to 2022.

4. Discussion

This section analyzes the global impact of the regulation strategies above regarding global costs, the entire system, the final impact on consumer costs, and the impact of specific promotion schemes in the global market and different power sources' competitiveness. The conclusions listed are of great interest for similar market scenarios aiming to promote RE deployment.

To analyze the historical background of RE in Spain, the most relevant indicators that are analyzed are 1) total RE capacity (MW), 2) RE power capacity share (%), 3) RE generation share (%), 4) Final market cost (€/MWh) and, 5) Spot market cost (€/MWh). These factors can be used as KPIs (key performance indicators) to analyze the impact of support schemes.

4.1. Large growth of renewable generation phase (2008–2013)

Several public and private organizations widely agree that renewable energy generation in Spain experienced significant growth during the 2008–2013 period, particularly in solar generation, as shown in Figs. 7 and 8. This growth placed a significant strain on system costs. Royal Decree 661/2007 introduced a regulated tariff that was more than ten times the market price to encourage the development of renewable energy sources despite their higher average costs compared to other generation technologies. Although a competitive bidding system with power quotas was established in 2008, the growth far exceeded expectations. In 2012, Royal Decree-Law 1/2012 eliminated economic incentives for new renewable electricity production facilities, resulting in a complete halt to the entry of new renewable generation, as shown in previous sections. Total renewable peak power remained almost constant as potential investors lacked the economic incentive to invest in new renewable plants, particularly wind or solar plants.

4.2. Introduction of a reasonable profitability regime (2014-Present)

Subsequently, Royal Decree 413/2014 and its implementing regulations eliminated the original regulated tariff. It replaced it with a remuneration system that ensures reasonable profitability, allowing these facilities to compete with other technologies. The current system, regulated by Royal Decree 413/2014, primarily compensates for investment costs and is designed such that the remuneration received from regulated payments financed by charges is not independent of market receipts but acts as a complement. This ensures that the total remuneration provides a reasonable return on investment.

The regulated remuneration (the so-called specific remuneration regime) is intended to be established on a provisional basis, relying on a market price forecast. Consequently, the system implies that installations are remunerated through provisional monthly settlements adjusted ex-post through reassessments based on actual price trends. To this end, the regulatory framework is based on six-year regulatory periods divided into two three-year sub-periods. Specifically, the current period covers the six years 2020–2025, divided into two sub-periods (2020–2022 and 2023–2025). The resettlement is carried out at the end of each sub-period. It may involve additional income for renewables

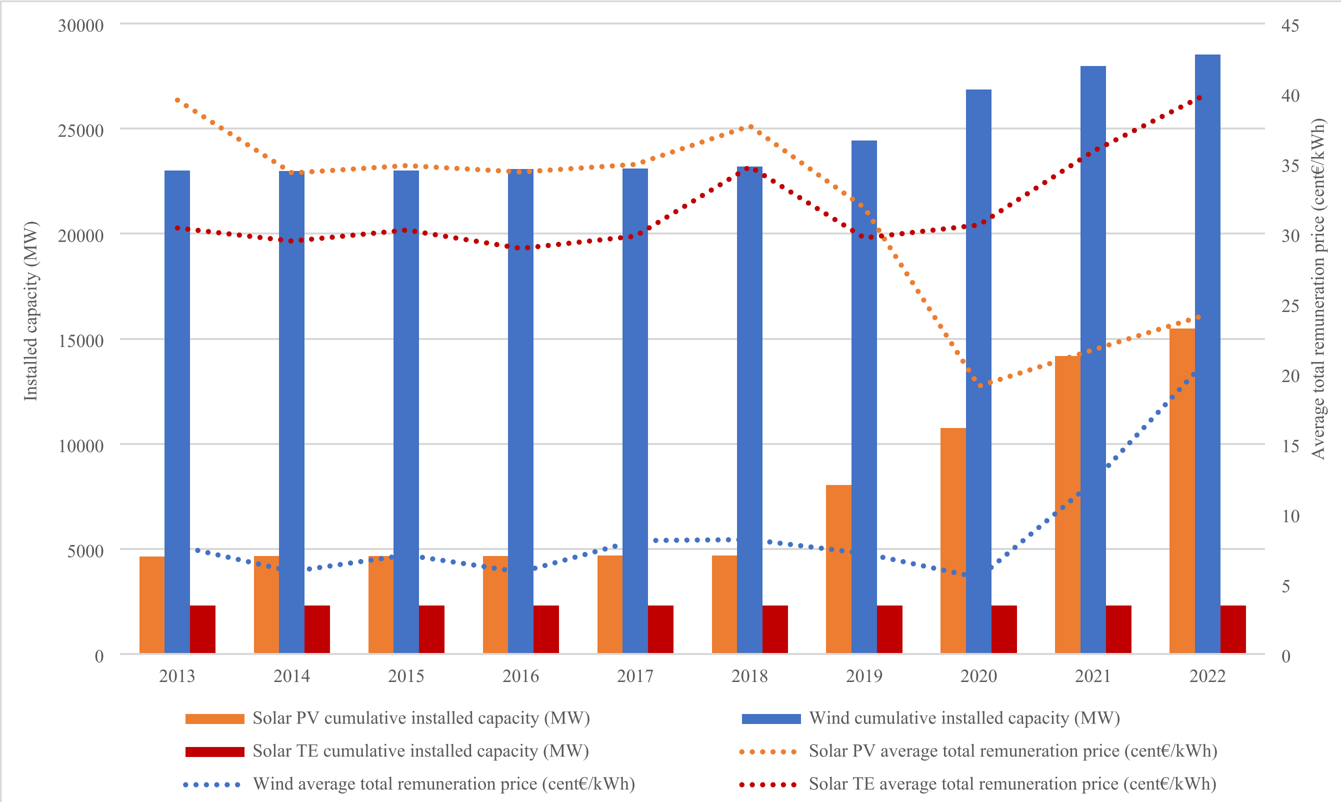

Fig. 9. Evolution of cumulative installed capacity (MW) and average total remuneration price (in cent€/kWh) from 2013 to 2022 under the SRR. Source: Adapted from [126].

if the actual market price was lower than expected or refunds to the settlement system if it was higher than expected.

Considering the evolution of the final market price, it is highly foreseeable that the price estimate used in this period will fall short. Therefore, renewables must return significant overpayments to the system from 2023 onwards.

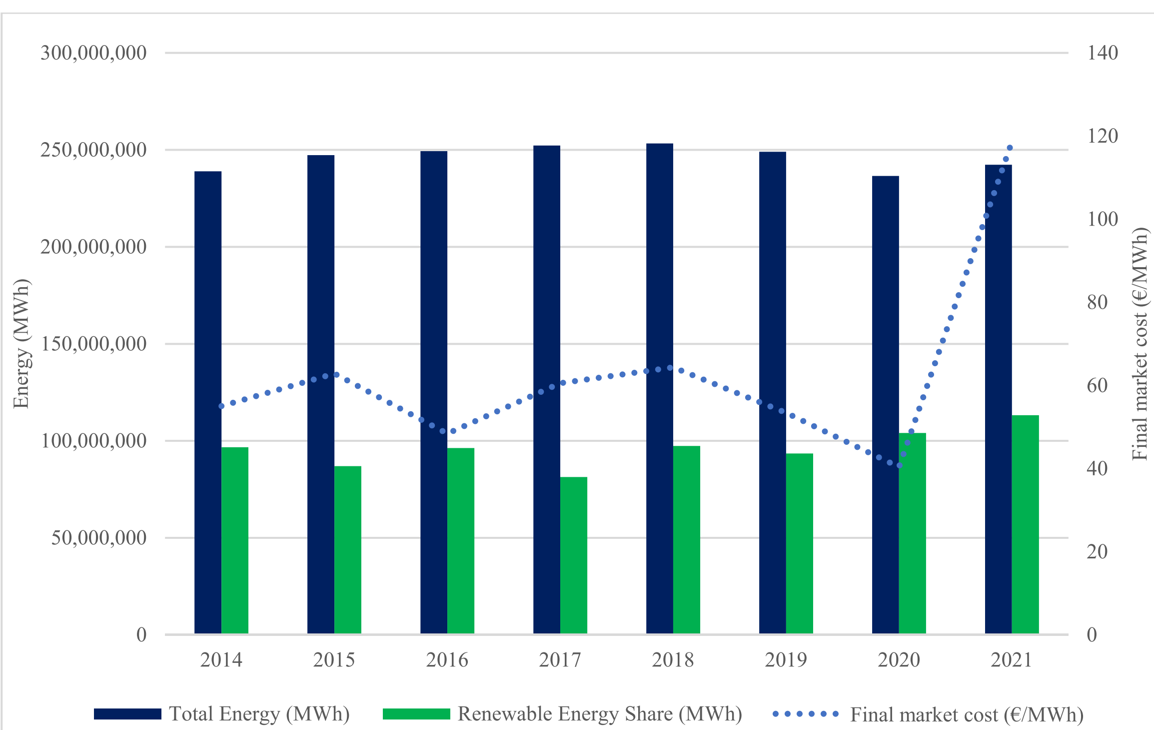

Fig. 10. Evolution of total and renewable energy production and final market cost. Source: Adapted from [126].

4.3. Impact on market share, generated energy, and final market cost

The integration of renewable energy into the Spanish electricity market has had a multifaceted impact, influencing market share, generated energy, and final market costs. As depicted in Fig. 10 and Table 3, renewable energy production peaked at 46.71 % in 2021. Previously, in the period 2015–2019, there were some fluctuations. All provided data are based on public market results published by the Spanish market operator and regulator [126]. Despite this fluctuation, total installed capacity has continuously increased throughout the analyzed period, exceeding all objectives set by Spanish authorities and the European Union (Fig. 4).

The final market cost is calculated as the spot market price by adding different operational expenses incurred for market functioning incorporated into the spot market price to obtain the actual cost. These extra costs include various operational expenditures for market operation, including regulator and operator costs, capacity payments to generators to maintain readiness for additional generation demands, secondary and tertiary regulation costs, energy demand forecasting costs, and actual demand diversion-derived costs.

Despite efforts to control costs, the final market cost has experienced a significant rise in recent years. This increase is partly attributed to the escalating cost of natural gas, Spain's primary fuel for electricity generation. Additionally, the cost of renewable energy subsidies has increased as renewables' share in the energy mix has expanded. The Spanish government has implemented measures to address the rising cost of electricity, including investments in renewable energy and energy efficiency initiatives. However, the cost of electricity is likely to remain elevated shortly due to various factors, including the ongoing global energy crisis and the need to invest in grid infrastructure to accommodate the increasing share of renewables.

4.4. Impact of remuneration regimes on current market dynamics

The coexistence of diverse remuneration regimes for renewable energy installations has significantly impacted the Spanish electricity market. The old FiT and FiP schemes for the oldest renewable energy plants will continue to provide generous subsidies for quite some time, as the regulatory useful lives of the facilities are long. In contrast, newer renewable installations are primarily entering the market through auction processes, receiving a fixed price for their electricity, with regulated remuneration only coming into play if market prices fall substantially. Additionally, some renewable generators participate directly in the market, selling their electricity at the prevailing market price without receiving any regulated remuneration.

This diverse remuneration landscape has influenced the cost of renewable energy support schemes and the final energy costs for consumers. The FiT schemes initially contributed to higher consumer costs, while the introduction of auctions and increased market participation have helped to moderate these costs.

In Spain, these market dynamics, scenarios, and support schemes are now coexisting with the large deployment of the Power Purchase Agreement (PPA), which is a type of long-term supply contract that allows energy-consuming companies to ensure a RE supply with a fixed and predictable price in the long term [31]. On the other hand, RE generators ensure a future sale of all or part of the energy produced at a fixed price a certain price. This represents a novel scenario that requires specific regulation as the PPAs can operate mainly under three schemes: 1) PPAs for self-consumption, where a RE generation plant produces energy that is directly consumed by the purchased a fixed price; 2) physical PPAs, that comprises physical sale of energy and 3) financial PPAs that does not include physical energy supply and are based on a compensation scheme for the market purchase price and the fixed PPA cost [166]. This new scenario lacks a specific regulatory framework in Spain. Still, the market share is continuously increasing, and this new model will represent an important new paradigm in renewable energy supply.

4.5. Market distortions avoidance and future considerations

The complex regulatory framework surrounding renewable energy remuneration has raised concerns about potential market distortions, particularly in windfall profits from rising CO_2 emissions prices. Designing regulatory mechanisms that balance market efficiency with fair compensation for non-emitting technologies is crucial to prevent market distortions and maintain public support for renewable energy policies.

As the Spanish renewable energy sector matures, the regulatory framework must adapt to ensure a balanced approach that supports renewable deployment while maintaining market efficiency and addressing market distortions. Defining a clear and stable regulatory framework for the future is essential to attract investment and ensure the continued growth of renewable energy in Spain. Additionally, striking a balance between the incomes received by renewable generators and the costs borne by consumers will be crucial to maintaining public support for renewable energy policies. Developing effective mechanisms to address windfall profits from CO_2 emissions pricing will be necessary to prevent market distortions and protect consumers.

4.6. Study of renewable energy path in Spain

As analyzed and shown in previous sections, Spain experienced remarkable growth in wind power, solar PV, and solar TE production under a more favorable policy environment and technological advancements in recent years. Spain's Integrated National Energy and Climate Plan 2021–2030 [5] projected a significant increase in renewable energy production compared to the previous scenarios [11]. This ambitious plan has propelled Spain to the forefront of renewable development, surpassing all other EU nations in key factors such as wind power capacity installations [12]. These achievements demonstrate Spain's commitment to renewable energy and its strategic position as a global technology leader. They have served as examples to the International Energy Agency (IEA), which reported that Spain is progressing toward its 2030 targets, especially in the electricity sector [160]. Overall, it can be said that the Spanish government is working to expand renewable installations throughout the country and promote the use of renewables for industry and heating. Additionally, the production of advanced biofuels, renewable gases, and hydrogen is in the country's pathway [167]. However, if Spain aims to achieve its renewable energy targets, it must continue investing in new renewable energy projects and developing a supportive regulatory framework. The country also needs to address the challenges of intermittency and storage, which are key

Table 3
Evolution total energy and renewable energy production and final market cost. Source: Adapted from [126].

	2014	2015	2016	2017	2018	2019	2020	2021
Spot market cost (€/MWh)	43.46	51.67	40.63	53.41	58.12	48.58	35.21	113.17
Final market cost (€/MWh)	55.05	62.84	48.42	60.55	64.37	53.41	40.38	118.69
Total Energy (MWh)	238,985,133	247,272,773	249,365,738	252,278,917	253,286,725	249,000,239	236,538,585	242,356,970
Renewable Energy Production (MWh)	96,734,012	86,988,088	96,275,124	81,377,610	97,386,212	93,472,199	104,067,515	113,212,211
Renewable Energy Share (%)	40.48 %	35.18 %	38.61 %	32.26 %	38.45 %	37.54 %	44.00 %	46.71 %

issues for integrating renewable energy into the electricity grid [168]. Despite these challenges, Spain is well-placed to remain a leader in renewable energy development. The country has a strong track record of renewable energy deployment and has several advantages that could help it achieve its ambitious goals. Among them: it has a good endowment of RES; several policies to support renewable energy have been implemented; the country has a large and growing demand for electricity, which provides a substantial market for renewable energy projects; it has a strong track record of renewable energy technology development and manufacturing.

Regarding this initiated pathway, this study demonstrates that integrating renewable energy into the Spanish electricity market has had a multifaceted impact, influencing market share, generated energy, and final market costs. Concretely, the diverse remuneration regimes have introduced complexities but have also contributed to the growth of renewable energy. In this sense, addressing market distortions and ensuring a balanced regulatory framework will be crucial for the continued success of renewable energy in Spain.

5. Conclusions and implications for renewable energy promotion policies

This research analyzes the most important support schemes for RE deployment and particularly studies the Spain case study, as it presents important aspects that can be useful for potential similar scenarios. As shown in this research, the Spanish case can be used as an example of how different support schemes for renewable energy (mainly wind and solar energy) can be introduced to support and encourage renewable energy generation effectively. The research presented here examines various mechanisms established from 2005 to date, assessing their ability to produce the desired outcome in supporting the implementation of clean energy projects and how the inefficiencies of the different systems have made necessary subsequent modifications in the retribution scheme. The different support schemes have evolved from a FiT to a FiP to a remuneration plan based on specific technologies and aiming to promote potential investors in the power field that, if this scheme did not exist, could have no incentive to choose renewable energy plants over conventional ones. The analysis results show that the lack of a correct limitation of installed power under FiT regulation can lead to a vast increase in installed power and associated costs that can make the whole market an unfeasible one, but, on the other hand, it is an effective strategy in countries where the renewable energy development is in its initial phase if correct supervision of installed capacity is provided. The associated costs to renewable energy support in the final costs for consumers can be compensated with the additional benefits related to a global reduction in the non-renewable spot prices because of the minor required contribution of conventional sources.

The most relevant conclusions and also policies associated with risks analyzed here can be used as a roadmap scheme for any other country aiming to develop their renewable energy generation as it has proved to be an effective way to achieve or even surpass the renewable energy generation objectives and the risks and regulative failures that happened in Spain can be used as a model to avoid similar scenarios. It must be noted that the large regulatory lifetime for these plants, up to 30 years, extends the associated costs for a long period in which many of these new technologies would have achieved their market maturity, and these costs can affect the whole market feasibility and, therefore, a detailed and exhaustive planning is required. Finally, with a mature market that makes possible the integration of new plants at a reasonable cost, Spain and other similar markets have to propose a regulatory framework that avoids the excess retribution associated with CO_2 emission taxes in non-emitting technologies but without compromising the renewable energy generation objectives and the feasibility of operating plants.

CRediT authorship contribution statement

Enrique Rosales-Asensio: Writing – original draft, Methodology, Conceptualization. **David Borge Diez:** Writing – original draft, Data curation. **Pedro Cabrera:** Writing – review & editing, Validation, Supervision. **Paula Sarmento:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

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

Data availability

The link to the data has been shared in the paper

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