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Review

Which policy instruments promote innovation in renewable electricity technologies? A critical review of the literature with a focus on auctions

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ABSTRACT

Innovation in general, and innovation in renewable electricity technologies (RETs) in particular, are a main element of the clean energy transition. Traditionally, policy measures to spur innovation have fallen into two main categories: supply-push and demand-pull. The latter category includes auctions, which are now the most popular scheme to support renewable energy worldwide. Although renewable energy auctions have been assessed according to several criteria (e.g., effectiveness and efficiency), their impact on innovation has not received much attention in the past. Since auctions will continue to be the instrument of choice in many countries, it is crucial to identify their effects on innovation. This paper aims to identify and discuss the comparative innovation effects of renewable energy instruments, focusing on auctions, with the help of an in-depth literature review of demand-pull (deployment) instruments. The results suggest that auctions do not score well in encouraging innovation, although the evidence for that is limited. In contrast, there is a broad agreement that administratively-set feed-in tariffs have played a much stronger role in this sense, with consistent (and more abundant) evidence that they have promoted innovation. Some reasons which explain this result are provided, taking into account different innovation mechanisms discussed in the literature. The findings of this paper are deemed policy-relevant. If the demand-pull side of innovation processes is missing due to the implementation of an instrument (auctions) which does not generate such demand-pull, then the RET innovation processes which are needed in the clean energy transition may be put at risk.

1. Introduction

Climate change mitigation is a huge challenge facing humanity. Accordingly, there is a widespread agreement on the need for a decarbonised energy transition, in which renewable energy would play a critical role. The increase in the deployment of renewable electricity in the last years has been substantial, although the penetration of renewable energy (RE) in electricity generation is still limited. Renewables generated 29% of global electricity in 2020, up from 18% in 2010 [1]. RE will need to increase significantly in the next decade(s) in order to meet the targets set in the Paris Agreement [2]. Targets for the penetration of RE are widespread all over the world (see [1]). In particular, the EU has set a 32% RE target as a share of energy consumption in 2030. The EU aims to be fully carbon-neutral by 2050 [3], which involves a fully decarbonised electricity generation sector by then.

Innovation in general, and innovation in renewable electricity technologies (RETs) in particular, are a main component of the clean energy transition [4]. Innovation may be technological, organizational and social. In this paper, innovation refers to technological innovation. The most widespread definition of technological innovation is the one by the OECD Oslo Manual as “a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)” [5 p. 1]. A recent, important contribution in the realm of clean energy innovation is IEA [4]. For [4 p. 20] innovation is “the process of improving the means of performing tasks through the practical application of science and knowledge, usually resulting in higher performing equipment as measured by, for example, energy efficiency, user friendliness or cost”. In line with those contributions, innovation is defined in this article as a technology with an economic value which is ready to be adopted by the market, whereby technology is “any device, component of a device or process for its use that is dedicated to the production, storage and distribution of energy, or the provision of new or improved energy services

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or commodities to users" [4 p. 20].

Innovation in RETs would help to meet the aforementioned long-term RE targets cost-efficiently. For example, the EU Green Deal mentions that new technologies, sustainable solutions and disruptive innovation are critical to achieve its objectives [3]. Innovation contributes to the improvement and cost reductions of these technologies and makes it easier (or less costly) to achieve renewable energy targets and the aforementioned clean energy transition. This is exactly what has happened in the past. If we look back at the costs of RETs in the last decade, we can observe impressive cost reductions [6], which are partly the result of innovation (see, e.g., [2]).

Three main stages characterize the technological change process: invention, innovation and diffusion.[1] According to the chain-linked model, there are feedbacks between them, which play a crucial role as drivers of innovation [4,9]. Since R&D investments and learning effects that take place in the diffusion stage influence RET innovation, they should be considered [10].

It is usually mentioned that clean innovation faces multiple barriers and, in particular, a triple externality problem (an environmental, an innovation and a deployment externality, (see [11]) which justifies public intervention to support it. Governments can intervene to support innovation in many different ways (see [4]). Traditionally, policy measures to spur innovation have fallen into two main categories: supply-push and demand-pull. The former refers to public support for R&D investments in research centers and universities. Public R&D support can also be directed to firms. They can benefit from fiscal incentives and grants, which lower the cost and risk of private research efforts in RETs. Demand-pull interventions increase market volumes and, thus, decrease uncertainty for producers of renewable electricity, improving the incentive of firms to innovate [12], and increasing the private payoff to successful innovation [13]. There is a widespread agreement that both types of policy measures are complementary and, thus, needed to spur innovation [14,15], although their relative importance differs in the different stages of the innovation process.

In this article, it is assumed that demand-pull instruments, such as auctions, have an impact on diffusion, but also on invention and innovation. The aforementioned chain-linked model of innovation provides justification for public policy intervention to indirectly influence innovation through demand-pull measures. The focus of this paper is precisely on one type of demand-pull policies (auctions) and their role in inducing innovation compared to other instruments.

Within demand-pull policies, a classical distinction to support investments in RETs has been between price-based and quantity-based measures. Investments in renewable electricity were traditionally supported through price-based instruments in the past. These refer to administratively-set feed-in tariffs (FITs) or feed-in premiums (FIPs) (ASFITs/FIPs from now on). A FIT is a total amount of support for generation (in €/MWh) whereas, in a FIP, an amount of support additional to the wholesale electricity price is received by the renewable electricity generators (in €/MWh). However, the support level in FITs and FIPs does not need to be set by governments. Instead, the government can set a volume of renewable electricity that it is willing to support, letting the market decide the support level and allowing investors to compete between them for support. This can be done through (procurement) auctions or quotas with tradable green certificates (TGCs).[2] Auctions for RE support are procurement auctions, "where typically a certain amount of power (MW) or energy (MWh) of renewables are offered up for bidding. Bidders compete to be allowed to deliver these volumes on the basis of their required support level (often a premium in €/MWh). The projects with the lowest required support levels typically win the auction. Winners are then granted the right to construct their RE projects and the right to receive support payments for these projects for a given period of time" [16 p. 1].

Auctions have the advantage that the government does not need to know the level of RET costs in order to set the support level. This circumvents the asymmetric information problem which often occurs in ASFITs/FIPs, although it still needs to have some information on those costs in order to set the ceiling prices in the auction. If auctions are well designed, competition between investors results, leading to the lowest possible support costs for RETs (which are usually finally paid by consumers) [16,17]). This alleged advantage of auctions is probably behind the impressive increase of their implementation worldwide.[3] 116 countries had adopted auctions by 2020 [1], compared to only 6 countries in 2005 [21]. ASFITs/FIPs were implemented in 83 countries in 2020 [1].

In addition to lower support costs than other instruments and, particularly, ASFITs/FIPs, there is a presumption in the literature that auctions lead to technological innovation. This is the case in the auction-general literature, in the literature on RE auctions and in policy documents. The influence of competition on innovation has been emphasized by renown economists (see, e.g., [22]), including auction experts [23].[4] It has also been stressed by authors writing more specifically on RE auctions [24,25] and even in official policy documents [26]).[5]

However, such presumption is not based on empirical findings. Thus, the aim of this paper is to identify and discuss the comparative innovation effects of RE support instruments, focusing on RE auctions, with the help of an in-depth literature review of demand-pull (deployment) instruments. The findings of the review suggest that auctions do not score well in encouraging innovation, although these results should be taken with caution because the evidence is limited. This is in contrast with the broad agreement (and substantial evidence) that ASFITs/FIPs have played a much stronger role in this sense. This result, which may be related to ASFITs/FIPs activating several innovation mechanisms that play a more relevant role in encouraging innovation than the competition effects of auctions (see Section 4), is deemed to be policy-relevant. If innovation requires both supply-push and demand-pull instruments, and the demand-pull side is missing due to the implementation of an instrument (auctions) which does not generate such demand-pull, then RET innovation processes, which are needed in the clean energy transition, may be put at risk.

This article covers a gap in the literature since, to the best of our knowledge, there isn't an in-depth discussion of this topic. Extensive analyses of the effects of auctions on other criteria such as their impact on support costs [27], the realization rate of projects [28,29], local industry creation [30], actor diversity [31], technological diversity [32] or geographic diversity [33] have been carried out (see also [16,34], which analyse some of these effects), but their innovation effects have received scant attention.

Despite being praised in academic and policy documents (see, e.g., [21,26,35]), some papers in the literature are critical of the role of

[1] An invention is the first development of a scientifically or technically new or significantly improved product or process. The first commercial transaction involving the new product or process represents innovation. Diffusion is the adoption and use of the new technology over time [7,8].

[2] In quotas with TGCs, RE generators have two sources of revenue (the sales of electricity in the market and the sales of TGCs to obligated parties, usually electricity suppliers).

[3] For an analysis of the reasons behind the adoption of auctions around the world and in Europe, see [18–20].

[4] "Enhancing competition is another driver of innovation seen in all of the applications (…). Competition inspires innovation, and good market design enhances competition" [23 p. 1–2].

[5] The European Commission guidance on support schemes states that "a well designed premium scheme will also limit costs and drive innovation by granting support based on a competitive allocation process" [26 p. 8] and that "the Commission recommends supporting renewables in a stable, transparent, credible, cost-efficient and market integrating way. This will lead to technological innovation and competitiveness of renewable sources" [26 p. 15].

auctions in contributing to support cost reductions (e.g., [36]), actor diversity [31,37], market concentration [38], effectiveness in the deployment of renewable energy projects [33] or technological diversity [32]. An already abundant literature suggests that the success of auctions in addressing these issues strongly depends on their design [16,17,32,34]. The choice of different design elements can be expected to lead to different auction outcomes [32,34]. This can also be the case with their innovation effects, which may be mediated by the design elements adopted in the auction (see Section 4).

Some reviews assessed the impact of demand-pull instruments on innovation [39–42]. [39] was a pioneering contribution, but it was performed when the adoption of auctions was very limited (2013). [40] include auctions and quotas with TGC schemes in the "quantity-based" policy category, which makes it difficult to isolate their respective effects on innovation. [42] carry out a systematic review on the effects of "demand-pull" forces on technological innovation in low-carbon and energy-efficient technologies. However, they do not explicitly compare the innovation effects of auctions with other demand-pull instruments, as done in this article. [41] provide a general review of the evidence on the impact of ten decarbonization policy instruments (including auctions) on seven outcomes (including innovation). Compared to [41], the scope of this article is narrower, since it focuses on only three instruments (auctions, ASFITs/FIPs and quotas with TGCs, with a special attention on the former), one sector (electricity) and only one outcome (innovation effects). In addition, in this article, more recent references on the innovation impacts of these instruments are identified. Finally, this article focuses more specifically on the comparison of support instruments for electricity deployment (auctions and ASFITs/FIPs) and discusses the finding on the more limited innovation impacts of auctions in depth, trying to find an explanation for it.

Compared to those contributions, the thematic scope of this article is narrower albeit complementary and tries to go deeper into the comparison between instruments. Our focus is on the comparative effects on innovation of instruments supporting the deployment of RETs (which is often not the case in those reviews), with special attention to the role played by auctions in this regard. It zooms into some of the issues discussed in the aforementioned papers, providing more systematic evidence and making an effort to explain the reasons behind the results.

Accordingly, this article is structured as follows. The next section describes the methodology which has been followed in the literature review. The results of this review are provided and discussed in Sections 3 and 4, respectively. The paper closes with some conclusions and policy implications.

2. Method

A systematic literature review on studies which have assessed the effects of RE deployment instruments on innovation has been performed, focusing on auctions. Therefore, the following methodological steps were followed, adhering closely to the recommendations for systematic literature reviews in [43]. First, an explicit research question was developed (see Section 1). Second, a precise search strategy was defined comprising several searches and search terms that are relevant for this study. Then, the search was executed in Scopus and the Web of Science (WoS). Third, criteria for the retention and exclusion of the resulting articles were established and applied to the collected sample. Fourth, a protocol for the analysis was defined, and fifth, the analysis itself was undertaken. Details on this procedure are provided in the following paragraphs.

The search strategy consisted of two equally relevant searches with the keywords "innovation AND renewable energy AND policies" as well as "(auctions OR tenders OR bidding) AND renewable energy". Both searches were undertaken in Scopus and WoS. The keywords and their combinations were chosen for a specific reason. The aim of the former search was to look for papers which have specifically analysed the innovation effects of RE instruments. The aim of the latter search was to identify contributions on RE auctions.

These searches resulted in very large numbers of articles. Specifically, the first search led to the identification of 1093 articles in Scopus and 665 in WoS.[6] The second search resulted in 1710 articles in Scopus and 965 in WoS. Some overlap between the resulting articles was observed and the duplicates were eliminated. Hence, in total, the searches resulted in a sample of 3096 unique articles.

In order to identify those articles that were potentially useful for the purpose of this study, some criteria for the exclusion and retention of articles were defined. In a first step, all articles that had either a purely technical focus (i.e., new designs for innovative hybrid power plants) or with a radically different focus than the issue under study (e.g., focus on fossil fuels only, impact of RETs on job creation or sustainability in general, etc.…) were excluded from the sample. The focus of the papers was identified by reading the title. In case of doubt, the paper in question was maintained in the sample. In total, 2867 papers were excluded, resulting in 229 potentially relevant papers for this study.

In a second step, all articles that jointly addressed innovation/innovation effects and RE instruments/auctions, as detailed in the research question outlined above, were maintained in the sample. Specifically, as per the design of the searches, this meant that articles on the innovation effects of RE instruments also needed to treat auctions and articles on RE auctions also needed to treat the impact of these on innovation. This was checked by reading the title, abstract, keywords, introduction and conclusion sections. All the articles which did not match the criteria (133) were excluded from the sample. The remaining 96 articles were carefully read by the authors, and the same retention criteria were applied again.

A final list of 33 papers resulted (see Annex 1). 21 use econometric modelling and the rest are either theoretical or qualitative. Further details on these papers are provided in the Supplementary material 1.

We searched for auctions in those papers, and we concluded that only four papers explicitly identify the impact of auctions on innovation and compare it with other deployment instruments [44–47]. [44,45] are theoretical (or use a qualitative method), whereas [46,47] use quantitative (econometric) methods.

In addition, we used the literature review on the drivers and barriers to RETs in the technological innovation systems (TIS) approach carried out in [48]. 59 papers were identified (see Supplementary material 2) and their insights on the impact of different types of instruments on innovation/diffusion were considered. A special attention was paid to the influence of auctions on innovation. Such review concluded that only four papers mentioned auctions [45,49,50] but none of them analysed their impact on innovation, with the aforementioned exception of [45]. Thus, the insights on the influence of auctions on innovation using the TIS approach have been very limited in the literature (see Section 3).

3. Results

The results of our review show that 1) both supply-push and demand-pull instruments are needed to encourage innovation in RETs; 2) there is small evidence that auctions do not encourage innovation to the same extent as ASFITs/FIPs; and 3) in contrast, the evidence that ASFITs/FIPs encourage innovation is large.

Supply-push and demand-pull instruments are complementary and, thus, should be implemented jointly. The impact of public R&D is stronger on the less mature technologies, whereas deployment support has stronger innovation effects on the more mature ones. In addition to policy factors (whether in the form of supply-push and demand-pull instruments), other policy and non-policy factors (such as the general investment climate or the existing innovation capabilities in the country) have a considerable effect on innovation.

[6] Only contributions in English have been taken into account (in all searches).

The literature also shows that the innovation impacts of deployment support are contingent upon the type of instrument being implemented and the maturity of the RET being considered. On the one hand, there is a strong consensus that ASFITs/FIPs induce technological innovation to a greater extent than other instruments. However, the focus has not been on the comparison between ASFITs/FIPs and auctions, but rather on the innovation effects of ASFITs/FIPs and quotas with TGCs. The contributions generally show that TGCs have a more limited effect on innovation than ASFITs/FIPs. On the other hand, a few papers show that the comparative innovation effects also depend on the RET being considered, with a relatively greater impact of ASFITs/FIPs on the less mature RETs (at the time, all RETs except onshore wind and hydro) and stronger innovation effects of quotas with TGCs on the more mature ones (those two technologies) [51,52].

However, only four of these papers included auctions in their analysis (Table 1). This may look surprising at first, but it is probably related to the recent adoption of this instrument (see [1,53]), the dearth of implementation of auctions in the period which has been covered by the quantitative studies (the 2000s)[7] and the time gap which exists in the feedback loop between deployment and innovation, as measured by patents.

Some papers which use econometric methods do not include auctions (e.g., [52]). Others include auctions as a dummy variable together with other instruments, which does not allow to identify the specific effect of auctions with respect to other instruments. For example, [54] includes a non-FIT variable (which practically means quotas with TGCs) in the regression. Other non-econometric contributions using qualitative analysis do not perform an in-depth analysis of auctions, but identify some isolated impacts of their influence on innovation (see below regarding the contributions using the TIS approach).

Regarding the four papers which specifically focus on the innovation effects of auctions, large differences between the technologies analysed in these studies (all RETs in both) cannot be observed, although there are some differences in the geographical scope: there is more focus on EU countries in the qualitative literature, and a broader focus on other OECD countries [47] or the world [46]. The temporal scope starts in the 1990s in all the papers, but ends in the early 2000s [44], 2011/2012 [45,47] or 2016 [46]. They cover a relatively old period, when wind and PV were less mature and when they became mature, but not yet competitive. This is different nowadays, when these two technologies are competitive [2].

The two econometric studies use patents as the dependent variable to measure innovation. Regarding the explanatory variables, they use a mix of policy variables and innovation capabilities and investment climate conditions in the respective countries.[8] The auction variable is included as a continuous variable (kW) in [47]. [46] use a dummy for the presence (or absence) of each instrument and a measure of "regulatory intensity" (the implementation of an instrument over consecutive years).

The general conclusion of the fours papers (whether qualitative or quantitative) is that auctions generate a smaller incentive to innovate than alternative instruments and, particularly, ASFITs/FIPs. [44] argue that the lack of influence of auctions on innovation is due to the low expected profits and the relatively unambitious level of RE targets (low auctioned volumes) in the countries which adopted competitive bidding systems (UK, Ireland, France) compared to those with ASFITs/FIPs (Germany, Denmark and Spain). Using a functional approach to the TIS, [45] showed that ASFITs/FIPs would lead to a greater incentive to innovate than auctions. Furthermore, they showed how the specific design elements of ASFITs/FIPs could influence RET innovation.

Concerning the quantitative studies, innovation is driven by a supply-push instrument (R&D) and by one demand-pull instrument (ASFITs/FIPs), whereas they show that auctions and quotas with TGCs do not encourage innovation. In [46], patent applications are driven by ASFITs/FIPs and competitive bidding doesn't have a significant effect on innovation in solar and wind power technologies. This effect is insignificant both in the presence of competitive bidding itself, and with regards to the regulatory intensity of the competitive bidding. Similarly, [47] identifies the impact of several explanatory variables on RET innovation, including policy drivers. Their results show that FITs and public spending on research, development and demonstration (RD&D) drive RET patents in OECD and G20 countries, whereas tenders do not drive RET innovation. In addition, [47] stresses the effects of other context conditions (attractive investment conditions).

None of the papers (whether quantitative or qualitative) include the influence of the design elements of auctions on innovation (with the exception of the aforementioned measure of regulatory intensity in [46] and the volume auctioned in [44]). However, the theoretical/qualitative literature emphasises the important influence of the lower level of granularity within instruments (the specific way in which the instruments are designed) on innovation outcomes.

Finally, there is a striking dearth of studies in the TIS literature which compare the impact of instruments on innovation. Only a few contributions consider auctions [45,49,50], although none of them carry out a systematic analysis of their effects (with the aforementioned exception of [45]). All of them mention the negative impact of auctions on market creation (and learning effects), which has an indirect effect on innovation.[9] However, those negative effects are preliminary and should be taken with caution.

4. Discussion

4.1. Competition in auctions as a source of innovation

The results of the literature review show that there is some (albeit small) evidence that auctions do not drive innovation as much as ASFITs/FIPs. At first sight, this result may look striking, given the traditional idea, in the auction literature, that the competition inherent in auctions would increase the incentive to develop new products and processes which reduce the costs of technologies or enhance their revenue-increasing possibilities.

The economic literature has analysed the relationship between innovation and competition (see, e.g., [52,55]) and has considered two main effects: a "Schumpeterian effect" (whereby stronger competition reduces the post-innovation rents of laggard firms and decreases innovation) and a "escaping competition effect" (whereby firms innovate to escape competition).

Several contributions stress that competition is a major driver of energy innovation, which suggests that auctions could induce innovation. According to [56], innovation in clean technologies, including RETs, is positively influenced by competition. Project developers participate in the auction and purchase the equipment. Compared to ASFITs/FIPs, they may feel greater competitive pressures to reduce their

[7] For instance, [54 p. 687] argue that "other support mechanisms were implemented for a few years only, and did not justify including a separate variable. For example, the UK had a tender system for renewable wind power for five years only (1997–2001)".

[8] [47] include four groups of variables: climate mitigation policy (with FITs and auctions, among others), investment environment, innovation environment and natural resource endowments. [46] include the existence of the instruments (with FITs/FIPs and auctions, among others), the policy intensity of those instruments, the stock of domestic patent families in solar/wind power, the simple count of all patent families by domestic applicants for any technology, the year-by-year change in total global electricity generation capacity and the share of solar/wind in total electricity generation.

[9] "Market creation" is a crucial function in the TIS, since it acts as a motor for the activation of other functions. In turn, it is positively influenced by deployment instruments.

Table 1
Details on the papers analyzing the impacts of auctions on innovation.

Article	Geographical scope	Period	Technologies	Aim/focus	Method	Main results	Consideration of policy variables	Consideration of design elements of instruments
[44]	European countries	1990s and early 2000s	All RETs	A comparative static and dynamic analysis of the efficiency of RE promotion instruments.	Theoretical (graphical) analysis. Results are checked with empirical observations.	– Competitive pressure in auctions has forced developers/producers to reduce their costs in order to remain competitive. The lower surplus for those actors, however, discourages investments in technological innovation programs and the emergence of new RE equipment manufacturers. – The RE targets set in countries with auctions (UK, Ireland, France) were much less ambitious than in countries with FITs (Germany, Denmark and Spain).	Three deployment support instruments: FITs, auctions and quotas with TGC schemes.	Only partially, not systematically.
[45]	Several countries from around the world	1990–2011	All RETs	To provide a comparative assessment of the innovation effects of instruments which support the diffusion of RETs	Theoretical analysis (technological innovation system perspective), qualitative	– FITs are likely to encourage innovation more than other policy instruments (quotas with TGCs and auctions). – Such innovation effects are affected by the specific design elements of the instruments chosen.	FITs, TGCs, tendering.	Yes (for FITs and TGCs)
[46]	194 countries and territories	1990–2016	All RETs	Impact of different RE support policies on RET innovation (solar and wind).	Econometric modelling with patent data	– Patents are driven by FITs and FIPs. Technology-specific differences in the effectiveness of FITs are not detected. – Auctions and quotas with TGCs do not promote innovation. – Relevance of public RD&D programs and targets in stimulating patenting activity.	Many instrument types are considered (dummy variables) including RE quotas with and without TGCs, FIPs, FITs, net metering, auctions, tax credits, tax reductions, capital subsidies, low-cost loans and GHG trading.	No
[47]	46 OECD and G20 countries	2000–2012	All RETs	Effects of several explanatory variables on RET innovation	A negative binomial fixed effects regression on patent counts	– FITs and public RD&D stimulate patenting activity in RETs. – Auctions do not stimulate RET innovation, while RECs do so only in emerging economies. – Broader investment conditions (e.g., ease of doing business) also stimulate or deter RET innovation.	Public RD&D spending, FITs and FIPs (in USD/kWh, weighted with the contract duration of FITs), tenders (measured as capacity in MW tendered), TGCs (proxied by % produced by a RE source), carbon taxes, emission trading schemes, energy taxes and support measures to fossil fuels use.	No (only technology-specific vs technology-neutral FITs)

Source: Own elaboration.

costs substantially in an auction. In turn, these pressures would influence previous stages of the value chain. A greater competition between equipment manufacturers could be expected. This would lead them to dedicate more efforts to innovation activities in order to reduce the costs of their products or to provide new or improved ones [4].

It is often argued that quantity-based instruments (e.g. auctions and quotas with TGCs) are better suited to promote innovation, because they encourage competition between technologies, leading to lower costs [39]. Furthermore, since competition is probably less intense with higher support levels (which is considered to be the case in ASFITs/FIPs), cost-reducing innovation would be less attractive with ASFITs/FIPs compared to auctions [57].[10] However, given the scarcity of

[10] As argued by [57 p. 171], "if feed-in prices increase, and the competition with other energy sources thus becomes less intense, innovation activities aimed at reducing costs become, ceteris paribus, less attractive on the part of the windmill producer".

auction-based schemes in the past, the conclusions on "quantity" vs. "price" instruments were mostly based on one quantity-based instrument (quotas with TGCs). A priori, competitive pressures would be greater under auctions than under ASFITs/FIPs, which would encourage innovation, either to reduce the costs of technologies or to increase the efficiency in electricity production (higher generation per MW of installed capacity) [44]. The Non-Fossil Fuel Obligation (NFFO), a U.K. RE auction scheme with several rounds in the 1990s, has been used in the past to argue that auctions lead to greater competitive pressures (see, e.g., [58]). Referring to this scheme, [44 p. 78] claim that "in the bidding system, competitive pressure has indisputably forced the developers/ producers to cut their costs down, in order to remain competitive".

The idea that competition spurs innovation seems undisputable. However, the results of our review, which show that the innovation effects of competition-based instruments such as auctions and quotas with TGCs are at best more limited and at worst inexistent when compared to ASFITs/FIPs, suggest that, in fact, something else than competition drives innovation.

Indeed, a nuanced view on how innovation is affected by competition is provided by [59]. They could not find evidence that "stronger competition leads to a focus on either exploration or exploitation" [59 p. 999] and observed that a higher competitive intensity does not necessarily encourage greater R&D investments because this also depends on the firm's specific core competencies, among other factors. [60] noticed that manufacturers compete between them to provide better technologies and this happens with any instrument.

4.2. Other mechanisms mediating the influence of auctions on innovation

Several streams of the literature suggest that innovation processes are complex, that there are several drivers to innovation in RETs and that competition (as encouraged by auctions) is not the only determinant of innovation.[11]

More specifically, there might be two types of reasons for the observed limited effect of auctions on innovation. One is related to the inherent properties of the instrument itself, whereas the other might be related to the way it has traditionally been designed.

Auctions have one distinctive feature with respect to ASFITs/FIPs which might influence their comparative innovation effects: they have inherent capacity caps and, therefore, in contrast to administratively-set remuneration (which usually does not have a capacity cap), not all the capacity which is eligible for support will receive it. In addition, the real-world practice of auctions has shown that they may lead to outcomes with an (indirect) impact on innovation. First, as a result of the greater competition in auctions compared to administratively-set remuneration and the mitigation of the asymmetric information problem when setting the level of support, lower levels of support in auctions can be expected in comparison with administratively-set remuneration [17,62]. Second, auctions generally lead to greater risks, sunk costs and transaction costs (before the auction) than administratively-set support [17,37]. Third, delays in building the awarded projects (and even non-completion) have been frequent under auctions [33,37,63]. These three aspects suggest that they may not be as effective as ASFITs/FIPs in triggering capacity additions, which has a detrimental effect on innovation through the non-activation of the market-creation and learning mechanisms (see below).

If, as suggested by the chain-linked model of innovation, RET diffusion leads to innovative activities, and diffusion is promoted through RE policies such as auctions, then deployment policies would influence innovation [64].[12] This may happen through several channels. [61] identify five mechanisms which relate RET diffusion and innovation: private investments in R&D as a result of a reinvestment of profits, market creation, learning effects, competitive pressure (competition) and spillovers. The rest of this section heavily draws on the discussion of those mechanisms in [61]. The impact of competition has already been discussed above. Below, we comment on the potential effects of auctions on the first three sources of innovation compared to ASFITs/FIPs.[13]

4.3. Reinvestment of profits into private R&D

The differential economic conditions faced by project developers under auctions (compared to ASFITs/FIPs) would probably influence previous stages of the value chain, including equipment manufacturing. Different design elements in auctions would also have different effects on those economic conditions (risks, revenues and costs). It is often argued that, compared to ASFITs/FIPs, auctions lead to higher risks [65] and lower levels of support [26] for project developers. This puts additional pressure on developers to maximise those revenues and to minimise their costs [44]. If profits are lower for project developers under auctions, this is likely to negatively affect the profits of equipment manufacturers, reducing their ability to innovate. Thus, auctions and auction design elements would affect innovation indirectly, i.e., through their impacts on the R&D decisions of equipment manufacturers [61]. Private investment in R&D in the RET sectors is mostly undertaken by equipment manufacturers.[14]

Unfortunately, empirical analyses on the profit margins under different support instruments and on the reinvestment of those profits on R&D are not available. Thus, the proposition that auctions lead to lower innovation levels as a result of lower profit margins is based on theoretical arguments. [54] claim that higher profits as a result of higher support levels can be used for additional innovation. [59] observe that firms partly used the income generated through policy-induced markets to explore alternative technologies in solar PV. [57 p. 182] argue that "under ASFITs/FIPs, technical progress increases the producers' surplus and, in this way, encourages them to innovate". In auctions, however, the surplus of producers is normally lower [65]. According to [44 p. 78], "the wider diffusion observed in countries with FITs, and the more favourable sharing of surpluses, has been profitable to RE producers and constructors who have had time to consolidate their industrial basis and invest in R&D programs. Conversely, the experience with the bidding system in the United Kingdom shows that the reduced margins inherent in the system limit the budgets of developers and manufacturers. It has encouraged producers to adopt foreign best-available technologies in order to remain competitive, but it has not enabled them to present well-structured industrial supplies or invest major resources in R&D".

Notwithstanding, the argument that a higher producer surplus increases the ability to innovate should not be taken to the extreme, since deployment policies may lead to over-support for technologies which, in turn, may reduce the incentives to innovate. Too much support may shift

[11] These include the literatures on the role of competitive pressure as a source of innovation, learning effects, auction design elements, market creation (effectiveness in investment) as a source of innovation, the TIS and its functions and R&D spillovers (see [61] for an in-depth review of all these streams of the literature).

[12] As put by [59 p. 1000], "deployment policies are effective instruments for inducing innovation as they trigger investments in exploration and provide firms pursuing more mature technologies with the possibility to benefit from exploitation".

[13] This article does not analyse the influence of auctions on knowledge spillovers, since these are considered less directly related to auctions compared to the other sources of innovation. They are mostly the outcome of contributions to the knowledge stock as a result of public R&D support.

[14] For example, equipment manufacturers in the PV sector in Spain dedicate 3.6% of their turnover to "technological innovation" activities. Electricity producers dedicate less than 0.3% to those activities [66].

innovative activities towards incremental innovation or exploitation to the detriment of radical innovation (or to exploration) since, with high margins, innovation pressure may be lower [59,67].

4.4. Market creation

On the other hand, auctions may have a limited impact on *market creation* compared to ASFITs/FIPs, which leads to a lower incentive to innovate. The influence of market demand on RET innovation is shown by, e.g. [59,67–69]. There are several reasons for such influence. For [69], growing markets increase the potential to stimulate inventive talents to identify solutions to a given problem. [30] notes that a critical market size may be required to amortize investments in manufacturing facilities or to provide incentives for R&D investments. [69] argues that RETs diffusion further signals commercial opportunities for (potential) domestic technology producers and may also stimulate domestic innovation activities.

In fact, whether equipment manufacturers will be able to sell their innovation outputs to the project developers certainly depends on their demand. In other words, this is contingent upon the existence of a market for the innovation and, thus, it depends on the type of RE support schemes which have been implemented [70], although this market does not necessarily has to be the domestic one. As argued by [67 p. 546], "policies that mitigate the inherent riskiness of investments would most likely stimulate R&D investment and drive innovation". Deployment policies play a crucial role in reducing such uncertainty on the (future) existence of a market for RETs. As put by [59 p. 999], they are an "important catalyst for innovation beyond existing technological trajectories as they raise investor interest in an industry".

The expectation of a stable market for RETs makes it attractive for potential innovators to invest in R&D activities and also reduces the capital risks of so doing because banks would probably be more eager to provide financing [61].[15] Such market is unlikely to be stable in the absence of a schedule of auctions, Indeed, ad-hoc auctions (i.e., without a long-term schedule) have been more common worldwide (see below and [54,71]).

The literature suggests that the stronger effect of ASFITs/FIPs on demand could incentivise innovation more than auctions [44,54,72,73]. [54,71] observed that the development of the turbine industry was facilitated by the security created by FITs, which encouraged market participants to adopt a long-term perspective. According to [73 p. 1863], "the international market of wind turbines was dominated by manufacturers from countries that implemented feed-in tariffs, namely Germany, Denmark and Spain. By contrast, the emphasis that the NFFO and the RO (renewable obligation) place on reductions in the price paid for wind energy, or the volatile demand created under these schemes, might have hampered the growth of domestic turbine producers. Instead, developers are likely to rely on technological advancements in other countries". Higher capacity additions under ASFITs/FIPs than under auctions can be expected according to [47,74–76]. Therefore, market creation (and learning effects, see below) would probably be triggered by ASFITs/FIPs to a greater extent than by auctions.

4.5. Learning effects

Market creation affects the incentives of manufacturers to invest in R&D, but it also has an additional impact on innovation through its influence on *learning effects*.[16] Learning refers to the accumulation of technological, managerial, and organizational knowledge [30], which is a driver of innovation. As [77] notes, opportunities to make technical improvements emerge from firms' experiences in manufacturing and these (incremental) improvements in the technologies cannot be replaced by R&D investments. Learning by doing [78], learning by using [9] and learning by interacting [79] are all learning mechanisms which are activated by diffusion and lead to RET innovation (e.g., "post-adoption innovation" improvements).

RETs in distinct phases of the innovation process are likely to be affected differently by auctions. Auctions would probably lead to lower levels of innovation in the less mature RETs (LMRs), since these are less likely to be supported, especially if they participate in technology-neutral auctions [61]. However, as argued in [37], there isn't a large database of auctions and a parallel ASFIT/FIPs database which would show how well LMRs are deployed under each alternative instrument in order to test if auctions perform poorly compared to ASFITs/FIPs. There isn't an uncontested proof that ASFITs/FIPs score better than auctions in this context. However, some data suggest that auctions are probably worse than ASFITs/FIPs to promote LMRs and their value chains.

[63,80] show that RE auctions have not encouraged the uptake of LMRs. IRENA [33] and IEA [81] show that the auction volumes awarded to less mature technologies have been very small, and that wind and solar PV technologies have dominated. The very low costs of these latter technologies are probably behind this outcome.

On the other hand, as argued by [37], value chains for RETs which are now mature, but which were obviously much less mature decades ago, prospered under ASFITs/FIPs (especially, wind energy in Germany, Denmark and Spain) [82–85]. In contrast, this was not the case under the auction scheme of the U.K. NFFO [73]. It is argued in those contributions that auctions have generally led to weak domestic industries, with countries importing a significant part of their renewable energy-related products [73]. The widespread adoption of ASFITs/FIPs, and their influence on renewable energy deployment, is probably one important factor behind the cost reductions of RETs related to advancements along their learning curves. In contrast, capacity additions triggered by auctions have been much lower, given the lower adoption of this instrument.

5. Summary

To sum up, it may be argued that, although the competition in auctions provides an incentive to innovate, it also leads to low profit margins (and, thus, lower private R&D investments), that the market creation abilities of auctions can be put into question and that learning effects may also not be triggered to the same extent as in other instruments and, particularly, ASFITs/FIPs. The effects are likely to be different depending on the maturity of the technologies. Lower impacts on the more mature RETs (PV and wind on-shore) could be expected.

However, it may also be argued that the reason for the more limited innovation effects of auctions in the empirical literature is related to the way they have been designed in real-world practice rather than to their inherent features. The influence of auction design elements on innovation is likely to be mediated by their impact on the aforementioned mechanisms (reinvestment of profits, market creation, learning effects and competition). Several studies show how the choice of design elements has a considerable impact on the success of auctions, which is measured with different criteria, generally efficiency and effectiveness [16,17,34].

[15] See [59] for further insights on the influence of financial conditions on innovation in RETs.

[16] Although both "learning effects" and "market creation" effects stem from RE diffusion, they capture different effects on innovation. The former refers to the improvements which are associated with such diffusion, whereas the latter captures the expectation on the existence of diffusion of RE in the future which makes it worthwhile to invest in R&D now [70].

Notwithstanding, there is a lack of analysis on the comparative effects of different RE instrument design elements on innovation, particularly in the empirical literature using quantitative methods. This is also the case in the RE auction literature.

However, the theoretical and qualitative literature suggests that, indeed, some design elements in auctions may play a relevant role in this regard. [61] carry out a preliminary theoretical analysis and an expert elicitation on the most influential design elements on the innovation activities of equipment manufacturers. They find that the existence of a schedule of future auctions (compared to the absence of a schedule), a relatively high frequency of auctions (compared to ad-hoc auctions, conducted at irregular intervals) and technology-specific auctions (compared to technology-neutral ones) would have the greatest positive effect on innovation.

A *schedule* of auctions, with a predefined date for auction rounds and/or a relatively high *frequency* (e.g., at least once per year) would provide a stronger signal to equipment manufacturers on the potential market for their products [44]. Survey data suggest that the long and unpredictable periods between the different auction rounds in the NFFO discouraged both innovation and a domestic industry [73 p. 1863]. [47] argues that the lack of statistical significance of auctions in their study may be related to the absence of visibility for future tenders.

On the other hand, the innovation impacts of deployment policies are likely to depend on whether the policy is technology-specific or technology-neutral [86]. The more mature RETs (e.g., PV and wind onshore) are more likely to be awarded in technology-neutral auctions (compared to technology-specific ones), to the detriment of the less mature RETs. Therefore, positive innovation effects for less mature RETs (learning effects, market creation and profit margins) are more likely to be activated under technology-specific auctions. The less mature technologies would probably be favoured by technology-specific auctions or technology-specific auction designs [63,87], leading to higher levels of technological diversity. In contrast, [67 p. 550] argues that "the empirical evidence so far casts doubt as to whether technology-specific schemes pay off in terms of innovation output as compared to a uniform tariff scheme".

The analysis of [53] on the design of RE auctions in the last 30 years shows that they have seldom had a schedule and that their frequency has been low. They also show that technology-specific auctions dominate technology-neutral ones, but this was not necessarily the case when the empirical analyses on the innovation effects of RE instruments were carried out.

In the case of ASFITs/FIPs, the literature suggests that three design elements may have had a relevant effect on innovation: their relatively high levels of support, their continuity and the lack of eligible capacity limits. For example, according to [47], the result that the impacts of ASFITs/FIPs on innovation are significant but those of tenders aren't can probably be explained by the generosity of ASFITs/FIPs in the past across OECD and G20 countries, and the long-term incentives and visibility that they provide to innovators. In contrast, auctions are used on a one-off basis, without visibility for future rounds [47 p. 52]. However, the generosity of ASFITs/FIPs is a double-edge sword. According to [67 p. 546], if they are too generous, the deployment of high-cost and inefficient technologies and short- to medium-term exploitative behavior are incentivised, rather than explorative investment in R&D by technology producers. Capacity limits have seldom been adopted in ASFITs/FIPs [45]. Furthermore, the instrument has been continually available, i.e., there has traditionally not been a specific date at which installations had to ask for support, but this was provided on an on-going basis. This is in contrast to auctions, which were most often conducted at irregular intervals (see [53]).[17]

6. Conclusions

RE auctions have emerged as a main pillar of the clean energy transition in many countries around the world. Whereas this instrument may have had a positive impact on support cost efficiency and control (minimization of costs for consumers), the review carried out in this paper casts doubts on its capacity to trigger RET innovation. Using different methodologies, the papers reviewed on the comparative innovation effects of auctions suggest that they do not drive innovation to the same extent as ASFITs/FIPs. However, it should be taken into account that the evidence is limited in this regard. This is in sharp contrast to the overwhelming evidence which show that ASFITs/FIPs do support RET innovation, especially when combined with technology-push instruments in the form of public R&D investments. It is also somehow in contrast to the findings in the literature review of [41,42]. The former argue that "the evidence regarding the innovation impact of energy auctions assessments is inconclusive" ([41 p.26] of supplementary material), whereas [42] do not mention any evidence in the literature on the impact of auctions on innovation. Therefore, our results suggest that the replacement of ASFITs/FIPs by auctions could make sense with respect to the minimization of the costs for consumers, but that it may bring non-desirable effects in terms of innovation.

This paper has tried to provide some explanation(s) for this result of the literature review, considering possible demand-pull drivers of innovation (competition, reinvestment of profits into R&D, market creation and learning effects) and two main factors (the inherent features of auctions vs. ASFITs/FIPs and the dominant real-world design of auctions in the past). It has been argued that, although the competitive pressure inflicted by auctions on project developers and, thus, on equipment manufacturers would tend to induce innovation, some inherent features of auctions (most notably, the capacity caps and low support as a result of competitive pressure) would lead to detrimental effects on innovation as mediated by their negative impact on market creation, reinvestment of profits into R&D and learning effects.

In addition, auctions and ASFITs/FIPs have included design elements in the past which may have encouraged or discouraged innovation. In the case of auctions, a lack of a schedule and a high frequency of auctions, as well as technology-neutral auctions (vs. technology-specific ones) may not have generated a favourable climate for innovation in RETs. In contrast, the continuity, relatively high levels of support and the lack of capacity caps for support eligibility under ASFITs/FIPs may have triggered innovation (although they may have been negative in other respects, such as support cost efficiency and control, suggesting the presence of trade-offs).

A main policy implication of the above analysis is that, if auctions are and will continue to be chosen everywhere as the main instrument to support the deployment of RETs, the demand-pull which is needed in innovation processes would be weak or may even be absent. When a demand-pull instrument fails to create a market for new technologies or squeezes margins too much along the value chain, as it may have been the case with auctions, then it may have detrimental effects on innovation, even if the competition/selection pressures play a positive role in this regard. This should be a concern for governments all over the world because the literature on innovation has shown that demand-pull is

[17] It should be taken into account that ASFITs experienced retroactive cuts in some European countries in the early 2010s (partly because they were believed to be too generous, partly because the total support skyrocketed in some countries and partly because this coincided with an economic crisis). However, the effects of this lack of continuity are unlikely to have been captured by the econometric estimations, which include data which were previous to those cuts.

complementary and, thus, as important as supply-push in RET innovation [15,42]. However, it has also been suggested in this article that the devil lies in the details and that some auction design elements would probably induce innovation more than others.

On the other hand, some RETs are now more mature and they may not need a strong demand-pull instrument. This can certainly be the case with onshore wind and PV, which can compete on LCOE terms in many countries with other electricity generation technologies, even in the absence of support (e.g., on a merchant basis, receiving only the wholesale electricity price) [2]. Thus, the need for a demand-pull influence would be particularly relevant for less mature and relatively high-cost-gap technologies and much less important for already mature technologies, which are already competitive on a LCOE basis with respect to their fossil-fuel counterparts (e.g., solar PV and on-shore wind). For the former, the adoption of ASFITs/FIPs could be justified.

In addition, the importance of demand-pull instruments should not be overstressed. The demand-pull driver requires, both, instruments and appropriate context conditions, including ambitious targets and a stable regulation. The literature shows that target setting and stability of the regulatory framework are conducive to patenting in RETs (see, e.g. [54]). Furthermore, it should not be forgotten that the main reason for deployment support is precisely to encourage the diffusion of the technologies and innovation should only be regarded as a side-effect of this support (albeit an important one). It is an instrument specifically aimed at supporting deployment, and innovation is only a secondary goal [13,42]. Therefore, the success of the instrument should primarily be judged according to its capacity to trigger such deployment and not innovation.

As any research, this one has some limitations. The most obvious one concerns the results, with only four papers focusing explicitly on auctions. Although this is not strictly attributable to our research design, it affects the strength of the conclusions that we may infer on the innovation effects of auctions. Second, a limitation of our research may be related to the method used (a systematic review). Although systematic reviews "are more suited to relatively narrow research questions rather than multidimensional problems" [43 p. 23], such as the one addressed in this paper, a systematic review "is not guaranteed to be comprehensive or unbiased—the inclusion and coding of articles is still sensitive to the researcher's selection of criteria and concepts" (op. cit.). Third, according to [43 p. 23] "most systematic reviews give greater weight to methodologically rigorous studies, although not all meet this criteria". Our paper belongs to this latter group. The reason that different weights to different contributions are not given in this article lies in the small set of available papers on the impact of auctions on innovation. Fourth, we cannot reject the possibility that we have missed qualitative papers which indirectly (but maybe insightfully) address this topic. This may also be the result of an inherent shortcoming of systematic reviews which are "biased towards quantitative research methodologies" [43 p. 23]. More specifically, this may happen with those papers which analyse the drivers of innovation, and include policy together with other variables, i.e., in which policies are only one among other factors. Notwithstanding, we have tried to mitigate this risk by also looking to the TIS literature.

There is clearly a need for further research on the topic. The tiny empirical base on the innovation effects of auctions suggests that much more empirical research is needed in this context. In particular, investigations should focus on the effect of auctions on innovation compared to other instruments, as well as on the role of auction design elements in this context. To the extent possible, this should be carried out with quantitative methods. However, the qualitative aspects of the impact of design elements make it likely that qualitative methods would also provide useful insights in this context. Due to the relatively long periods between the adoption of an instrument and its impact on innovation, and the relatively recent implementation of auctions, some years will probably need to pass in order to be able to carry out appropriate econometric analyses on the influence of auctions on innovation.

An additional data challenge will be to obtain unitary support levels for auctions, which are non-available in many jurisdictions. Sometimes policies are included as a dummy variable in econometric modelling, which is the simplest (but also more simplistic) way to account for the impact of policies on innovation. Dummies provide information on the year of adoption of the instrument, but do not allow researchers to analyse the impacts of the design elements of the instrument, and particularly the level of intensity of the instrument adopted. Instruments have also been measured in units but, when this has happened, those units have been different for different instruments, which limit the comparison between them. For example, in [47], FITs are expressed in USD/kWh and tenders in kW. In [46], a dummy for each instrument is used.

Other possible themes for further research include an analysis of the interactions between auctions and supply-push support (and whether the synergies are greater using auctions or ASFITs/FIPs), carrying out differentiated analyses per RET (taking into account that RETs have different features, such as different maturity levels), analyzing the type of innovation (e.g., radical or incremental) which results from each instrument (and particularly auctions) and focusing on the decisions of equipment manufacturers, using their private R&D investments as the dependent variable rather than patents. The latter analysis is particularly suitable if we are interested not only in a particular innovation outcome, but in the innovation efforts made at the microeconomic level by actors (e.g., equipment manufacturers) in the supply chain which are influenced by the auction and auction design elements [47]. In this case, private R&D data are clearly superior to patents but they require that interviews or a survey to equipment manufacturers about their R&D expenditures and innovation activities are carried out. This represents a challenge and non-response rates are likely to be high (as shown by [61]).

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Declaration of competing interest

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

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Annex 1. Contributions in the literature on the innovation effects of deployment policies.

	Geographical scope	Period	Technologies
1. [88] Emodi et al 2015	12 OECD countries	1997-2011	PV and wind
2. [86] Palage et al 2019	13 OECD contries	1978-2008	PV
3. [72] Kim et al 2017			PV and wind

(continued on next page)

(*continued*)

	Geographical scope	Period	Technologies
	16 OECD countries (PV) 13 OECD countries (wind)	1992-2007 (PV) 1991-2006 (wind)	
4. [45] Del Río 2012	Several countries from around the world with FITs, but focus on Spain	1990-2011	All RETs
5. [51] Johnstone and Hascic 2010	25 OECD countries	1978-2003	Wind, solar, ocean, geothermal, biomass and waste-to-energy
6. [69] Xia et al (2019)	China (29 provinces)	2006-2013	Wind, solar, geothermal, ocean, biomass
7. [44] Finon and Menanteau 2003	Theoretical approach, but empirical evidence on FITs, TGCs and auctions in European countries used to check the theoretical results.	1990s and early 2000s	All RETs
8. [39] Groba and Breitschof 2013	Focus on (some) European countries and U.S.	Studies reviewed until 2013	All
9. [68] Watanabe 2000	Japan	1976-1995	Solar PV
10. [45] Del Río and Bleda 2012	Several countries from around the world	1990-2011	All RETs
11. [59] Hoppmann et al 2013	European, US, Chinese and Japanese firms	2012	PV
12. [89] Huenteler et al (2016)	World	1963-2009	PV, wind
13. [90] Peters et al (2012)	15 OECD countries	1978-2005	PV
14. [15] Pitelis (2019)	21 OECD countries	1990-2014	All RETs
15. [30] Matsuo and Smichdt (2019)	Mexico and South Africa	2017-2018	PV, wind
16. [77] Nemet (2009)	California	1980-2005	Wind
17. [91] EEA 2014	Czech Republic, the Netherlands, Spain and Switzerland	2006-2010	All RETs
18. [57] Soderholm and Klaassen (2007)	Denmark, Germany, Spain and the United Kingdom	1986-2000	Wind
19. [46] Hille et al 2020	194 countries and territories	1990-2016	All RETs
20. [92] Walz et al 2008	Ten OECD countries	1991-2004	Wind
21. [54] Schleich et al 2017	12 OECD countries	1991-2011	Wind
22. [93] Samant et al (2020)	Turkey, India, Brazil, and China	2000-2015	All RETs
23. [47] Ang et al 2017	46 OECD and G20 countries	2000-2012	All RETs
24. [73] Butler and Neuhoff 2008	Germany, U.K.	2003 (survey)	Wind
25. [67] Böhringer et al 2017	Germany	1990-2014	All RETs
26. [52] Nicolli and Vona 2016	19 EU countries	1980-2007	All RETs
27. [94] Gao and Rai (2019)	China	2005-2014	Distributed PV
28. [95] Dechezleprêtre and Glachant (2014).	28 OECD countries	1991-2008	Wind
29 [12] Vincenzi and Ozabaci (2017)	11 countries (nine European countries, Japan, and the United States)	1990-2008	PV
30 [13] Horner et al 2013.	States in the USA.	1974-2009	Wind on-shore
31. [96] Grafstrom and Lindman 2017	8 Western European countries	1991-2008	Wind on-shore
32 [97] Lindman and Soderholm 2016	Four western European countries	1977-2009	Wind on-shore
33. [98] Brolund and Lundmark 2014	13 European countries and Japan	1978-2009	Bioenergy

Source: Own elaboration.

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