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Multilevel governance, PV solar energy, and entrepreneurship: the generation of green hydrogen as a fuel of renewable origin

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ABSTRACT

In Spain, the institutional framework for photovoltaic energy production has experienced distinct stages. From 2007 to 2012, the feed-in-tariff system led to high annual growth rates of this renewable energy, but after the suppression of the policy of public subsidies, the sector stagnated. In recent years, green hydrogen, an innocuous gas in the atmosphere, has become a driving force that stimulates photovoltaic energy production. Since 2020, encouraged by the European energy strategies and corresponding funds, Spain has established a regulation to promote green hydrogen as a form of energy resource. Adopting the new institutional economics (NIE) approach, this article investigates the process of changing incentives for the energy business sector and its impact on photovoltaic energy production. The results show an increase in the number of both projects, approved or on approval, and companies involved in green hydrogen, that are planning to use photovoltaic energy in Spain, thus engendering the creation of a new photovoltaic business environment based on innovation and sustainability.

1. Introduction

Climate change is a widely accepted reality (Taube et al., 2021). Its negative impact, both biophysical and economic, has resulted in floods, melting ice and sea level rise, droughts, deforestation, and increased anthropogenic pressure (Cook et al., 2018; Dellink et al., 2019; Lambin et al., 2018; Moon et al., 2018; Rojas et al., 2013; Slater et al., 2020; Thuiller et al., 2011). Given the gravity of the situation, there has been a succession of international initiatives to mitigate the effects of this phenomenon, the most important being the Paris Agreement adopted in December 2015. According to this agreement, the 55 signatory countries undertook to keep the global average temperature below 2 °C above pre-industrial levels (Correia-da-Silva et al., 2020; Gao et al., 2017). The gas that contributes most to global warming is CO2; its emissions fell by 5.8% worldwide in 2020 (Stoll and Mehling, 2020), representing the most significant reduction in CO2 emissions since records have been available. However, despite this single beneficial effect of the economic activity shut down due to the COVID-19 pandemic crisis, emissions are predicted to increase by 4.8% in 2021 (Liu et al., 2020).

In turn, the European Union established that greenhouse gas emissions must be reduced by 55% in 2030 through the "Fit for 55″ program, which is part of the European Green Deal (European Commission, 2019, 2021a). The most ambitious objective of this supranational entity is to achieve climate neutrality by 2050. The measures to achieve these commitments are specified in the European Climate Law (European Parliament, 2021). Although efforts have been redoubled since the 1990s, the EU has been leading the fight against climate change by approving and applying active policies regarding environmental protection in its member countries (Rehfeldt et al., 2020). In the last ten years, the succession of European guidelines against climate change has been prolific ("Climate change adaptation strategy" in 2013, "Policy framework for climate and energy from 2020 to 2030″ in 2014, and "A clean planet for all" in 2018) (Keppo et al., 2022; Rayner and Jordan, 2016). Concerning the European institutional framework for renewable resources, the Renewable Energy Directive (RED), approved in 2009, laid the foundations for the current recast Renewable Energy Directive (RED II), which establishes the objective that by 2030 renewable resources should account for 32% of gross final energy consumption (Official Journal of the European Union, 2009). The RED II Directive, revised in 2018, is undergoing a second revision to adapt it to the new EU climate regulatory framework (European Commission, 2022a).

Given the importance of energy in human activity, the European authorities place consumers at the core of the policies promoted. Ensuring sustainable energy at affordable prices and in a competitive

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manner represents the main objectives set by the establishment of the Energy Union in 2015 (European Council For an Energy Efficient Economy, 2022). The complexity of the energy transition phenomenon, in which the countries of the European Union have been extensively involved, has engendered interconnections pursued at the European and national levels through specific tools and mechanisms. The most critical dimension is energy security, the reality of 2022 demonstrating the need to reduce dependence on specific resources from Russia, considering the economic and political consequences involved. The reconfiguration of the energy transition strategy is necessary as increased member states try reviving previously abandoned projects to recharge coal for energy production (European Commission, 2022b). Therefore, in the current context, the metamorphosis of the European energy transition strategy is a reality which intensifies the public authorities' concern with energy security as a critical issue.

The economic crisis brought about by the COVID-19 pandemic has outlined a new social scenario, which has resulted in the creation of specific financial engineering adapted to the needs of the European Union (Birindelli and Chiappini, 2021). Two major financial instruments are the multi-annual financial framework 2021–2027 and the Next Generation EU recovery plan (Cifuentes-Faura, 2021). Among the seven categories that constitute these two plans, there is also the "Natural resources and environment" plan, which assigns the new EU green economy its identity and funding (European Commission, 2021a).

As a member of the European Union, Spain is also a beneficiary of the post-COVID-19 recovery plans. The received European funding is conditional on approving an investment plan that structures the expenditure. Consequently, the Spanish government approved the "Plan for the Recovery, Transformation, and Resilience of the Economy" (Crescenzi et al., 2021; La Moncloa. Gobierno de La Moncloa.de España, 2021). One of its main lines of action is represented by the ecological transition, which provides financing and infrastructure for the promotion of renewable resources. Major programs of the plan promote green hydrogen as a form of energy storage, aiming to use photovoltaic solar energy as one of its essential sources of production. By 2020, 96% of hydrogen production has used natural gas, resulting in high CO2 emissions. The European Commission has set up a dedicated hydrogen strategy for Europe to highlight the potential of green hydrogen production through renewable resources. This initiative has resulted in its member countries, including Spain, creating national strategies (European Commission, 2020a). The promotion of this fuel was already included in measure 1.7 of the Spanish National Energy and Climate Plan, submitted to the European Commission in 2019 (European Commission, 2021b). Like the other member countries, Spain described its climate and energy strategy, and hydrogen was deemed an essential part of the solution to the challenges faced by sustainable transport and energy storage.

Adopting the New Institutional Economics approach, this article analyses the change in the governance of the solar PV sector and attempts to answer the question of whether the new incentive scenario created in Spain will boost solar PV electricity production. Although there are examples in academia of the technical relationship between hydrogen and solar energy (García-Magariño and Belintxon, 2021; Kakoulaki et al., 2021; Longoria et al., 2021; Touili et al., 2020) or on Spanish energy policy (Bean et al., 2017; Blanco et al., 2021; Duffield, 2021; García-Alvarez and Mariz-Pérez, 2012; Gürtler et al., 2019; Marques et al., 2019; Martín-García et al., 2020) and more specifically, those concerning the regulation of solar photovoltaic energy (Fernández-González et al., 2020, 2021a; García-Álvarez et al., 2018; López Prol, 2018), the novelty of this article lies in the fact that it combines the study of the regulatory framework with that of the promotion of a new way to boost renewable energy through green hydrogen.

The article is structured as follows: Section 2 outlines the foundations of the methodology applied to the case study on the process of institutional change. Section 3 describes the evolution of the changes in the governance of solar energy policy in Spain, focusing on the potential growth of the green hydrogen sector. Section 4 enlarges upon the discussions and conclusions of the article.

2. Methodology: the new institutional economics and institutional change

Williamson (1975) introduced the new academic term "New Institutional Economics". Along with North and Coase (Coase, 1984; North, 1986), Williamson is one of the most prominent representatives of this economic approach, although other authors have also contributed to the development of NIE through their research, such as Ostrom (Ostrom, 1990, 2002, 2007, 2009), Weingast (Weingast, 1993, 1995, 2008), Eggertsson (Eggertsson, 1990, 1997, 2013), Ménard and Shirley (Ménard and Shirley, 2005, 2014) and Rutherford (Rutherford, 1989, 1995).

The institutions represent the central concept of the NIE approach. Hodgson (2006) defines institutions as " (…) systems of established and prevalent social rules that structure social interactions" (Hodgson, 2006) (p. 2). Institutions are presented in the form of rules, norms, and constraints and are divided into three categories: (i) formal rules, such as laws, constitutions, property rights, or written agreements, (ii) informal rules, which include beliefs, traditions, customs or unwritten codes of behavior, and (iii) enforcement mechanisms, i.e. instruments to ensure the achievement of formal and informal rules (Ménard and Shirley, 2005; Douglass C North, 1991). Agents engage in transactions to satisfy their needs in an environment where resources are scarce. However, these transactions imply control, definition, and compliance costs. These are the so-called transaction costs, a basic notion of NIE. In addition, the concept of property rights results from rules and determines the authorized actions an agent is allowed to take in the economy (Coase, 1988; North, 1987).

The need for developing an innovative approach to the study of economics derives from the strictness with which neoclassical economics, the prevailing school of thought in economics during the twentieth century, approached social reality. Neoclassical economics excluded from its analysis the complex interrelationships between the legal and judicial system, beliefs and traditions, culture, and social structure (Coase, 1998; Vromen, 1995). Consequently, in many cases, the study of practical cases showed that the reality did not conform to the optimal outcome of neoclassical theory (market without externalities, complete markets, or price equal to marginal cost), and this reality was labeled as a market failure. Implemented policies might not have been entirely appropriate since their design left out market-influencing institutional factors (Posner, 1993).

The new institutionalists do not entirely reject neoclassical economics, as the old institutionalists did; instead, they propose an updated view of economics by advocating a more integrated approach enriched with concepts that may belong to other scientific disciplines. Thus, NIE adopts the neo-classical foundations of scarcity and competition and its analytical tools (North, 1993, 1994). However, it also incorporates the notions of bounded rationality and "path dependence", where the time path and reputation of the parties involved in a transaction determine the potential outcomes of economic exchanges.

Institutions determine social, economic, and political interaction (Douglass C North, 1991). Their influence has been latent throughout history and evolving. Providing an institutional framework guarantees property rights, minimizes transaction costs, and protects people to achieve sustained development. This way, confidence in the market will be strengthened, and agents will increase their incentives to trade (Shirley, 2005). The historical component of institutions is intricately linked to the previously discussed term "path dependence". In practice, this means the impact of that past action upon the present and future performance. Thus, both reputation and past interactions determine part of the market incentives. Negative past experiences can enhance distrust, increasing transaction costs and producing inefficient economic outcomes (Sitkin and Roth, 1993). There are cases in which high transaction costs prevent the approval or enforcement of rules that would benefit the market. If the legitimacy of the authority approving these rules is questionable, the probability of failure is high. Institutional change is an incremental process with past dependence, affected by underlying market structures and forces (Farrell and Knight, 2003; Scott, 2010). Analyzing the institutional diversity of social environments is needed to apply the rules that determine exchanges in the economy successfully. Case studies, such as the one presented in this article, are indispensable to this aim.

To facilitate the understanding of the institutional framework, we analyze the case study following the approach proposed by Williamson (2000: 596). This approach differentiates four levels of analysis that can be adopted in the application of the NEI methodology. The first level analyzes informal rules, such as culture, religion, or popular beliefs. As reiterated by Williamson, these rules result from a long-term evolutionary process of communities and are situated at the level of social theory but not in the rigorous study of economics since their slow evolution implies that they represent deeply entrenched factors. The second level focuses on formal rules, which result from economic activity derived from a process of collective choice. This level analyzes the elaboration of laws, decrees, and constitutions and points out the role of each of the branches of government (legislative, executive, and judicial) in defining and changing the formal framework of society. The third level introduces the institutions of governance, highlighting the extent to which their functioning encourages or discourages the conclusion of contracts. At the same time, it also evaluates the application of enforcement mechanisms. Thus, the effect of the governance formulas in force in society and their consequences on economic exchanges are studied. Finally, the fourth level focuses on the allocation of resources and labor. This level is the closest to neoclassical economics since it is based on agency theory and regulates prices and outputs through marginal returns.

Future research will address level 1, which focuses on informal rules and whose methodology requires a long-term historical analysis or plenty of surveys and interviews (North, 1991, p 111), and level 4, based on marginal analysis. Therefore, the study conducted in this article focuses on levels 2 and 3 of Williamson's approach. To this aim, an investigation of the evolution of the formal rules and their implications in the Spanish solar sector will be conducted. In this way, it will be outlined the trend followed in the modification of the rules and its consequences for the sector will be identified. In addition, the governance formula applicable to this industry will be analyzed, in this case, a multilevel structure, where the supranational agent, the EU, has high bargaining power and determines national energy policy.

3. Institutional change in the Spanish photovoltaic sector

The energy sector has had a heterogeneous trend in Spain in the last two decades, and it is thus necessary to analyze the institutional framework in which its activity has taken place. Analyzing the formal regulations, the actors involved, and governance will contribute to a thorough understanding of a sector that is becoming increasingly important at the economic and social levels. It is also essential to consider whether any negative interactions may have diminished the incentives provided to invest in the sector. Thus, Section 3 will analyze the institutional change in the sector, including the formal rules defining macroeconomic policy, the actors involved, and the governance structure.

The increasing social concern about climate change has led to the creation of new global energy governance (Ciplet and Roberts, 2017; Hess and Renner, 2019). Solar energy and wind energy have shown the most substantial growth given their low CO2 emissions and lower dependence on biophysical conditions (as opposed to hydroelectric energy) (Liu and van den Bergh, 2020). In developed countries, there has been a succession of policies to support photovoltaic energy, which has been adapted to the changes in this market, such as the decrease in raw material costs and the increase in competitors, as well as to the political, economic, and social conditions of the region (Griffiths, 2017). During the 21st century, Spain has passed different energy laws that have marked the solar PV market's discrete stages of expansion and recession.

3.1. *Feed-in tariff and its cancellation*

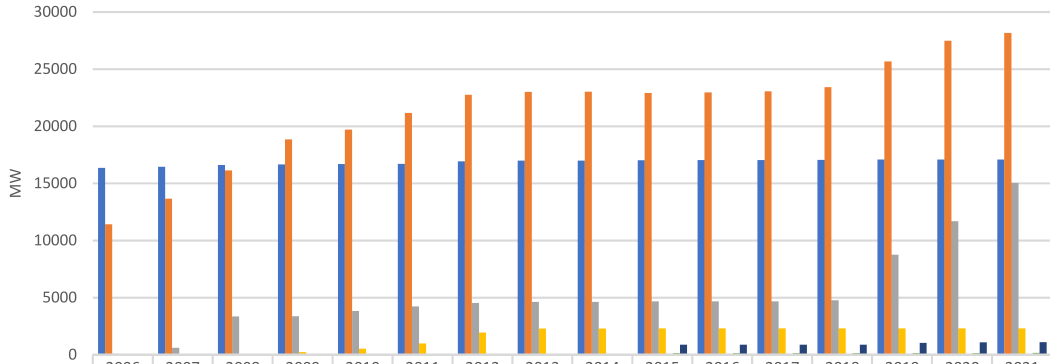
European Union membership has had a decisive influence on the development of the energy sector in Spain. In 1996, the Council of the Union approved the Directive on Common Rules for the Internal Electricity Market to promote free competition. Spain was one of the first countries to adopt this directive, with the approval of Law 54/1997 on the Electricity Sector, which introduced substantial regulatory changes in the country's electricity sector's history (Salas and Olías, 2009; Sánchez-Ortiz et al., 2016).

As a result of the approval of Law 54/1997, the deregulated electricity market began operating in Spain on January 1, 1998. The main consequences of this legislative process were (i) a decrease in the degree of intervention of the Spanish government in the electricity market, (ii) free access to generation and access the electricity transmission and distribution networks, and (iii) the implementation of the right to decide on behalf of consumers, which electricity company contracts their services from (Urzaiz, 1998). Royal Decree (RD) 2019/1997, which complemented Law 54/1997, introduced the Feed-in Tariff (FIT) system for renewable resources, boosting wind energy generation in Spain (Gallego-Castillo and Victoria, 2015). Regarding photovoltaic solar energy, RD 2818/1998 was the one that included this type of energy in the FIT system.

However, the boom of photovoltaic energy derived from state premiums occurred with the approval of RD 661/2007 and RD 1578/2008 (Fig. 1) (Mir-Artigues et al., 2018). The entry into force of this new regulation was due to the need to accelerate compliance with the goals established in the Spanish renewable energy plan (2005–2010), and these were achieved due to the high growth rates of photovoltaic energy between 2007 and 2008 (Fig. 2). The new FIT system, especially beneficial for PV installations with capacity >100 kW and ≤10 MW, together with the lower risk associated with PV power production, as electricity prices no longer determined the level of support, attracted investors looking for a new refuge sector to diversify investments from the once lucrative construction sector (Red Eléctrica de España, 2021a; Talavera et al., 2016).

Solar photovoltaic energy was promoted institutionally mainly for two reasons. The first was since, in Spain, there is a high availability of the natural resource for solar PV: solar radiation. This argument concerning suitable climatic conditions also applies to wind energy. However, the high initial investment for implementing wind infrastructure was a barrier to entry for small investors. Therefore, the second reason for boosting photovoltaic solar energy is related to the relatively low initial investment, which encouraged many investors to commit to photovoltaic energy in a context of crisis where the construction sector, the traditional haven sector in Spain, was no longer so profitable (Fernández-González et al., 2021b).

The FIT system had as its primary beneficiaries solar PV production companies, whether they had a low production capacity (less than or equal to 20 kW) or medium/high capacity (greater than 20 kW). Even though the legislation on state subsidies for photovoltaic energy also included self-production facilities as beneficiaries, the scope of the FIT system for this type of facility was much smaller than in the private sector (Table 1). The reason for this phenomenon is related to the conditions stipulated by the Spanish administration for self-consumption: it took an average of 45 days to complete the bureaucratic process for a self-consumption installation, the consumption tax applied was 21%, connection to medium voltage electricity was not allowed, installations over 100 kW were required to have a grid connection point, and collective self-consumption was not allowed unless it was located within 500 m of a generation and consumption point. The institutional



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Hydro	16364	16450	16614	16657	16688	16705	16928	16986	16992	17042	17050	17054	17064	17099	17098	17094
Wind	11416	13664	16133	18861	19707	21167	22758	23009	23028	22919	22971	23064	23429	25678	27497	28175
Solar photovoltaic	125	618	3351	3392	3829	4233	4532	4638	4646	4681	4686	4688	4767	8755	11685	15048
Thermal solar	11	11	61	232	532	999	1950	2299	2299	2304	2304	2304	2304	2304	2304	2304
Hydroeolian	0	0	0	0	0	0	0	0	11	11	11	11	11	11	11	11
Renewable waste biomass	0	0	0	0	0	0	0	0	0	153	153	157	157	157	157	170
Other renewables	0	0	0	0	0	0	0	0	0	887	890	886	891	1042	1091	1093

Fig. 1. Renewable installed capacity in Spain. Source: Own elaboration based on Eurostat (2021).

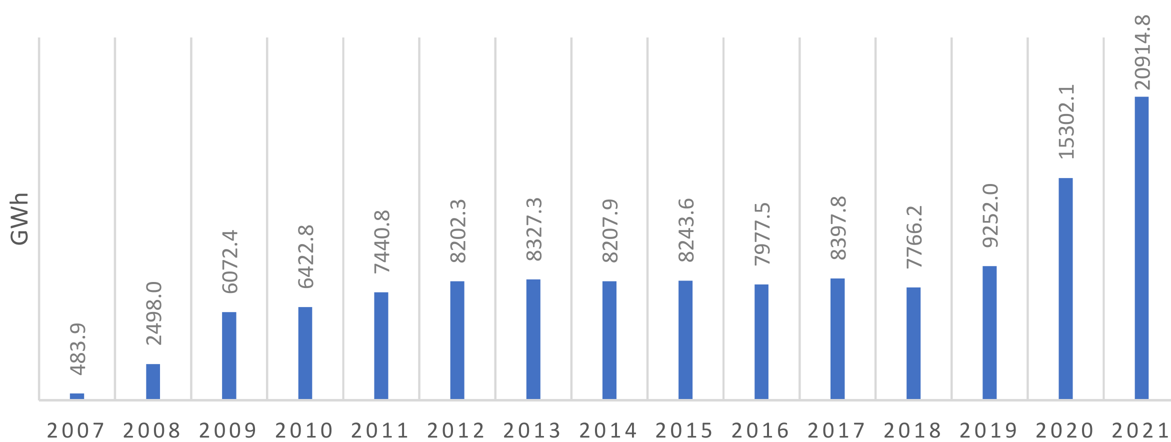


Fig. 2. Photovoltaic solar energy generation in Spain. Source: Own elaboration based on Red Eléctrica de España (2021a).

obstacles reduced self-consumption to a residual part of the subsidized PV installations. Most public resources subsidized photovoltaic companies, which grew in number year after year, aggravating the Spanish electricity tariff deficit (UNEF, 2013). Even though tariff revenues since 2006 were reduced, the Spanish Government decided to maintain the low level of regulated electricity tariffs. As a result, in 2011, a tariff deficit of €24 billion was accumulated. In the social debate, the Spanish government was encouraged to reduce the deficit by using the funds allocated to the FIT system applied to photovoltaic energy.

Nevertheless, the Spanish energy tariff system was inefficiently designed. In 2005, in the face of rising wholesale electricity prices, electricity tariffs remained stable. Regulated tariffs were lower than market prices, ranging from €8/MWh (small companies) to €47/MWh (large companies) (Journal officiel de l'Union européenne C 43/9, 2007). The performance of this system resulted in an overall deficit of €3811 million. In a scenario in which the country was going through a deep economic crisis, this situation, in which a considerable amount of revenue was derived from the energy sector, was unsustainable.

For this reason, in 2010, RD 14/2010 was approved, which adopted urgent measures to reduce the tariff deficit. This Royal Decree proposed the division of the Spanish territory into five zones according to the intensity of solar radiation and established several maximum daily hours to produce photovoltaic solar energy. Finally, in 2012, via Royal Decree-Law 1/2012, the Spanish central government significantly decreased subsidies to all types of pre-existing solar PV production facilities and canceled calls for the registration of new PV projects, preventing new installations from benefiting from public incentives (Álvarez-Díaz et al., 2017; Dufo-López and Bernal-Agustín, 2015).

A consequence of the cancellation of the feed-in tariff system was a sharp decrease in the number of new PV installations from 2012 onwards. This recession stage in solar PV was consolidated with the approval of Royal Decree-Law September 2013 and Law 24/2013, which is still in force and represents the primary energy regulation in Spain (Red Eléctrica de España, 2021b). This legislative framework relies on the concept of "reasonable profitability", whereby producers receive the wholesale price of electricity plus a bonus, which depends on the specific parameters of each plant, whose objective is to cover the investment and operating costs of the plant (Mir-Artigues et al., 2018). Imposing these measures, the central government has decreased the share of the energy debt derived from the FIT system, but, at the same time, the attractiveness of the renewable energy market is much lower, and thus the five-year period following the approval of these laws has presented a stagnation phase in the solar PV sector (Fig. 3) (Aragonés et al., 2016).

Table 1
Beneficiaries of the FIT system in Spain according to the legislation. Source: Own elaboration based on IDAE (2021).

Legislation	FIT beneficiaries	Types of beneficiaries	Status
Royal Decree 436/2004	Electrical energy production facilities referred to in article 27.1 of Law 54/1997.	a) Auto-producers. b) Installations with renewable primary energy.	Royal Decree repealed by Royal Decree 661/2007.
Royal Decree 661/2007	Electrical energy production facilities referred to in article 27.1 of Law 54/1997.	a) Producers that use cogeneration or base their production on residual energies. b) Installations with renewable primary energy.	Royal Decree repealed by Royal Decree-Law September 2013.
Royal Decree 1578/2008	Photovoltaic installations are registered in the special regime's administrative registry of production facilities.	a) Installations on roofs or façades of buildings. b) Other types of photovoltaic energy-producing installations.	Royal Decree repealed by Royal Decree-Law September 2013.
Royal Decree-Law January 2012	Photovoltaic installations registered in the Administrative Register of Installations before 2012	a) Installations on roofs or façades of buildings. b) Other types of photovoltaic energy-producing installations.	Royal Decree-Law in force.

3.2. The promotion of photovoltaic energy through the European Green Deal

The forecasts for solar PV production capacity in Spain show an upward growth trend in the coming years (Table 2). A determining factor in promoting this favorable scenario is the approval of the European Green Deal, which is part of the climate action strategy of the European Union (European Commision, 2019a). The European Green Deal is the new European climate strategy, and its main objective is to make the European Union the first climate-neutral region in the world by 2050 (Montanarella and Panagos, 2021). To this aim, the plan envisages far-reaching reforms in the economic, social, and industrial fields, whereas, for renewable resources, the production targets and the reduction of polluting gas emissions are even more ambitious than in previous European strategies (Schuelke-Leech, 2021). By 2050, renewable resources should be responsible for more than 74% of the European energy share, while coal should be phased out by the same date. In addition, the target for reducing gas emissions for 2030 is updated: it is increased from the current −43% to −63% compared to the value recorded in 2005 (reference year) (Pietzcker et al., 2021).

Photovoltaic energy has a central role in the Green Deal. This technology has reached technological maturity and has a solid legal framework, so these characteristics make it a fundamental pillar for EU climate policies (Jäger-Waldau, 2020). In order to achieve the proposed 200 emissions reduction target, 21–22 GWac of solar PV must be installed per year (Kougias et al., 2021). This scenario would require successive growth rates in PV installation higher than the historical EU peak values. Therefore, fostering the PV market beyond residential and industrial self-consumption and auctions is necessary. Commercial production should lead to PV growth, and the possibility of storage provided by green hydrogen has emerged as an alternative to explore (Jäger-Waldau, 2020).

The adoption of the Green Deal expanded the European regulatory framework for renewable energy. The Green Deal complemented an existing regulatory framework to achieve EU climate neutrality, which was based on Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate and the Renewable Energy Directive (RED) II (European Parliament, 2018a, 2018b). These directives included harmonising the European energy strategy and requiring each member country to implement a national energy plan. Spain approved the National Integrated Energy and Climate Change Plan (PNIE) (2021–2030) in 2020, which is currently being revised to incorporate the new requirements of the Green Deal. This plan included the following objectives for 2030: to increase the share of renewable resources in electricity generation to 42%, to reduce hydrocarbon imports by 12%, and to save

Table 2
Solar PV generation, low and high demand scenario, Spain, 2015–2030. Source: Own elaboration based on Ministry for the ecological transition and the demographic challenge (2020).

	Total capacity (MW)		Net additions (MW)	
	Low demand scenario	High demand scenario	Low demand scenario	High demand scenario
2015	4681	4681	–	–
2020	11,685	11,685	7004	7004
2025[a]	13,921	21,713	2236	10,028
2030[a]	18,921	39,181	5000	17,468

[a] The data for 2025 and 2030 are estimates.

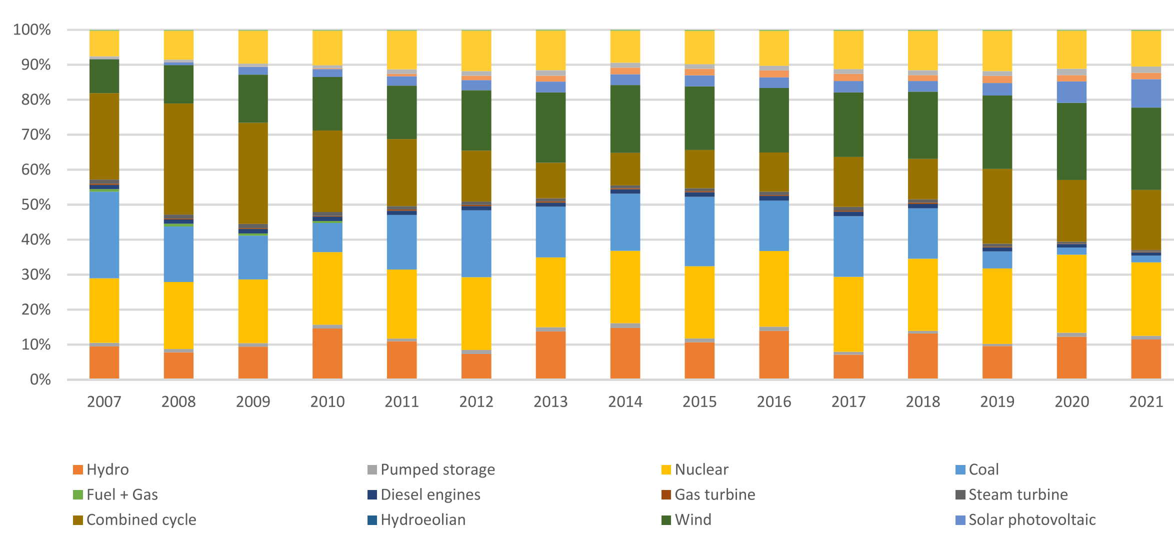


Fig. 3. Structure of generation by technology in Spain (GWh). Source: Own elaboration based on Red Eléctrica de España (2021a).

67 billion euros by reducing the demand for fossil fuels (Ministerio para la transformación ecológica y el reto demográfico, 2020b). The primary renewable resources on which the energy transition was focused were wind and solar photovoltaic energy. The arguments put forward by the Spanish Ministry of Energy emphasized companies' high level of participation in the sector and the country's competitive position. At the residential level, photovoltaic energy emerged as the main source for increasing domestic renewable electricity generation to 9 GW by 2030. However, even though with the approval of Royal Decree 244/2019, the shared self-consumption, previously prohibited by Royal Decree 900/2015, was allowed, this measure was not enough for domestic PV consumption to thrive.

In the residential segment, self-consumption has not been consolidated. Consumer perception of the high costs of photovoltaic installation, insufficient supply to cover all domestic needs, and doubts about the durability and reliability of photovoltaic technology have limited the expansion of solar panels in Spanish households (Roldán Fernández et al., 2021). However, photovoltaic energy is during a new boom in the industrial sphere. Given the subsidies for innovation and implementation of solar parks, companies have invested in this energy. In addition, the price of photovoltaic technology, which is more competitive than its closest competitors, has boosted its recovery (Colasante et al., 2022).

3.3. European recovery plans and the boost for green hydrogen

In July 2020, the EU pledged to boost green hydrogen production to achieve the Green Deal targets and approved the "A hydrogen strategy for a climate-neutral Europe" to establish an institutional framework for its promotion. As part of this strategy, investment in electrolyzes (€24–42 billion), as well as in connections between electrolyzes and a solar photovoltaic and wind energy production capacity of 80–120 GW (€220–340 billion) is being implemented until 2030 (European Commission, 2020b).

This investment is channeled to the European Union member countries under the financing instruments of the "Next Generation EU" recovery plan. Likewise, the multilevel governance of the European Union means that each nation must elaborate its green hydrogen plan to encourage supply and demand of this type of energy, either through subsidies, public calls, or tax benefits, and consequently, also promote renewable energy sources such as solar photovoltaic and wind energy (Table 3) (European Commision, 2019b).

In the case of Spain, the general guidelines for the national green hydrogen plan design can be found in the "Recovery, Transformation and Resilience Plan". This Recovery Plan, designed in August 2020 and approved by the European Commission in 2021, is aligned with the EU's strategic agenda on ecological transition (Green Deal) and is a requirement for accessing Next Generation EU funds. It includes the Spanish industrial energy policy by 2030, which promotes the value chains of those industrial sectors with a substantial economic impact on the economy. These target sectors must promote a more sustainable production and consumption model, present a medium or high digital component, and drive Spain towards achieving the goal of zero emissions. The green hydrogen industry is one of the key sectors towards a fair and inclusive energy transition (Government of Spain, 2020).

To develop green hydrogen growth in a more concise and detailed way, in October 2020, by EU guidelines and within the EU's strategic energy and climate framework, Spain approved the "Green hydrogen roadmap: a commitment to renewable hydrogen". With European funds from the "Next Generation EU" program, the central government earmarked 1.5 billion euros, which, together with private investment, could increase to 8.9 billion euros by 2030. The plan includes sixty measures, including increasing the availability of land for the installation of large solar power plants. This plan is divided into several phases: the first is from 2020 to 2024, which is expected to reach an installed capacity of 300–600 MW electrolyzes in Spain. The second phase is from 2025 to 2030, in which hydrogen production is consolidated, and it is estimated that a reduction of 4.6 million tons of CO2 equivalent will be achieved. The third phase covers the 2030–2050 time horizon, in which it is intended to reach an installed capacity of electrolyzes of 40 GW. Given the combination of suitable climatic conditions, the maturity of the sector, and the legal security achieved in the last five years, Spain is

Table 3
Main European H_2 National strategies. Source: Own elaboration based on European Commission (2021b).

Country	Document, year	Deployment targets (2030)	Production	Public investment committed
Czech Republic	Hydrogen Strategy, 2021	Low-carbon demand: 97 kt H_2/yr.	Electrolysis	n.a.
France	Hydrogen Deployment Plan, 2018National Strategy for Decarbonized Hydrogen Development, 2020	6.5 GW electrolysis 20–40% industrial H_2 decarbonized 20,000–50,000 FC LDVs 800-2000 FC HDVs 400-1000 HRS	Electrolysis	EUR 7.2 bln by 2030
Germany	National Hydrogen Strategy, 2020	5 GW electrolysis	Electrolysis (renewable)	EUR 9 bln by 2030
Hungary	National Hydrogen Strategy, 2021	Production: 20 kt/yr of low-carbon H_2 16 kt/yr of carbon-free H_2 240 MW electrolysis Use: 34 kt/yr of low-carbon H_2 4800 FCEVs 20 HRSs	Electrolysis Fossil fuels with CCUS	n.a.
Italy	Piano Nazionale di Ripresa e Resilienza, (2021)	5 GW electrolysis 2% of the energy demand forecast by 2030	Electrolysis (renewables)	EUR 10 bln by 2030
Netherlands	National Climate Agreement, 2019 Government Strategy on Hydrogen, 2020	3–4 GW electrolysis 300,000 FC cars 3000 FC HDVs	Electrolysis (renewables) Natural gas with CCUS	EUR 70 mln/yr.
Portugal	National Hydrogen Strategy, 2020	2–2.5 GW electrolysis 1.5–2% TFEC 1–5% TFEC in road transport 2–5% TFEC in industry 10-15 vol% H_2 in the gas grid 3–5% TFEC in maritime transport 50–100 HRS	Electrolysis (renewables)	EUR 900 mln by 2030
Spain	National Hydrogen Roadmap, 2020	4 GW electrolysis 25% industrial H_2 decarbonized 5000–7500 FC LDVs-HDVs 150-200 FC buses 100-150 HRSs	Electrolysis (renewables)	EUR 8.9 bln by 2030

committed to photovoltaic solar energy as one of the primary resources for the generation of green hydrogen as a fuel of renewable origin (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a). Thus, it will position itself as one of the leading European countries in the production of green hydrogen (Table 4).

The beneficiaries of the state aid under the "Hydrogen Roadmap" are varied in nature. This plan is much more inclusive than the previous institutional framework for promoting photovoltaic energy and includes public and private initiatives through different funding programs (Table 4). Thus, companies and public agencies can access subsidies to promote green hydrogen. As far as the private initiative is concerned, several calls for tenders have been designed for natural and legal persons in areas such as sustainable mobility or energy efficiency. However, the public initiative is subsidized in order, above all, to increase the number and scope of research projects for obtaining energy based on hydrogen (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a; Sun et al., 2021). The strong commitment of the EU and Spain to a more sustainable energy model has attracted investment (Table 5).

However, this strategy makes no explicit reference to environmental justice. The approval and installation of large photovoltaic plants have generated growing social unrest as communities have not been compensated for the impacts they suffer. Landscape damage, rivalry in the use of sites, or the impact on fauna and flora has not been internalized. There are gaps in Spanish regulations concerning the management of uses and technology, so the agents suffer the largest negative externalities with the least bargaining power: the neighboring communities (Copena and Simon, 2018; Munda and Russi, 2008). Another problem not included in the "Hydrogen Roadmap" is the energy losses in

Table 4
Impact on different H2 demand scenarios in the major countries of the European Union. Source: Own elaboration based on European Commission (2021b).

Country	Demand scenario (2030)	Technology	Source			Expected H2 demand (by sector)				New Jobs	Emissions avoided	Value Added
		Electrolyzer	PV solar	Onshore Wind	Offshore Wind	Industry	Buildings	Transport	Power			
Czech Republic	Low	140 MW (440 GWh_{H2}/a[a])	130 MW (100 GWh/a[b])	280 MW (600 GWh/a)	0 MW	176 GWh/a	28 GWh/a	237 GWh/a	0.3 GWh/a	540,000	0.2 Mt CO_2/a	EUR 77 mln
	High	560 MW (1790 GWhH2/a)	520 MW (4110 GWh/a)	1140 MW (2400 GWh/a)	0 MW	829 GWh/a	280 GWh/a	675 GWh/a	3 GWh/a	1330,000	0.6 Mt CO_2/a	EUR 290 mln
France	Low	1150 MW (4260 GWh_{H2}/a)	1300 MW (1390 GWh/a)	2010 MW (5280 GWh/a)	30 MW (130 GWh/a)	969 GWh/a	578 GWh/a	2703 GWh/a	14 GWh/a	10,380	1.9 Mt CO_2/a	EUR 270 mln
	High	5290 MW (19,590 GWh_{H2}/a)	6060 MW (6380 GWh/a)	9230 MW (24,270 GWh/a)	140 MW (580 GWh/a)	5850 GWh/a	5780 GWh/a	7818 GWh/a	137 GWh/a	33,650	6.2 Mt CO_2/a	EUR 2680 mln
Germany	Low	2970 MW (8940 GWh_{H2}/a)	6800 MW (6580 GWh/a)	3040 MW (6740 GWh/a)	270 MW (920 GWh/a)	4880 GWh/a	868 GWh/a	3125 GWh/a	64 GWh/a	23,190	5.8 Mt CO_2/a	EUR 1900 mln
	High	13,680 MW (41,200 GWh_{H2}/a)	31,360 MW (30,350 GWh/a)	14,030 MW (31,030 GWh/a)	1250 MW (4250 GWh/a)	22,805 GWh/a	8680 GWh/a	9078 GWh/a	638 GWh/a	82,800	18.7 Mt CO_2/a	EUR 7620 mln
Hungary	Low	330 MW (810 GWh_{H2}/a)	180 MW (170 GWh/a)	530 MW (1100 GWh/a)	0 MW	504 GWh/a	32 GWh/a	272 GWh/a	2 GWh/a	720,000	0.3 Mt CO_2/a	EUR 130 mln
	High	940 MW (2310 GWh_{H2}/a)	500 MW (480 GWh/a)	1520 MW (3200 GWh/a)	0 MW	1316 GWh/a	320 GWh/a	654 GWh/a	17 GWh/a	1550	0.7 Mt CO_2/a	EUR 360 mln
Italy	Low	1330 MW (3900 GWh_{H2}/a)	1810 MW (2010 GWh/a)	2320 MW (4130 GWh/a)	20 MW (80 GWh/a)	1130 GWh/a	750 GWh/a	1977 GWh/a	40 GWh/a	11,510	1.6 Mt CO_2/a	EUR 780 mln
	High	6740 MW (19,720 GWh_{H2}/a)	9130 MW (10,150 GWh/a)	11,740 MW (20,890 GWh/a)	130 MW (390 GWh/a)	6412 GWh/a	7500 GWh/a	5407 GWh/a	400 GWh/a	41,760	6.3 Mt CO_2/a	EUR 3510 mln
Netherlands	Low	790 MW (2690 GWh_{H2}/a)	790 MW (610 GWh/a)	660 MW (1560 GWh/a)	570 MW (2110 GWh/a)	1634 GWh/a	251 GWh/a	788 GWh/a	13 GWh/a	5110	0.9 Mt CO_2/a	EUR 460 mln
	High	3550 MW (12,070 GWh_{H2}/a)	3530 MW (2740 GWh/a)	2980 MW (7020 GWh/a)	2540 MW (9490 GWh/a)	6814 GWh/a	2510 GWh/a	2614 GWh/a	135 GWh/a	18,200	3.2 Mt CO_2/a	EUR 1930 mln
Portugal	Low	280 MW (770 GWh_{H2}/a)	400 MW (740 GWh/a)	140 MW (380 GWh/a)	0 MW	390 GWh/a	20 GWh/a	358 GWh/a	5 GWh/a	2500	0.3 Mt CO_2/a	EUR 92 mln
	High	2740 MW (7450 GWh_{H2}/a)	3850 MW (7120 GWh/a)	1360 MW (3670 GWh/a)	0 MW	3643 GWh/a	1820 GWh/a	1089 GWh/a	900 GWh/a	18,450	1.8 Mt CO_2/a	EUR 740 mln
Spain	Low	1.010 MW (4120 GWh_{H2}/a)	790 MW (1020 GWh/a)	2000 MW (5540 GWh/a)	1 MW (4 GWh/a)	2114 GWh/a	163 GWh/a	1836 GWh/a	3 GWh/a	10,530	1.6 Mt CO_2/a	600 EUR mln
	High	4140 MW (16,860 GWh_{H2}/a)	3230 MW (4170 GWh/a)	8260 MW (22,690 GWh/a)	4 MW (20 GWh/a)	6585 GWh/a	1630 GWh/a	5753 GWh/a	2889 GWh/a	35,830	5.2 Mt CO_2/a	2360 EUR mln

[a] GWh_{H2}/a = annual generation of GWh_{H2}.
[b] GWh/a = annual generation of GWh.

Table 5
Position of Spain in the ranking of the forty best countries to invest in renewable energy. Source: Own elaboration based on Ernst & Young (2021).

Total or PV ranking	Date	France	Germany	Italy	Netherlands	Portugal	Spain
Overall rank	may-14	9	3	11	16	17	18
Overall rank	nov-14	8	3	15	13	18	22
Overall rank	may-15	7	3	16	12	21	24
Overall rank	nov-15	7	4	17	10	21	25
Overall rank	may-16	8	5	25	17	27	28
Overall rank	nov-16	7	4	23	20	22	25
Overall rank	may-17	8	4	18	16	22	29
Overall rank	nov-17	6	4	18	15	20	27
Overall rank	may-18	5	4	19	9	25	17
Overall rank	nov-18	5	4	19	9	25	17
Overall rank	may-19	3	6	18	10	25	16
Solar PV	**may-19**	**9**	**10**	**24**	**23**	**30**	**17**
Overall rank	nov-19	4	6	17	10	21	15
Solar PV	**nov-19**	**7**	**11**	**21**	**24**	**26**	**14**
Overall rank	may-20	3	5	19	9	27	11
Solar PV	**may-20**	**5**	**8**	**20**	**17**	**25**	**13**
Overall rank	nov-20	6	7	17	9	22	10
Solar PV	**nov-20**	**6**	**7**	**11**	**12**	**13**	**8**
Overall rank	may-21	5	7	15	9	21	10
Solar PV	**jun-21**	**7**	**8**	**14**	**24**	**22**	**11**
Overall rank	nov-21	4	6	13	11	23	10
Solar PV	**nov-21**	**7**	**8**	**14**	**25**	**24**	**10**

producing and storing green hydrogen. Estimates made by the Spanish Ministry of Energy do not consider this factor, which can reduce the efficiency of the process by up to 20% (Kakoulaki et al., 2021).

This new socio-economic scenario for the promotion of green hydrogen has engendered a boost for the solar photovoltaic market in Spain. In the field of technology transfer, the three existing national projects to generate green hydrogen (Seafuel, H2ports, and Sun2hy) have been joined by two more in 2020 (Higgs and Green Hysland). In addition, at the end of 2020, the Ministry for Ecological Transition and the demographic challenge of Spain issued a call for "Major Projects of Common European Interest" focused on the green hydrogen value chain (Table 6). The call was successful, as 20 projects meeting the requirements for approval were submitted (Fig. 4) (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a).

The major firms in the Spanish energy sector (Repsol, Iberdrola, Naturgy, Acciona, or Enegás- Gas Natural) are associated with this type of project (Table 7). Between 2020 and 2021, the leading companies in the electricity sector presented about 150 projects (Energías renovables, 2021). Only about ten projects have been approved, with some of these proposals are still in the evaluation period. However, the high number of projects submitted demonstrates the industry's strong interest in green hydrogen as a form of energy storage. As for small and medium-sized companies in hydrogen-related projects, their presence is scarce. The requirements, both bureaucratic and financial, to launch an energy proposal of interest are remarkably high, so the administration should facilitate entry into this type of company sector in the face of the incipient risk of a high market concentration.

European granted loans distributed through the Spanish public administration play a decisive role in attracting the sector to green hydrogen production. Although the main criterion of the public calls for proposals is the reduction of CO2 emissions, they also consider the value of creating an industrial network based on this fuel. Phase III of the "Renewable Hydrogen Roadmap" includes the strategy of creating renewable hydrogen clusters or valleys, which values the creation of Power Purchase Agreements (PPAs). This measure encourages PPAs in a country, Spain, which leads to the conclusion of this type of agreement (4.2 GW) in the photovoltaic sector in Europe by 2020. The main PPAs are taking place between leading companies in the energy sector and companies in the chemical, steel, and iron sector. In Spain, it is particularly in these sectors where hydrogen decarbonization is being

Table 6
Major programs in the Hydrogen Roadmap that subsidize hydrogen promotion. Source: Own elaboration based on Ministerio para la transición ecológica y el reto demográfico (2021b).

Hydrogen Program	Responsible state agency	Objectives	Beneficiaries	Public financing
MOVES II program.	Spanish Institute for Energy Diversification and Saving (IDAE).	Acquisition of alternative energy vehicles includes purchasing hydrogen fuel cell vehicles. Implementation of electric vehicle recharging infrastructure.	Individuals who conduct economic activities. Individuals of legal age with tax residence in Spain and not included in the previous section. The communities of owners. Legal entities are constituted in Spain. Local entities and institutional public sector.	€ 100 million. Vehicle grants: between €600 and €1500. Other grants: 40–50% of the project cost.
Science and Innovation Program.	Center for the Development of Industrial Technology (CDTI).	To produce energy through green, safe, efficient, and clean hydrogen for the 21st century. Promote sustainable and intelligent mobility through renewable hydrogen. Promote the Spanish industry in the industrial revolution of the XXI century using green hydrogen.	Large companies. Small and medium-sized companies.	€70 million. €60 million (large companies). €10 million (small companies).
CIEN program.	Center for the Development of Industrial Technology (CDTI).	Promote large industrial research and experimental development projects in hydrogen through the effective collaboration of business consortiums of 3–8 companies.	Large companies. Small and medium-sized companies. Self-employed entrepreneurs.	€100 million Funding per project: €5–20 million.

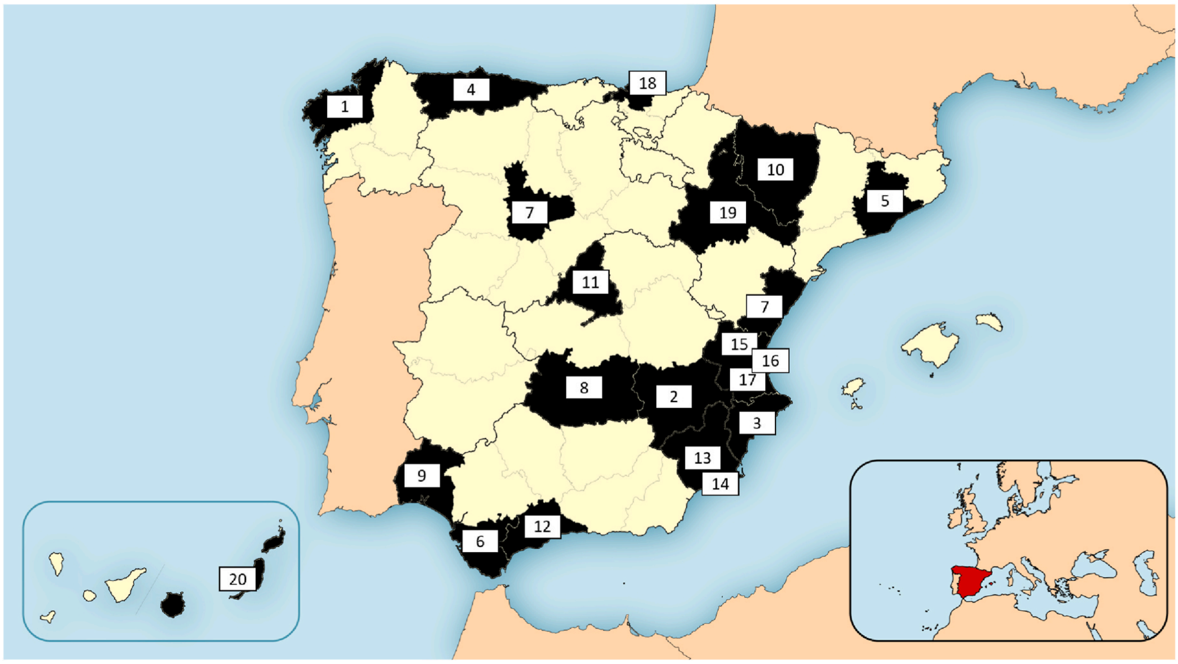


Fig. 4. Projects on the green hydrogen value chain submitted to public calls for proposals in Spain in 2020. Source: Own elaboration based on Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a.

prioritized (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a).

In addition, the high dependence on foreign technology is another point where the transfer of public funds is generating a new paradigm. Most of the technology used for green hydrogen production in Spain is imported. The Norwegian company Nel is the largest supplier of electrolyzes for Spanish projects. This trend is being reversed through the innovation grants included in the Green Hydrogen Roadmap. For this reason, an increasing number of agreements are being signed between Spanish companies for the production, manufacture, and installation of electrolyzes in Spain, such as the partnership agreements already signed between Iberdrola and Ingeteam or Petronor and SENER.

At present (), there are still no photovoltaic plants dedicated to green hydrogen in operation, but given the advanced state of the projects, it is estimated that two plants will start their activity in a brief period. The first PV plant is in Puertollano (Castilla-La Mancha) and will be dedicated to producing green hydrogen from solar photovoltaic energy to produce ammonia. This project derives from a PPA between the electricity company Iberdrola and Fertiberia. Its first phase, planned for 2021 but finally postponed to 2022, will generate green hydrogen using an electrolyze of up to 40 MW and a 100 MW photovoltaic plant. In 2027, when the fourth phase will be reached, an 810 MW electrolyzer will be in operation. The 400 MW solar photovoltaic plant and a 60 MW electrolyze in La Robla (Castilla y León) are also scheduled to come into operation shortly. This project involves energy companies Energás and Naturgy for a thermal power plant (Ministerio para la Transición Ecológica y el Reto Demográfico, 2022).

In addition, several Spanish private initiatives related to green hydrogen have also been promoted at the European level. In July 2022, the European Commission approved the "IPCEI Hy2Tech" project with €5.4 billion in aid. This project was developed by fifteen member states, including Spain, to boost the value chain of green hydrogen technology. Its most important goals are to generate hydrogen, create fuel cells, store and transport hydrogen, and advance in the final applications of hydrogen. The program will finance 41 projects from 35 companies, including 4 Spanish partners (H2B2, Nordex, Sener, and Iveco ES) (European Commission, 2022c).

4. Conclusions and policy implications

Sharp changes in the direction of formal rules can lead to disinvestment scenarios because the expected returns are not guaranteed, as happened in Spain between 2012 and 2019. Following the approval of the European Green Deal and the NECPs, a favorable investment scenario was created through the implementation of new rules and laws. Moreover, a new factor was also introduced that gave Spain credibility as a destination for PV investment: the reinforcement of the European Union's role as a developer and supervisor of the policy framework for the promotion of renewable energy.

In this case study, despite the "path dependence" and the legislative instability in Spain, which has generated the investors' distrust, there appears to be a new agent actively participating in creating the new institutional energy framework. The European Union, a supranational body, has not only designed the main objectives of the future environmental strategy but also finances the instruments needed to achieve them. The presence of the European Union represents a reliable and stable guarantee for investors in the photovoltaic market, which encourages the re-entry, or greater involvement, of companies in the sector. The 2.5 billion euros that the Spanish government spent on the feed-in tariff system is much smaller than the funding envisaged by the European Union for the advancement of green hydrogen: between 180 and 470 billion euros (European Commission, 2021).

Moreover, the loss of credibility, which hurt the Spanish government, affected the European Union to a lesser extent. However, while the photovoltaic boom initiated after the approval of RD 661/2007 and RD 1578/2008 was driven by small and medium-sized companies, the growth scenario of green hydrogen generation is led by large companies. These companies are involved in most projects and are attracting the most funding from Spanish industrial plans to activate the green hydrogen industry. Although the decline in the price of solar energy production technology has attracted smaller companies to the sector, entry barriers are acting as a disincentive, limiting their participation in the market. This scenario leads to increased market concentration. Therefore, legislators should reverse this situation by reducing or facilitating bureaucratic processes, promoting associationism, increasing the participation of companies in innovation and technology transfer

Table 7
Main green hydrogen projects presented in public calls for proposals. Source: Own elaboration based on Ministerio para la Transición Ecológica y el Reto Demográfico (2022).

Companies	Projects	MW (electrolyzer)	Region
Acciona and Enegás	Green Hysland	2.5	Baleares
Enagás	La Robla (with Naturgy)	60	Castilla yLeón
	Green Spideo	100	Asturias
	Asturias (with Naturgy)	105	Asturias
	Refinería Castellón (with BP, Iberdrola)	20	Comunidad Valenciana
Endesa	Tarragona	20	Cataluña
	As Pontes (Coruña)	100	Galicia
	Andorra (Teruel)	60	Aragón
	Compostilla (León	4	Castilla y León
	Seseña (Toledo	−4	Castilla-La Mancha
	Huelva	100	Andalucía
	Hidrógeno El Cierzo	7.2	Aragón
	Almería	20	Andalucía
		7	
	Barranco de Tirajana		Canarias
	Granadilla	10	Canarias
	Alcudia	8	Baleares
Iberdrola	Puertollano I	20	Castilla-La Mancha
	Palos I	230	Andalucía
	Puertollano II	210	Castilla-La Mancho
	Palos II	n.a.	Andalucía
	Refinería Castellón (with BP y Enagás)	370	Comunidad Valenciana
Naturgy	La Robla (with Enagás)	60	Castilla y León
	Meirama-Cerceda	n.a.	Galicia
	Huelva	n.a.	Andalucía
	Alcázar de San Juan	n.a.	Castilla-La Mancha
	Valencia	n.a.	Comunidad Valenciana
Repsol	BH2C	112	País Vasco
White Summit Capital	Amorebieta	20	País Vasco
ACS	Castellón (with Endesa)	100	Comunidad Valenciana
FAEN	Coordination 19 projects	395	Asturias
BP	Refinería Castellón (with Iberdrola and Enagás)	20	Comunidad Valenciana
AIN and CENER	Navarra	40	Navarra
Estimated total		2377.5	

projects, and facilitating access to financing.

Therefore, the use of photovoltaic energy involves economic, social, and technological challenges, some of which are being solved thanks to the involvement of European and national authorities through administrative and financial measures that have supported the production and consumption of energy. Thus, although the green hydrogen boom represents an opportunity to boost renewable energy generation, this transition could adversely affect society. Through level 1 of the analysis of the NEI methodology, policymakers should evaluate, with particular attention to, the social implications of deploying wind, photovoltaic, and electrolysis facilities. To this end, stakeholders should play a more vital role in the decision-making process, providing information and a new perspective for measuring the socio-environmental impact of projects. Establishing social dialogue would increase the degree of acceptance and participation of the communities, which could also be compensated for any adverse effects. Policymakers need to avoid panacea solutions, identifying the particularities of each case and proposing a consensual solution that strengthens the governance of energy resources. In addition, public authorities should also facilitate the involvement of SMEs in research related to green hydrogen production. Although national and international programs encourage private sector research in this type of energy, financial and bureaucratic barriers to entry make it difficult for SMEs to get involved. Therefore, public initiatives on credit line programs or personalized consulting are necessary.

The limitations of the exclusive use of levels 2 and 3 of Williamson's (2000) institutional analysis, which only focuses on the formal components of the institutional framework and its organization, can be overcome through future lines of research. It would be of interest to stakeholders and policymakers to conduct an analysis, following level 4 of the approach, on the efficiency of resource allocation when there is a substantial transfer of public subsidies, as in this case study, and to propose feasible alternative scenarios on the number and level of subsidies. Regarding level 1, the promotion of solar PV and green hydrogen production depends, to a greater or lesser extent, on the respect of the approved rules and their enforcement. In order to analyze the future success or failure of the institutional framework for solar energy, it would be helpful to conduct surveys and interviews with the various actors involved, to get a coherent view, intertwining social, political, and business perspectives.

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

Data will be made available on request.

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References

Álvarez-Díaz, M., Fernández-González, R., Caballero, G., 2017. Institutional change, specific investments and photovoltaic power plants: the empirical effects of the energy policy of "solar farms" in Spain. In: Schofield, N., Caballero-Miguez, G. (Eds.), State, Institutions and Democracy. Springer-Verlag Berlin Heidelberg, Berlin, pp. 327–347. https://doi.org/10.1007/978-3-319-44582-3_14.

Aragonés, V., Barquín, J., Alba, J., 2016. The new Spanish self -consumption regulation. In: Energy Procedia, Energy Economics Iberian Conference, EEIC 2016, 4-5 February 2016, Lisbon, Portugal, vol. 106, pp. 245–257. https://doi.org/10.1016/j.egypro.2016.12.120.

Bean, P., Blazquez, J., Nezamuddin, N., 2017. Assessing the cost of renewable energy policy options – a Spanish wind case study. Renew. Energy 103, 180–186. https://doi.org/10.1016/j.renene.2016.11.001.

Birindelli, G., Chiappini, H., 2021. Climate change policies: good news or bad news for firms in the European Union? Corp. Soc. Responsib. Environ. Manag. 28, 831–848. https://doi.org/10.1002/csr.2093.

Blanco, M., Ferasso, M., Bares, L., 2021. Evaluation of the effects on regional production and employment in Spain of the renewable energy plan 2011–2020. Sustainability 13, 3587. https://doi.org/10.3390/su13063587.

Cifuentes-Faura, J., 2021. Analysis of containment measures and economic policies arising from COVID -19 in the European Union. Int. Rev. Appl. Econ. 35, 242–255. https://doi.org/10.1080/02692171.2020.1864300.

Ciplet, D., Roberts, J.T., 2017. Climate change and the transition to neoliberal environmental governance. Global Environ. Change 46, 148–156. https://doi.org/10.1016/j.gloenvcha.2017.09.003.

Coase, R.H., 1984. The new institutional economics. Z. Gesamte Staatswiss./J. Inst. Theor. Econ. JITE 140, 229–231.

Coase, R.H., 1988. The nature of the firm: meaning. Journal of Law, Economics, \& Organization 4, 19–32.

Coase, R., 1998. The new institutional economics. American Economic Review 88, 72–74.

Colasante, A., D'Adamo, I., Morone, P., 2022. What drives the solar energy transition? The effect of policies, incentives and behavior in a cross-country comparison. Energy Research & Social Science 85, 102405. https://doi.org/10.1016/j.erss.2021.102405 accessed 09.27.22.
European Commision, 2021. Fit for 55": Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality [WWW Document]. URL. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0550. accessed 3.14.22.
Cook, B.I., Mankin, J.S., Anchukaitis, K.J., 2018. Climate change and drought: from past to future. Current Climate Change Reports 4, 164–179. https://doi.org/10.1007/s40641-018-0093-2.
Copena, D., Simon, X., 2018. Wind farms and payments to landowners: opportunities for rural development for the case of Galicia. Renewable and Sustainable Energy Reviews 95, 38–47. https://doi.org/10.1016/j.rser.2018.06.043.
Correia-da-Silva, J., Soares, I., Fernández, R., 2020. Impact of dynamic pricing on investment in renewables. Energy 202. https://doi.org/10.1016/j.energy.2020.117695.
Crescenzi, R., Giua, M., Sonzogno, G.V., 2021. Mind the covid -19 crisis: an evidence-based implementation of Next generation EU. Journal of Policy Modeling 43, 278–297. https://doi.org/10.1016/j.jpolmod.2021.03.002.
Dellink, R., Lanzi, E., Chateau, J., 2019. The sectoral and regional economic consequences of climate change to 2060. Environmental and Resource Economics 72, 309–363. https://doi.org/10.1007/s10640-017-0197-5.
Duffield, J.S., 2021. The politics of renewable power in Spain. In: Duffield, J.S. (Ed.), Making Renewable Electricity Policy in Spain: the Politics of Power, Environmental Politics and Theory. Springer International Publishing, Cham, pp. 163–183. https://doi.org/10.1007/978-3-030-75641-3_8.
Dufo-López, R., Bernal-Agustín, J.L., 2015. A comparative assessment of net metering and net billing policies. Study cases for Spain. Energy 84, 684–694. https://doi.org/10.1016/j.energy.2015.03.031.
Eggertsson, T., 1990. Economic Behavior and Institutions: Principles of Neoinstitutional Economics, first ed. ed. Cambridge University Press, Cambridge.
Eggertsson, T., 1997. The old theory of economic policy and the new institutionalism. World Development 25, 1187–1203. https://doi.org/10.1016/S0305-750X(97)00037-5.
Eggertsson, T., 2013. Quick guide to new institutional economics. Journal of Comparative Economics, Symposium in Honor of Thrainn Eggertson 41, 1–5. https://doi.org/10.1016/j.jce.2013.01.002.
Ernst & Young, 2021. Renewable Energy Country Attractiveness Index | EY - Global [WWW Document]. URL. https://www.ey.com/en_gl/recai. accessed 3.16.22).
European Commission, 2019. The European Green Deal. Brussels, Belgium.
European Commision, 2019a. EU climate action and the European Green Deal. Climate Action - European Commission [WWW Document]. URL. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/climate-action-and-green-deal_en. (Accessed 27 September 2022).
European Commision, 2019b. Energy system integration - Hydrogen Energy - European Commission [WWW Document]. URL. https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en.
European Commission, 2020a. A hydrogen strategy for a climate-neutral Europe [WWW Document]. URL. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf. accessed 3.13.22.
European Commission, 2020b. EUR-Lex - 52020DC0301 - EN - EUR-Lex. [WWW Document]. URL. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0301. accessed 09.27.22).
European Commission, 2021a. Plan de recuperación para Europa. Comisión Europea - European Commission [WWW Document]. URL. https://ec.europa.eu/info/strategy/recovery-plan-europe_es. accessed 09.27.22.
European Commission, 2021b. National energy and climate plans (NECPs) [WWW Document]. URL. https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en. accessed 3.16.22.
European Commission, 2022a. Renewable energy directive. Renewable energy – directive, targets and rules [WWW Document]. URL. https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en. accessed 5.25.22.
European Commission, 2022b. Reference regulatory framework [WWW Document]. URL. https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework_en. accessed 4.18.22.
European Commission, 2022c. State Aid [WWW Document]. URL. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_4544. accessed 8.20.22.
European Council For an Energy Efficient Economy, 2022. EU. Energy Union [WWW Document]. URL. https://www.eceee.org/policy-areas/energy-union/. accessed 4.18.22).
European Parliament, 2018a. Directive (EU) 2018/2001 on the Promotion of the Use of Energy from Renewable Sources [WWW Document]. URL. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01. ENG&toc=OJ:L:2018:328:TOC (accessed 5.30.22.
European Parliament, 2018b. Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate [WWW Document]. URL. https://eur-lex.europa.eu/eli/reg/2018/1999. accessed 5.30.22.
European Parliament, 2021. European Climate Law [WWW Document]. URL. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119. accessed 4.18.22.
Eurostat, 2021. SHARES Renewables - Energy. EU. https://ec.europa.eu/eurostat/web/energy/data/shares.
Farrell, H., Knight, J., 2003. Trust, institutions, and institutional change: industrial districts and the social capital hypothesis. Politics \& Society 31, 537–566.
Fernández-González, R., Suárez-García, A., Feijoo, M.Á.Á., Arce, E., Díez-Mediavilla, M., 2020. Spanish photovoltaic solar energy: institutional change, financial effects, and the business sector. Sustainability (Switzerland) 12. https://doi.org/10.3390/su12051892.
Fernández-González, R., Arce, E., Garza-Gil, D., 2021a. How political decisions affect the economy of a sector: the example of photovoltaic energy in Spain. Energy Reports 7, 2940–2949. https://doi.org/10.1016/j.egyr.2021.05.021.
Fernández-González, R., Arce, E., Garza-Gil, D., 2021b. How political decisions affect the economy of a sector: the example of photovoltaic energy in Spain. Energy Reports 7, 2940–2949. https://doi.org/10.1016/j.egyr.2021.05.021.
Gallego-Castillo, C., Victoria, M., 2015. Cost-free feed-in tariffs for renewable energy deployment in Spain. Renewable Energy 81, 411–420. https://doi.org/10.1016/j.renene.2015.03.052.
Gao, Y., Gao, X., Zhang, X., 2017. The 2 ° C global temperature target and the evolution of the long - term goal of addressing climate change — from the united nations framework convention on climate change to the Paris agreement. Engineering 3, 272–278. https://doi.org/10.1016/J.ENG.2017.01.022.
García-Alvarez, M.T., Mariz-Pérez, R.M., 2012. Analysis of the success of feed-in tariff for renewable energy promotion mechanism in the EU: lessons from Germany and Spain. Procedia - social and behavioral sciences. International Congress on Interdisciplinary Business and Social Sciences 2012 (ICIBSoS 2012) 65, 52–57. https://doi.org/10.1016/j.sbspro.2012.11.090.
García-Álvarez, M.T., Cabeza-García, L., Soares, I., 2018. Assessment of energy policies to promote photovoltaic generation in the European Union. Energy 151, 864–874. https://doi.org/10.1016/j.energy.2018.03.066.
García-Magariño, S., Belintxon, U., 2021. Cognitive and energetic sustainability for development: Spain and Europe before the green deal. Energies (Basel) 14, 3770. https://doi.org/10.3390/en14133770.
Government of Spain, 2020. Plan de Recuperación, Transformación y Resiliencia [WWW Document]. URL. https://www.lamoncloa.gob.es/temas/fondos-recuperacion/Documents/30042021-Plan_Recuperacion_%20Transformacion_%20Resiliencia.pdf. accessed 5.31.22.
Griffiths, S., 2017. Renewable energy policy trends and recommendations for GCC countries. Energy Transitions 1, 3. https://doi.org/10.1007/s41825-017-0003-6.
Gürtler, K., Postpischil, R., Quitzow, R., 2019. The dismantling of renewable energy policies: the cases of Spain and the Czech Republic. Energy Policy 133, 110881. https://doi.org/10.1016/j.enpol.2019.110881.
Hess, D.J., Renner, M., 2019. Conservative political parties and energy transitions in Europe: opposition to climate mitigation policies. Renewable and Sustainable Energy Reviews 104, 419–428. https://doi.org/10.1016/j.rser.2019.01.019.
Hodgson, G.M., 2006. What are institutions? J Econ Issues 40, 1–25.
IDAE, 2021. Información y publicaciones [WWW Document]. URL. https://www.idae.es/informacion-y-publicaciones. accessed 10.12.21.
Jäger-Waldau, A., 2020. The untapped area potential for photovoltaic power in the European union. Clean Technologies 2, 440–446. https://doi.org/10.3390/cleantechnol2040027.
Journal officiel de l'Union européenne C 43/9, 2007. Tarifs réglementés de l'électricité en Espagne Invitation à présenter des observations en application de l'article 88, paragraphe 2 du traité CE [WWW Document]. European Commision. URL. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2007:043:0009:0016:FR:PDF. accessed 3.15.22.
Kakoulaki, G., Kougias, I., Taylor, N., Dolci, F., Moya, J., Jäger-Waldau, A., 2021. Green hydrogen in Europe – a regional assessment: substituting existing production with electrolysis powered by renewables. Energy Conversion and Management 228, 113649. https://doi.org/10.1016/j.enconman.2020.113649.
Keppo, I., Mazza, A., Natalini, D., Pudjianto, D., Velasco-Fernández, R., 2022. Introduction to EMP-E 2019 special issue "modelling the implementation of 'A clean planet for all' strategy. Energy Strategy Reviews 100843. https://doi.org/10.1016/j.esr.2022.100843.
Kougias, I., Taylor, N., Kakoulaki, G., Jäger-Waldau, A., 2021. The role of photovoltaics for the European Green Deal and the recovery plan. Renewable and Sustainable Energy Reviews 111017. https://doi.org/10.1016/j.rser.2021.111017.
La Moncloa. Gobierno de España, 2021. Sánchez presenta el Plan de Recuperación que guiará la ejecución de 72.000 millones de euros de fondos europeos hasta 2023. Gobierno de España. https://planderecuperacion.gob.es/noticias/sanchez-presenta-el-plan-de-recuperacion-que-guiara-la-ejecucion-de-72000-millones-de-euros.
Lambin, E.F., Gibbs, H.K., Heilmayr, R., Carlson, K.M., Fleck, L.C., Garrett, R.D., le Polain de Waroux, Y., McDermott, C.L., McLaughlin, D., Newton, P., Nolte, C., Pacheco, P., Rausch, L.L., Streck, C., Thorlakson, T., Walker, N.F., 2018. The role of supply-chain initiatives in reducing deforestation. Nature Climate Change 8, 109–116. https://doi.org/10.1038/s41558-017-0061-1.
Liu, F., van den Bergh, J.C.J.M., 2020. Differences in CO2 emissions of solar PV production among technologies and regions: application to China, EU and USA. Energy Policy 138, 111234. https://doi.org/10.1016/j.enpol.2019.111234.
Liu, Z., Ciais, P., Deng, Z., Lei, R., Davis, S.J., Feng, S., Zheng, B., Cui, D., Dou, X., Zhu, B., Guo, Rui, Ke, P., Sun, T., Lu, C., He, P., Wang, Yuan, Yue, X., Wang, Yilong, Lei, Y., Zhou, H., Cai, Z., Wu, Y., Guo, Runtao, Han, T., Xue, J., Boucher, O., Boucher, E., Chevallier, F., Tanaka, K., Wei, Y., Zhong, H., Kang, C., Zhang, N., Chen, B., Xi, F., Liu, M., Bréon, F.-M., Lu, Y., Zhang, Q., Guan, D., Gong, P., Kammen, D.M., He, K., Schellnhuber, H.J., 2020. Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nature Communications 11, 5172. https://doi.org/10.1038/s41467-020-18922-7.
Longoria, G., Lynch, M., Curtis, J., 2021. Green hydrogen for heating and its impact on the power system. International Journal of Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2021.05.171.

López Prol, J., 2018. Regulation, profitability and diffusion of photovoltaic grid-connected systems: a comparative analysis of Germany and Spain. Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2018.04.030.
Marques, A.C., Fuinhas, J.A., Macedo, D.P., 2019. The impact of feed-in and capacity policies on electricity generation from renewable energy sources in Spain. Utilities Policy 56, 159–168. https://doi.org/10.1016/j.jup.2019.01.001.
Martín-García, Í., Rosales-Asensio, E., González-Martínez, A., Bracco, S., Delfino, F., de Simón-Martín, M., 2020. Hydrogen as an energy vector to optimize the energy exploitation of a self-consumption solar photovoltaic facility in a dwelling house. Energy Reports, Technologies and Materials for Renewable Energy, Environment and Sustainability 6, 155–166. https://doi.org/10.1016/j.egyr.2019.10.034.
Ménard, C., Shirley, M.M., 2005. Handbook of New Institutional Economics. Springer, Dordrecht.
Ménard, C., Shirley, M.M., 2014. The future of new institutional economics: from early intuitions to a new paradigm? Journal of Institutional Economics 10, 541–565. https://doi.org/10.1017/S174413741400006X.
Ministry for the ecological transition and the demographic challenge, 2020a. Integrated National Energy and Climate Plan 2021-2030 [WWW Document]. URL. https://energy.ec.europa.eu/system/files/2019-06/ec_courtesy_translation_es_necp_0.pdf. accessed 5.30.22.
Ministerio para la transformación ecológica y el reto demográfico, 2020b. Plan Nacional Integrado de Energía y Clima (PNIEC) 2021-2030 [WWW Document]. URL. https://www.miteco.gob.es/es/prensa/pniec.aspx. accessed 4.21.22.
Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a. Resolución de la S. E. Energía y de la S.G. de Industria y de la PYME que determina los criterios para la participación en el Proyecto Europeo en la cadena de valor del hidrógeno verde "Proyectos Importantes de Interés Común Europeo. Ministerio para la Transición Energética y el Reto Demográfico (MITERD). https://energia.gob.es/es-es/participacion/paginas/detalleparticipacionpublica.aspx?k=410.
Ministerio para la transición ecológica y el reto demográfico, 2021b. https://www.miteco.gob.es/es/ministerio/planes-estrategias/hidrogeno/default.aspx.
Ministerio para la Transición Ecológica y el Reto Demográfico, 2022. Participación Pública - Energía [WWW Document]. URL. https://energia.gob.es/es-es/Participacion/Paginas/Index.aspx. accessed 3.16.22.
Mir-Artigues, P., Cerdá, E., del Río, P., 2018. Analysing the economic impact of the new renewable electricity support scheme on solar PV plants in Spain. Energy Policy 114, 323–331. https://doi.org/10.1016/j.enpol.2017.11.048.
Montanarella, L., Panagos, P., 2021. The relevance of sustainable soil management within the European Green Deal. Land Use Policy 100, 104950. https://doi.org/10.1016/j.landusepol.2020.104950.
Moon, T., Ahlstrøm, A., Goelzer, H., Lipscomb, W., Nowicki, S., 2018. Rising oceans guaranteed: arctic land ice loss and sea level rise. Current Climate Change Reports 4, 211–222. https://doi.org/10.1007/s40641-018-0107-0.
Munda, G., Russi, D., 2008. Social multicriteria evaluation of conflict over rural electrification and solar energy in Spain. Environment and Planning C: Government and Policy 26 (4), 712–727.
North, D.C., 1986. The new institutional economics. Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft 142, 230–237.
North, D.C., 1987. Institutions, transaction costs and economic growth. Econ Inq 25, 419–428.
North, Douglass C., 1991. Institutions. Journal of Economic Perspectives 5, 97–112. https://doi.org/10.1257/jep.5.1.97.
North, Douglass, 1993. The new institutional economics and development. Economic History 9309002, 1–8.
North, D.C., 1994. Economic performance through time. The American Economic Review 84, 359–368.
Official Journal of the European Union, 2009. Directive 2009/28. EC. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF.
Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action. Land Economics. https://doi.org/10.2307/133271.
Ostrom, E., 2002. Common-pool resources and institutions: toward a revised theory. In: Gardner, B.L., Rausser, G.C. (Eds.), Handbook of Agricultural Economics. Elsevier Science, pp. 1315–1339. https://doi.org/10.1016/S1574-0072(02)10006-5.
Ostrom, E., 2007. Challenges and growth: the development of the interdisciplinary field of institutional analysis. Journal of Institutional Economics 3, 239–264. https://doi.org/10.1017/S1744137407000719.
Ostrom, E., 2009. Understanding Institutional Diversity. Princeton University Press.
Pietzcker, R.C., Osorio, S., Rodrigues, R., 2021. Tightening EU ETS targets in line with the European Green Deal: impacts on the decarbonization of the EU power sector. Applied Energy 293, 116914. https://doi.org/10.1016/j.apenergy.2021.116914.
Posner, R.A., 1993. The new institutional economics meets law and economics. Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft 149, 73–87.
Rayner, T., Jordan, A., 2016. Climate change policy in the European union. Oxford Research Encyclopedia of Climate Science. https://doi.org/10.1093/acrefore/9780190228620.013.47.
Red Eléctrica de España, 2021a. REData - Installed power. Red Eléctrica de España. https://www.ree.es/es/datos/generacion/potencia-instalada.
Red Eléctrica de España, 2021b. Marco regulatorio. https://www.ree.es/es/conocenos/marco-regulatorio.
Rehfeldt, M., Worrell, E., Eichhammer, W., Fleiter, T., 2020. A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030. Renewable and Sustainable Energy Reviews 120, 109672. https://doi.org/10.1016/j.rser.2019.109672.
renovables, Energías, 2021. Hidrógeno, el futuro de las renovables. Energías Renovables, el periodismo de las energías limpias [WWW Document]. URL. https://www.energias-renovables.com/hidrogeno/hidrogeno-el-futuro-de-las-renovables-20210727. accessed 09.27.22.
Rojas, R., Feyen, L., Watkiss, P., 2013. Climate change and river floods in the European Union: socio-economic consequences and the costs and benefits of adaptation. Global Environmental Change 23, 1737–1751. https://doi.org/10.1016/j.gloenvcha.2013.08.006.
Roldán Fernández, J.M., Burgos Payán, M., Riquelme Santos, J.M., 2021. Profitability of household photovoltaic self-consumption in Spain. Journal of Cleaner Production 279, 123439. https://doi.org/10.1016/j.jclepro.2020.123439.
Rutherford, M., 1989. What is wrong with the new institutional economics (and what is still wrong with the old)? Review of Political Economy 1, 299–318. https://doi.org/10.1080/09538258900000023.
Rutherford, M., 1995. The old and the new institutionalism: can bridges Be built? Journal of Economic Issues 29, 443–451. https://doi.org/10.1080/00213624.1995.11505681.
Salas, V., Olías, E., 2009. An analysis of the technical exigencies and CE marking relative to low voltage (less than 5k) photovoltaic inverters marketed in Spain. Renewable and Sustainable Energy Reviews 13, 1635–1640. https://doi.org/10.1016/j.rser.2008.04.002.
Sánchez-Ortiz, J., García-Valderrama, T., Rodríguez-Cornejo, V., 2016. Towards a balanced scorecard in regulated companies: a study of the Spanish electricity sector. The Electricity Journal 29, 36–43. https://doi.org/10.1016/j.tej.2016.11.001.
Schuelke-Leech, B.-A., 2021. Disruptive technologies for a green new deal. Current Opinion in Environmental Science & Health 21, 100245. https://doi.org/10.1016/j.coesh.2021.100245.
Scott, W.R., 2010. Reflections: the past and future of research on institutions and institutional change. Journal of Change Management 10, 5–21. https://doi.org/10.1080/14697010903549408.
Shirley, M.M., 2005. Institutions and development. In: Menard, C., Shirley, M.M. (Eds.), Handbook of New Institutional Economics. Springer US, Boston, MA, pp. 611–638. https://doi.org/10.1007/0-387-25092-1_25.
Sitkin, S.B., Roth, N.L., 1993. Explaining the limited effectiveness of legalistic "remedies" for trust/distrust. Organization science 4, 367–392.
Slater, T., Hogg, A.E., Mottram, R., 2020. Ice-sheet losses track high-end sea-level rise projections. Nature Climate Change 10, 879–881. https://doi.org/10.1038/s41558-020-0893-y.
Stoll, C., Mehling, M.A., 2020. COVID-19: clinching the climate opportunity. One Earth 3, 400–404. https://doi.org/10.1016/j.oneear.2020.09.003.
Sun, X., Alcalde, J., Bakhtbidar, M., Elío, J., Vilarrasa, V., Canal, J., Ballesteros, J., Heinemann, N., Haszeldine, S., Cavanagh, A., Vega-Maza, D., Rubiera, F., Martínez-Orio, R., Johnson, G., Carbonell, R., Marzan, I., Travé, A., Gomez-Rivas, E., 2021. Hubs and clusters approach to unlock the development of carbon capture and storage – case study in Spain. Applied Energy 300, 117418. https://doi.org/10.1016/J.APENERGY.2021.117418.
Talavera, D.L., Muñoz-Cerón, E., Ferrer-Rodríguez, J.P., Nofuentes, G., 2016. Evolution of the cost and economic profitability of grid-connected PV investments in Spain: long-term review according to the different regulatory frameworks approved. Renewable and Sustainable Energy Reviews 66, 233–247. https://doi.org/10.1016/j.rser.2016.08.012.
Taube, O., Ranney, M.A., Henn, L., Kaiser, F.G., 2021. Increasing people's acceptance of anthropogenic climate change with scientific facts: is mechanistic information more effective for environmentalists? Journal of Environmental Psychology 73, 101549. https://doi.org/10.1016/j.jenvp.2021.101549.
Thuiller, W., Lavergne, S., Roquet, C., Boulangeat, I., Lafourcade, B., Araujo, M.B., 2011. Consequences of climate change on the tree of life in Europe. Nature 470, 531–534. https://doi.org/10.1038/nature09705.
Touili, S., Alami Merrouni, A., El Hassouani, Y., Amrani, A., Rachidi, S., 2020. Analysis of the yield and production cost of large-scale electrolytic hydrogen from different solar technologies and under several Moroccan climate zones. International Journal of Hydrogen Energy 45, 26785–26799. https://doi.org/10.1016/j.ijhydene.2020.07.118.
UNEF, 2013. Informe anual 2013 - Hacia nuevos modelos de desarrollo para la energía solar fotovoltaica. Madrid.
Urzaiz, Hon.J.I.U., 1998. Liberalization of the Spanish electricity sector: an advanced model. The Electricity Journal 11, 29–37. https://doi.org/10.1016/S1040-6190(98)00047-5.
Vromen, J.J., 1995. Economic Evolution: an Inquiry into the Foundations of the New Institutional Economics. Routledge, London. https://doi.org/10.4324/9780203434000.
Weingast, B.R., 1993. Constitutions as governance structures: the political foundations of secure markets. Journal of Institutional and Theoretical Economics (JITE)/Zeitschrift für die gesamte Staatswissenschaft 149, 286–311.
Weingast, B.R., 1995. The economic role of political institutions: market - preserving federalism and economic development. Journal of Law, Economics and Organization 11, 1–31.
Weingast, B.R., 2008. The performance and stability of federalism: an institutional perspective. In: Ménard, C., Shirley, M.M. (Eds.), Handbook of New Institutional Economics. Springer, Berlin, Heidelberg, pp. 149–172. https://doi.org/10.1007/978-3-540-69305-5_8.
Williamson, O.E., 1975. Markets and Hierarchies. Free Press, New York.
Williamson, O.E., 2000. The new institutional economics: taking stock, looking ahead. J. Econ. Literat. 38, 595–613. https://doi.org/10.1257/jel.38.3.595.