D4.3, January 2021

Analysing the effects of auctions on technological innovation

AURES II has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817619

D4.3, January 2021, Analysing the effects of auctions on technological innovation

Authors: Pablo del Rio (CSIC), Christoph P. Kiefer (CSIC).

With contributions from Craig James and Mats Marquardt (Factor), Oscar Fitch-Roy (University of Exeter) and Vasilios Anatolitis (Fraunhofer ISI).

Reviewed by: Craig James (Factor)
Submission date: 28 January 2021
Project start date: 01 November 2018
Work Package: WP4
Work Package leader: CSIC

Dissemination level: PU (Public)

Contents

Boxes, Figures and Tables

List of Acronyms

AEP	Annual energy production
ASR	Administratively-set remuneration
CfD	Contract for Differences
CSP	Concentrated Solar Power
DE	Design Elements
FiP	Feed-in Premium
FiT	Feed-in Tariff
GHG	Greenhouse gases
IRENA	International Renewable Energy Agency
NFFO	Non-Fossil Fuel Obligation
LCR	Local Content Requirements
MT	Multi-technology
PAB	Pay-as-bid
PV	Photovoltaics
RE	Renewable Energy
REC	Renewable energy certificate
RET	Renewable energy technology
RES	Renewable Energy Support
RO	Renewable obligation
RPS	Renewable Portfolio Standard
R&D	Research and development
RD&D	Research, development and demonstration
TGC	Tradable green certificate
TIS	Technological Innovation System
TN	Technologically-neutral
TS	Technologically-specific
WP	Work Package

1 Introduction

The drastic reductions of greenhouse gases (GHG) worldwide needed to mitigate the risk of climate change call for a decarbonised energy transition everywhere. This is also the case in Europe, where the European Green Deal has set ambitious targets for the decarbonisation of the EU economy. The continent aims to be fully climate-neutral by 2050, to protect human, animal and plant life, to help EU companies to become clean product and technology leaders, as well as to realize that sustainability transition in a just and inclusive way for the well-being of all people (EU, 2019). In the EU, around 75% of all GHG stem from the energy sector (EU, 2019). The correspondingly envisioned energy transition requires a substantial uptake of renewable energy technologies. Targets for the penetration of renewable energy sources (RES) and, particularly, for the deployment of electricity from renewable energy sources have been adopted EU-wide. A target of at least 32% of gross energy consumption from RES by 2030 has been set at the EU level, and countries have also set up RES targets domestically.

Those targets refer to the penetration of renewables and, thus, to project deployment. In order to comply with those deployment targets, policies have been and will be adopted in the 2030 timeframe, with auctions being the main instrument to support deployment, as envisaged in article 4 of the Renewable Energy Directive (Directive 2001/2018/EC). This relevance of auctions in the EU context matches the widespread diffusion of this deployment instrument worldwide, with about 106 countries having adopted auctions by 2019 (IRENA 2019) compared to 6 countries in 2005 (IRENA, 2017).

On the other hand, innovation in general and, more specifically, innovation in renewable energy technologies (RETs) will be a critical component of the aforementioned energy transition (IEA, 2020). Innovation efforts may enhance performance and help lower the costs of RETs, helping to achieve RES targets (Schleich et al., 2017). In turn, deployment policies will not only have impacts on deployment itself (e.g., on diffusion), but on previous stages of the innovation process as well (e.g., invention and innovation). The feedback effect from diffusion to innovation in RETs is supported by the innovation literature. According to the chain-linked model of innovation, and in contrast to the lineal model, there are feedback effects between stages in the innovation process and, particularly, from diffusion to innovation and invention (Kline & Rosenberg, 1986). Thus, diffusion can certainly influence innovation in RETs.

Therefore, deployment policies and, particularly, auctions may have an indirect contribution to the energy transition (supporting technological innovation in RETs) in addition to the direct one (supporting the deployment of those technologies). As observed by Hoppmann (2015, p. 543), "a critical question becomes whether and to which extent deployment policies have promoted technological advancement in clean energy technologies beyond a mere diffusion of existing technologies".

Indeed, auctions and choices of design elements are likely to have impacts on a wide-array of issues. Some of them have been analysed at length both in the AURES and AURES II projects, or outside these projects, including work carried out by IRENA and other authors. These well-researched topics include the impact on the effectiveness of the auctions, support costs and actor diversity, among others[1]. However, attention has not been paid so far in the auction literature to how auctions and auction design elements influence innovation in RETs (see section 4). The research carried out in this task 4.3 of the AURES II project aims to cover this gap. Therefore, this report provides a first contribution on this issue and explores the impacts of auctions and auction design elements on technological innovation.

Although, in the past, some analysis has been devoted to explore the impact of different demand-pull instruments on innovation, the literature on the comparative effects of auctions on innovation, whether performed at a theoretical level (del Río, 2012; Finon & Menanteau, 2003) or an empirical level, is very tiny (see section 4). In particular, the empirical literature which uses econometric modeling to analyse the impacts of different demand-pull instruments on innovation has focused on the comparison between administratively-set FITs and quotas with TGS (or RPS). The impact of auctions is virtually absent in those

[1] See AURES and AURES II project websites for further details (https://www.auresproject.eu/ and http://aures2project.eu/).

analysis (with the exception of Hille et al. (2020)), which is probably related to the fact that the empirical base on the projects built under auctions is much smaller than for the other two instruments.

In addition, the differential impact on innovation of different design elements of instruments (also auctions) has not been the focus of research (see the literature review in section 4). This is despite the well-known relevance of these design elements. The literature on RES support schemes has come to the conclusion than the devil lies in the details and that the success of RES policy is dependent on, both, the choice of RES support instruments as well as on how they are designed (del Río et al., 2012; IEA, 2011). Previous work in the EU-funded AURES project stressed the importance of the choice of design elements on the success of auctions, which is measured with different assessment criteria (del Río et al., 2015; Mora et al., 2017). The innovation literature also stresses that the detailed characteristics of policy instruments are critical to their effectiveness in inducing innovation (Nemet, 2009; Taylor et al., 2005).

Therefore, although some insights can be derived from the literature on the innovation impacts of deployment policies in general, this literature is unfortunately tiny, and the contributions on the innovation effects of auctions are even scarcer. Similarly to Nemet (2009), this study takes the perspective that improved understanding of the mechanisms linking public policies (with a focus on demand pull, i.e., auctions) and the incentives that innovators face is ultimately necessary for informed allocation decisions.

The aim of this report is thus to cover this gap in the literature by providing an analytical framework on the mechanisms linking diffusion-driven technological innovation and auctions and their design elements and to carry out a preliminary empirical analysis which allows us to identify the perception of key stakeholders on the topic and, based on theory and on those perceptions, to put forward some research proposals to be investigated in future research. This report also highlights some of the methodological challenges that will be faced by those aiming to undertake future in-depth empirical analyses on this topic.

Given the lack of previous research on the topic and even the absence of an analytical framework, and also taking into account the qualitative character of the topic (and the lack of hard data), an exploratory analysis is justified. This exploratory analysis is based on a literature review and a exchange of views on the main aspects (actors, variables, relationships between variables and causal links) with different relevant stakeholders knowledgeable of both innovation processes in RETs and auctions (and their design elements). Some interviews with Spanish actors which help us to identify or confirm the relationships between the relevant aspects and variables have been carried out. This is complemented with the insights from documents from renewable energy associations and technology platforms in Spain.

The analytical framework built is based on merging the insights from different approaches to identify the causal mechanisms linking auctions and design elements with innovation, taking into account relevant variables and relevant relationships between variables (see sections 3 and 5). The starting idea is that there are several determinants of diffusion-driven innovation in RETs and that some of these determinants, which are influenced by auctions and auction design, conflict between each other (competition vs. market creation effects). Thus, trade-offs between them can be expected, and it is difficult to tell a priori which effect dominates and what is the net effect. How auctions either activate those determinants of technological innovation or are barriers to it, how design elements in auctions activate those drivers and what is their relevance with respect to other factors driving technological innovation in RETs are all crucial issues that need to be explored.

It should certainly be taken into account that, apart from auctions, other policy factors (framework conditions, public investments in R&D and other measures in the policy mix) and non-policy factors (such as domestic innovation capabilities) influence innovation in RETs. Isolating the effects of auctions from the other factors is a challenging task. Thus, it makes sense to discuss with different types of relevant stakeholders (energy/innovation experts, RES sectoral experts, RES associations and equipment manufacturers) what the relevant influencing factors are (in addition to auction) and what the role of auctions in this context is.

The relative importance of deployment support (and, particularly, auctions) with respect to other factors calls for an analytical framework which merges the insights of different approaches and integrates the sources of innovation with the possible impact of auctions and auction design elements on those sources. This analytical framework is even more needed given the very few existing studies on the impact of auctions on innovation with respect to other instruments and the lack of studies on the innovation impacts of different design elements (see section 4).

Whereas the literature on innovation usually distinguishes between organizational and technological innovation, we focus on technological innovation in this report. There are several reasons for this choice. First, technological innovation has been the focus of the few previous contributions on the impacts of RES deployment support on innovation. Second, some indicators of technological innovation are publicly available (patents). Finally, a look at the reports from the renewable energy associations in Spain suggests that this is a very important type of innovation nowadays.

Accordingly, the report is structured as follows. The next section provides a brief description of the main design elements of RES auctions. Section 3 discusses the sources of technological innovation. Section 4 reviews the literature on the impact of deployment support (instruments) on technological innovation. Based on the work carried out in the previous two sections, the analytical framework on the link between auctions and auction design elements and technological innovation is provided and described in section 5, where a preliminary theoretical analysis of those impacts is carried out. The methodology for the empirical study is described in section 6. The results of the empirical research are provided in section 7. Section 8 concludes.

2 Auction design elements

The impact of different design alternatives on innovation can be analysed a priori by identifying the potential theoretical effects of those alternatives on the different innovation mechanisms. The following table includes a list of the different categories and alternatives of design elements and a description of the different options.

Table 1: Categories, options and description of design elements.

Design elements		Description
Category	Alternatives	
Volume	Generation, capacity or budget	The volume in renewable electricity auctions can be set in terms of capacity (MW), generation (MWh) or budget (e.g., million €) terms.
	Disclosure (vs. non-disclosure)	Such volume can be disclosed or not before the auction.
Schedule (vs. non-schedule)		A schedule of auctions implies a commitment to launch an auction at regular intervals and a programmed timetable of auctions to be organized at least during the next five years. The alternative is to conduct ad-hoc auctions, i.e. set at irregular intervals, without a timetable. Even if there isn't a schedule of auctions, these may be organized on a regular basis (i.e., with a high frequency).
Frequency: high (vs. low)		Frequency refers to the existence of de-facto regular auctions (i.e., auctions being conducted at least once per year) even if these are not envisaged in a pre-specified schedule.
Diversity	Technology-neutral (vs. technology-specific)	Auctions that target a given and specific category (e.g. a RES project in a particular location; use of a particular technology; or a particular project size, etc.) can be promoted through the use of several (auction design) options. A relevant distinction is between technology-neutral (TN) and technology-specific auctions (TS). All renewable energy technologies are in principle eligible to participate and be awarded in TN auctions. Only one technology is eligible to participate in TS auctions, or several of them in multi-technology auctions (MT).
	Geographically-neutral (vs. geographically-specific)	Auctions can also be geographically neutral (no requirement to deploy the project in a given location) or geographically-specific (the location is either pre-selected by the government or an incentive to locate in given places is provided).
	Actor-neutral (vs. actor-specific)	In actor-neutral auctions, large actors are likely to dominate participation and awarding, since they are more

<table>
<tr><td rowspan="3"></td><td></td><td>likely to offer low bids.</td></tr>
<tr><td>Size-neutral (vs. maximum size)</td><td rowspan="2">When there is a maximum or a minimum project size, only projects of a size below a maximum limit or above a minimum threshold may participate in the auction. Therefore, projects being awarded in the auction should have a maximum or a minimum size.</td></tr>
<tr><td>Size-neutral (vs. minimum size)</td></tr>
<tr><td rowspan="3">Prequalification (stringency)</td><td>Material prequalifications on projects</td><td rowspan="3">They may fall on the bidder (e.g., degree of previous experience, a good financial record or economic guarantees) or on the project (e.g., pre-development of sites or possession of administrative permits) and mitigate the risk of non-realization. They can be more stringent (e.g. requiring high bid bonds, that the project has an access and grid connection point and administrative permit) or more lenient.</td></tr>
<tr><td>Material prequalifications on project developers</td></tr>
<tr><td>Financial prequalifications</td></tr>
<tr><td colspan="2">Seller concentration rules (vs. their absence)</td><td>In order to ensure competition, the auction may be cancelled if there is not a minimum number of participants (e.g. Colombia and Portugal).</td></tr>
<tr><td colspan="2">Local content rules: local industry (vs. their absence)</td><td>Some countries require that the equipment used in the projects awarded in the auction is manufactured domestically.</td></tr>
<tr><td colspan="2">Local content rules: local employment (vs. their absence)</td><td>Some countries require that a share of the total staff in the projects awarded in the auction is hired domestically.</td></tr>
<tr><td colspan="2">Information provision</td><td>Governments may support participation in the auction by providing information to potential bidders (e.g., measurement of resource potentials).</td></tr>
<tr><td colspan="2">Remuneration type: generation (vs. capacity)</td><td>Remuneration in auctions can be provided for generation (MWh) or capacity (MW).</td></tr>
<tr><td colspan="2">Remuneration type (FIT, fixed FIP, sliding FIP)</td><td>Either a feed-in tariff (FITs) or a feed-in premium (FIP) can be set in an auction. Awarded bidders may receive a full payment (FIT) or a premium which is additional to the market price (FIP). Under a fixed FIP, a constant amount of support which complements the spot market price is granted. Thus, the total remuneration in this case depends on the evolution of the market price. A sliding FIP cover the difference between the average market price and the strike price set in the auction. A sliding FIP can be one-side or two-side (commonly known as contract-for-differences).</td></tr>
<tr><td colspan="2">Selection criteria: price-only (vs. multicriteria).</td><td>The award criterion may be only the lowest price (price-only auctions) or the lowest price and other criteria, such as local industry or employment creation (multi-criteria auctions).</td></tr>
<tr><td colspan="2">Auction format: multi-item (vs.</td><td>Auctions can be single-item or multiple-item ones. In the former, a single bidder is awarded a single product, i.e., the</td></tr>
</table>

single-item).		product cannot be divided into several units. In multi-item auctions, several bidders may be awarded the total amount of auctioned volume.
Auction type: static (vs. dynamic)		Auctions can be dynamic or static. In dynamic auctions, bidders interact with each other when submitting their bids, and can adjust them accordingly. In static (also called sealed bid) auctions, bidders provide undisclosed bids to the auctioneer, who then ranks the projects accordingly.
Pricing rule: PAB (vs. uniform)		Under pay-as-bid pricing, awarded bidders receive the price they have bid for. Under uniform pricing, all bidders receive the same (clearing) price.
Ceiling prices	Existence (vs. absence)	A ceiling on bid prices means that bids above such price are not considered in the bidding procedure.
	Disclosure (vs. non-disclosure)	Such price can be disclosed or not before the auction.
Realisation period (vs. absence)		The awarded projects should be built by a given date.
Minimum participation conditions (vs. their absence)		This refers to a minimum number of bidders being required to participate in the auction

3 The sources of RET innovation and feedbacks from diffusion

3.1 Defining innovation

Our starting point is that instruments to support the diffusion (deployment) of technologies, such as auctions or administratively-set support, may have an impact on previous stages of the technological change process. Generally, this process is characterized by three main stages: invention, innovation and diffusion. An invention constitutes the first development of a scientifically or technically new or significantly improved product or process. An innovation is accomplished only with the first commercial transaction involving the new product or process. Diffusion is the adoption and use of the new technology over time (del Rio, 2004; Jaffe et al., 2002).

However, several authors have used different definitions of innovation. For example, Taylor et al. (2005) uses the term "innovation process" to refer to the aforementioned three stages (i.e., including innovation *strictu sensu*). A similarly broad definition of innovation is used by Dosi and Orsenigo (1988), for who innovation concerns the search for, and the discovery, experimentation, development, imitation and adoption of new products, new production processes and new organisational set-ups.

Narrower definitions of innovation are also common. For ETH (2014, p. 1) "innovations can be defined as genuinely novel as well as significantly improved products, services and processes already on the market, which are not necessarily based on patented know-how. This definition implies that innovation should be measured by a variety of indicators. Alongside patents, conventional indicators include, e.g., the number of new products launched onto the market or products whose quality has improved; improved price/ performance; but also innovative start-ups and investments in research and development". For Ang et al. (2017) "innovative activity" refers to invention and technology development. Bergek and Berggren (2014) define innovation as the development, market introduction and early diffusion of new products and processes. For Anadon et al. (2016, p. 2) innovation is the "process by which technology is conceived, developed, codified, and deployed". The OECD Oslo Manual defines innovation 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)" (OECD, 2018, p. 1) and distinguishes between innovation as an outcome (an innovation) and the activities by which innovations come about (innovation activities). For IEA (2020, 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". This report stresses that innovation is not the same as invention: "After a new idea makes its way from the drawing board to the laboratory and out into the world, there are four key stages in the clean energy innovation pipeline (prototype, demonstration, early adoption and maturity)" (IEA, 2020, p. 11). In this report, innovation is defined as an invention with an economic value which is ready to be adopted by the market. There are several types of innovation, and a main distinction is between technological and organizational innovation. Technological innovation is the focus of this report. 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 or commodities to users" (IEA, 2020, p. 20).

3.2 The role of governments in the innovation process: public and private R&D

Governments play a very important role in promoting innovation, and even more so in clean innovation. Their intervention to support clean innovation is justified according to the so-called triple externality problem (the environmental externality, the innovation externality related to spillover effect and the deployment externality, see Del Río (2011). They can intervene in many different ways: "by educating people, funding R&D, providing network infrastructure, protecting intellectual property, supporting exporters, buying new products, helping small and medium-sized enterprises, shaping public values, and setting the overall regulatory framework for markets and finance" (IEA, 2020, p. 24).

In particular, they can directly promote renewable energy innovation by supporting public R&D in research centers and universities (by funding them) or in firms (through, e.g. fiscal incentives and grants). But government can also promote innovation indirectly by supporting the deployment of the technologies through several instruments, e.g., auctions. The direct policy influence is usually called technology-push policy whereas the indirect influence refers to demand-pull and it is often acknowledged that they are complementary instruments, i.e., both demand-pull and supply push measures are needed and should be coordinated (Popp, 2010). This suggests that auctions are only one of the possible policy drivers and in turn policy is only one among many other drivers of innovation processes. There are many factors which influence innovation beyond deployment support and which interact with it (e.g., demand potentials and changes in consumer preferences). Accordingly, the innovation impacts of individual instruments have to be embedded in this overall context and assessed from a systemic point of view (ETH, 2014, p. 1).

The reason why governments may influence innovation indirectly through demand-pull measures is related to the so-called chain-linked model of innovation. In the past, the innovation process was seen in a linear way, going through the different stages in a sequential manner, i.e., technologies would subsequently pass from one stage to another without interactions between stages[2]. However, since the seminal contribution on the chain-linked model of innovation of Kline and Rosenberg (1986), more and more contributions have acknowledged that feedbacks between stages are very relevant as drivers of the whole process and innovation in particular. As put by IEA (2020, p. 21), "innovation processes are rarely linear, and no technology passes all the way from idea to market without being modified. Their trajectories are influenced by feedback loops and spillovers between technologies at different stages of maturity and in different applications, and often involve setbacks and redesign". Today, the chain-linked (or systemic) model is considered as the most standard representation of the technological

[2] The linear model comes directly from the work of (Bush, 1945).

change process. Therefore, the influence on the innovation/diffusion of RETs of further improvements in such technologies as a result of R&D investments and learning effects that occur during diffusion should be considered (del Río, 2009).

Private R&D is a particularly important driver of innovation in RETs and it is complementary to public R&D, since both play different functions in the technological change process. Public R&D is especially relevant in the very first stages of such a process, when technological uncertainty, market imperfections, and failure in the knowledge market would lead to underinvestments by firms. R&D activities undertaken by private firms normally are more applied (Söderholm & Klaassen, 2007, p. 170). Private research, development and demonstration (RD&D) accounts for a large share of total RD&D in the RET sectors. According to IEA (2008), private-sector RD&D spending on energy technologies (both RETs and non-RETs) in 2008 was at 40 to 60 $billion a year, about four to six times the amount of government RD&D. Recent data confirm the importance of private R&D in renewable energy. In 2014, corporate (private) R&D in the RES sector accounted for about $7 billion out of a total of $12 billion, with the rest being government (public) R&D (UNEP, 2015). Both types of R&D are very important in explaining the cost reductions in RETs. For example, IEA (2020) suggests that around 60% of the cost reductions in producing solar PV panels between 1980 and 2012 arose from R&D (both public and private).

3.3 The sources of innovation in RETs: impacts from diffusion

As mentioned above, taking into account the chain-linked model of innovation, technology diffusion (deployment) in RETs can be expected to trigger innovation activities. In turn, diffusion is promoted through RES policies. This diffusion-related innovation is complementary and additional to the innovation effects of technology-push policies in the form of R&D support.

There is a widespread consensus that demand triggered by deployment policies induces innovation (Popp, 2019)[3]. This notion has been discussed in two separate streams of research: the literature on environmental policy and systems of innovation approaches to innovation policy (see section 4). This inducement effect of RES deployment policy is expected to act through several channels.

Our review of the specialized literature, together with previous work by the authors allow us to infer several sources of impacts from diffusion to innovation. We have identified five different (although possibly overlapping) mechanisms which relate RET diffusion and innovation. We describe those sources in this section, whereas their links to specific deployment policies (e.g., auctions and auction design elements) are left for the building of the analytical framework in section 5.

[3] As put by Hoppmann et al. (2013, p. 997), "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".

3.3.1 Learning effects[4]

Learning refers to the accumulation of technological, managerial, and organizational knowledge (Matsuo & Schmidt, 2019). This accumulation of knowledge is a direct and an indirect driver of innovation. On the one hand, it can be used by others, but the knowledge accumulated by a firm also helps the firm to absorb new knowledge. This indirect effect is called "absorption capacity" in the literature (Cohen & Levinthal, 1989).

Learning effects are directly related to diffusion of the technology through "post-adoption innovation" improvements that occur after a technology has entered into use. As (Nemet, 2009, p. 702) notes, opportunities to make technical improvements emerge from firms' experiences in manufacturing and these (incremental) improvements in the technologies are uniquely available from experience and cannot be substituted for by R&D investments.

Thus, diffusion activates several learning mechanisms which lead to innovation in RETs (box 1).

Box 1: Learning mechanisms.

- Learning-by-doing: The repetitious manufacturing of a product leads to improvements in the production process. This is a concept introduced for the first time by Arrow (1962). It takes place in the production stage after the product has been designed.
- Learning-by-using: Improvements in the technologies as a result of feedback from user experiences into the innovation process. Improvements in the products from their diffusion in the market are suggested by users and these improvements are carried out by the firms selling the products or their manufacturers.
- Learning-by-interacting: It takes place at the large diffusion stage as a result of the network interactions (including the exchange of knowledge) between actors (Lundvall, 1988). These actors include research laboratories, industry, end-users and policy-makers, among others. Learning-by-interacting allows the firm to benefit from external sources of learning and is greatly associated with the increasing diffusion of technology.

Source: Junginger et al. (2005), Kahouli-Brahmi (2008, p. 139).

The literature usually includes an additional learning mechanism: learning by researching, which "refers to the accumulation of knowledge by devoting R&D resources to the search for new ideas and their development into viable products and services, including prototypes and demonstration projects" (IEA, 2020, p. 20). Learning by researching does not only lead to the accumulation of knowledge, but also allows firms to increase their aforementioned "absorption capacity", i.e. to identify and use the existing knowledge. In this report we focus on the incentives of firms to dedicate resources to those R&D activities, which are directly related to the following three innovation effects of deployment policies.

[4] This and the next three subsections heavily draw from del Río and Peñasco (2014), but update it.

3.3.2 Market creation

A huge literature stresses the critical role of demand-pull in driving innovation (Schmookler, 1962). Demand-pull perspectives in innovation studies suggest that growing markets will increase the potential to stimulate inventive talents to identify solutions to a given problem (He et al., 2018). A critical market size may be required to amortize investments in manufacturing facilities or to provide incentives for R&D investments (Matsuo & Schmidt, 2019).

In general, but also in the realm of RETs, technology diffusion further signals commercial opportunities for (potential) domestic technology producers and may also stimulate domestic innovation activities (Schleich et al., 2017, p. 685). Equipment manufacturers are the actors mostly investing in R&D in the renewable energy sectors[5]. Investments in R&D by these firms depend on expectations on the future existence of a market where they can sell their products. As argued by Böhringer et al. (2017, p. 546) "the outcome of all phases of technological development in RETs is associated with a high degree of uncertainty. This impedes investment decisions by innovators or manufacturers, particularly if the economic significance of R&D investment, for example, is uncertain. Thus, policies (e.g., R&D subsidies, green quota) 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 stressed by (Hoppmann et al., 2013, p. 999) "deployment policies serve as an important catalyst for innovation beyond existing technological trajectories as they raise investor interest in an industry".

The foreseeability 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, i.e., a higher availability of capital would result[6]. They invent and innovate in new or improved products and processes which then sell to project developers. Therefore, whether equipment manufacturers will be able to sell their innovation outputs depends on the demand of those developers, i.e., on the existence of a market for the innovation and, in the case of RETs, on the existence and type of RES support schemes being implemented (del Río, 2012). Apparently, "learning effects" and "market creation" effects may look similar since both stem from diffusion (deployment of RES capacity), but they grasp different effects on innovation. The former capture the improvements which are associated with such diffusion, whereas the latter refer to the expectation on the existence of diffusion of RES in the future which makes it worthwhile to invest now in R&D (del Río, 2012).

Several empirical studies in the realm of RETs show the influence of market demand on RET innovation. For example, Watanabe et al. (2000) showed that the private R&D

[5] For example, in Spain, equipment manufacturers in the PV sector dedicate 3.6% of their turnover on "technological innovation" activities. This is less than 0.3% for electricity producers (UNEF, 2020a, p. 52).
[6] See Hoppmann et al. (2013) for further insights on the influence of financial conditions on innovation in RETs.

investments in PV in Japan depended on the creation of a market for PV. He et al. (2018) has found that, for all renewables, the estimated coefficient of electricity consumption (a proxy of market size) is the most important driver for innovation in RETs. In their analysis of PV, Hoppmann et al. (2013) showed that policy-induced market growth raises the absolute level of firm investments in technological exploration and, thus, drives innovation (Hoppmann et al., 2013, p. 989). Böhringer et al. (2017) show that the increasing deployment of solar PV and wind technologies correlate positively with patenting activities and the authors interpret this as the additional innovation impact of an increase in the market size for solar PV and wind technologies being positive (Böhringer et al., 2017, p. 551).

3.3.3 Private R&D investments: reinvestment of profits.

Market opportunities that come from technological diffusion may affect invention since expected profits from market opportunities stimulate technology developers to keep developing new technology (Jaffe et al., 2005; Kim et al., 2017). R&D investments by equipment manufacturers may depend on the existence of a producer surplus by project developers (Butler & Neuhoff, 2008; Finon & Menanteau, 2003; Menanteau et al., 2003). As put by Finon and Menanteau (2003, p. 15), this driver of R&D investments refers to "the technological progress resulting from dedicated R&D activities initiated by constructors and technology users seeking to reduce costs and gain temporary competitive advantage" and this depends on "the profit level that constructors could anticipate from their contracts with the developers, which depends on the instruments of the policies. Lower surplus for the developers would mean less favourable contracts for the constructors and weaker incentives to invest in ambitious R&D activities" (Finon & Menanteau, 2003, p. 15). The authors argue that the amount of this rent depends also on the instruments used. In the same line, Schleich et al. (2017, p. 685) argue that higher support levels generate higher profits which can then be used for additional innovation.

Although the existence of such surplus may be neither a necessary nor a sufficient condition, the squeezing of profits at the project development stage is likely to be transmitted to previous stages of the value chain, making it unlikely that equipment manufacturers would have sufficient ability to innovate. This theoretical proposition was empirically analysed by Hoppmann et al. (2013) for the case of solar PV. The authors confirmed that firms used parts of the income generated through policy-induced markets to explore alternative technologies. All company representatives of firms pursuing wafer-based crystalline PV technologies that they interviewed stressed that "the resources available for R&D are strongly linked to existing cash flows" (Hoppmann et al., 2013, p. 995).

Obviously, the existence of profit margins and market creation are to some extent related. It is difficult to imagine that relatively high profit margins exist in a small or stagnant market. However, both effects capture slightly different drivers. Whereas the latter refers to the fact that deployment support, which enlarges the market for renewable energy, is expected to stimulate innovation thanks to the higher expected return from R&D investments, the former refers to reinvestment of profits into R&D activities. In short, whereas the latter relates to expectations that a market for products will be there, the former refers to higher or lower profits in that market.

However, although according to the above proposition, higher deployment support may lead to higher R&D investments, too much support may shift innovative activities towards incremental innovation or exploitation to the detriment of radical ones (or exploitation)[7] since, with high margins, innovation pressure is lower (Hoppmann et al. (2013, p. 996). Similarly, Böhringer et al. (2017, p. 546) argue that "high tariffs – with relatively modest yearly reduction or "degression" rates – also enhance short- to medium-term exploitative behavior rather than intensive explorative investment in R&D by technology producers". Their finding for "the missing additional EEG innovation impacts" confirms their statement[8].

Nemet (2009) also argues that strong demand-pull policies leading to market creation and high profit margins may encourage incremental innovations rather than radical ones. The authors note that, "indeed, a main line of criticism of the demand-pull influence on innovation was that demand explains incremental technological change far better than it does discontinuous change, so it fails to account for the most important innovations" (Nemet, 2009, p. 701). In his analysis of wind patents, Nemet (2009, p. 700) findings confirm the conflict between policy-induced market growth which may incentivize technology producers to "exploit" existing products to benefit from learning-by-doing and economies of scale, while simultaneously setting a disincentive to "explore" alternative technological options. They find that "inventors of the most important inventions did not respond positively to strong demand-pull policies; filing of highly cited patents declined precipitously just as demand for wind power created a multi-billion dollar market" (Nemet, 2009, p. 700).

3.3.4 Competitive pressure (competition)

There is an abundant literature which shows the positive relationship between market competition and cost-reducing innovation (del Río, 2012). Competition can be considered a major driver of energy innovation. Firms of all sizes have incentives to refresh their offering to customers to increase market share and to avoid losing out to competitors with cheaper or better performing products (IEA, 2020). Competitive pressures in the project development stage can be expected to induce competition between equipment

---

[7] Hoppmann et al. (2013) define exploration as "search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation", whereas exploitation includes terms like "refinement, choice, production, efficiency, selection, implementation and execution".

[8] The authors explain this lack of impact because "for a potential innovator focusing on the domestic market, on the other hand, the revenue from an (ex-post) cost-effective new technology might be less or just the same as the revenue generated through pre-existing established technologies. Consequently, it does not pay to embark on risky technological innovations (...). The EEG-induced market growth – with its high-profit margins – induces firms with inefficient technologies to shift resources from intensive and risky explorative research activities towards exploitative activities (in terms of increased production to meet demand)" (Böhringer et al., 2017, p. 552).

manufacturers, leading them to innovate either to reduce the costs of their products and processes or to provide new or improved ones.

At the empirical level, Nesta et al. (2014) have shown that competition enhances innovation in green technologies, including RETs. However, it might be difficult to include this variable in econometric models due to lack of data. This is for example the case in the analysis of innovation in wind technologies of Schleich et al. (2017). These authors argue that "not all factors that might affect innovation in wind-power technologies could be included. Notably, due to the lack of data, we could not explore the role of competition among technology providers" (Schleich et al., 2017, p. 692).

Competitive pressures being faced by equipment manufacturers and leading them to innovate may be the result of a greater competition faced by project developers, which are the ones buying the equipment. Project developers may be required to reduce their costs substantially as a result of greater competitive pressures. In turn, this requires them to ask for cheaper or better equipment. Thus, there is an incentive to manufacture products which are either cheaper or better, i.e., with a better performance which allows project developers to increase their annual energy production and, thus, benefit from higher revenues. Therefore, in this context, lower wholesale electricity prices and/or lower support levels for RETs can be expected to drive innovation in RETs, and this effect would be in the opposite direction as in section 3.3.3. The analysis of He et al. (2018) confirms this relationship for China. The authors find that lowering electricity prices will lead to higher technological innovation in renewables.

Hoppmann et al. (2013) provide a more nuanced view of the impact of competition on innovation, however. They did not find evidence that "stronger competition leads to a focus on either exploration or exploitation" (Hoppmann et al., 2013, p. 999). The authors further argue that a higher competitive intensity does not necessarily lead to higher investments in R&D, since firms may have other alternatives, including sourcing, choice of location and operational excellence. "In fact, the way in which firms react to intensifying competition may depend on the firm's specific core competencies that determine its propensity to pursue a differentiation or a cost-leadership strategy" (Hoppmann et al., 2013, p. 999).

Finally, it is important to mention that the different drivers of private R&D investments may interact between each other. The greater the market growth (market creation) and the greater the generosity of deployment support and, thus, the higher the profit margins, the lower the competitive pressure. However, each driver may lead to different types of innovation. According to Nesta et al. (2014) the inducement effect of environmental policies leads to high-quality green patents, whereas competition in the energy market enhances the generation of low-quality green patents.

3.3.5 Spillovers

Spillovers are formally defined by IEA (2020, p. 20) as "positive externalities of learning-by-doing or learning-by-researching that increase the rate of innovation in an area that was not the target of the original innovative activity. Spillovers can be considered to be "free" inputs to parallel innovation ecosystems, related by geography or scientific proximity".

There are several classifications of spillover effects. For example, IEA (2020) stresses that knowledge accumulated in one technology area can be of great relevance and value in related technologies and distinguishes between knowledge and application spillovers[9]. On the other hand, there are spillovers at the national level, either within the same technology field or economic sector (intra-sectoral spillovers) or in related technologies or sectors (inter-sectoral spillovers), or at the international level (Braun et al., 2010). Overseas knowledge is adapted by domestic R&D and increases domestic knowledge generation. The more a country accumulates a domestic knowledge stock, the more it is able to absorb foreign knowledge and internalize it (Kim et al., 2017). Thus, domestic R&D efforts are necessary for the adaptation of overseas knowledge to the domestic market as well as for the sources of domestic invention Palage et al. (2019). Public R&D support provides knowledge that private companies can appropriate to develop their own technologies, i.e., such support generates knowledge spillovers.

An increase in domestic public R&D investments contributes directly, but also indirectly, to the knowledge stock, by allowing the absorption of foreign public R&D (knowledge spillovers) and appropriating learning effects. In addition, foreign public R&D (knowledge spillovers) influences the domestic knowledge stock. New inventions created in the country contribute to building domestic and overseas knowledge stocks. As noted by Kim et al. (2017), the knowledge stocks are a main source of cost reduction (innovation) by learning-by-searching and that effect continues over time (dynamic) because the new inventions accumulate in the stocks (Kim et al., 2017). In the review of the literature on the innovation in RETs, Bourgeois et al. (2017, p. 9) note that, according to the literature, the effect of an increase in the stock of knowledge in a country A and its transfer to country B is, however, less important for country B than its own domestic R&D expenditure, due to the existence of barriers to the dissemination of knowledge. For solar and wind technologies, however, there is no effect from R&D spending abroad.

Therefore, spillovers may be a result of the other drivers. In particular, they are an important consequence of public R&D investments. However, spillovers may also be the result of learning-by-doing, i.e. they would be related to the adoption and diffusion of technologies (as firms adapt technologies). If this is so, deployment support (demand-pull instruments) such as auctions would also induce knowledge spillovers.

---

[9] "Knowledge spillovers refer to the incorporation of new principles, e.g. the adoption of breakthroughs in semiconductor manufacturing by those producing solar PV. Application spillovers refer to the adoption of a technology in a new application only once it has been refined through innovation targeted at a separate, original application, e.g. the adoption of lithium-ion (Li-ion) batteries in vehicles after their development for consumer goods" (IEA, 2020, p. 21).

Different RETs may be influenced differently by spillovers. For example, Braun et al. (2010) find that wind and solar technologies exhibit distinct innovation characteristics: both are stimulated by intra-sectoral spillovers, but respond differently to inter-sectoral spillovers, which are only influential in the case of wind technology.

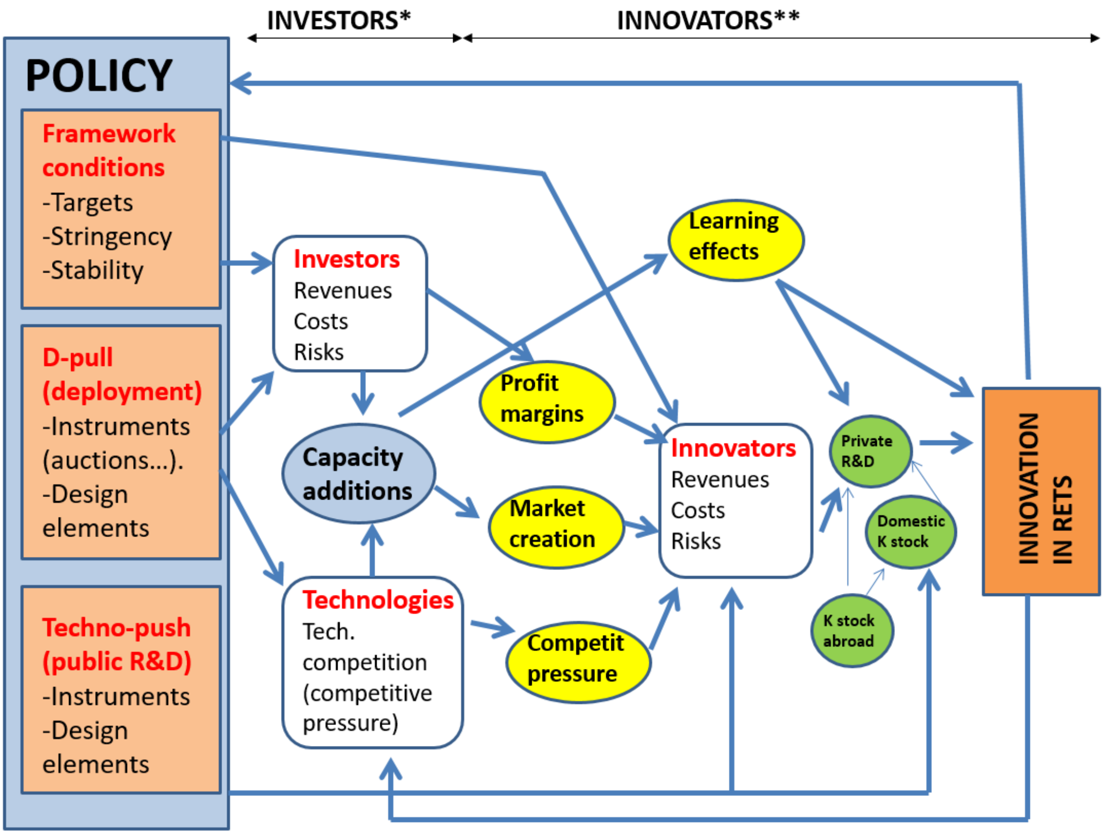
Spillovers are not explicitly considered in this paper, which focuses on the influence of auctions on the incentives to carry out R&D activities by firms.

3.3.6 Synthesis

The aforementioned relationships are triggered by policies. These refer to, both, policy framework conditions, specific instruments and design elements in those instruments. Framework conditions include three main aspects: targets, stability and stringency of policy (see section 5 for further details).

The following figure illustrates the relationships between policies, RET diffusion and innovation.

Figure 1: Illustrating the relationships between RET diffusion and innovation.



Source: Own elaboration. * Investors (bidders + project developers) ** Innovators (equipment manufacturers + technology developers).

These relationships lead to feedback loops and are inherently dynamic. For example, the reduction in the costs of the technologies may lead to more ambitious RES targets or lead to a change in the policy conditions (e.g., support levels). A closer look at the impact of auctions and auction design elements on innovation, within this broad picture, is provided in the analytical framework developed in section 5.

4 The innovation effects of renewable energy deployment policies: a literature review

4.1 The literature on the innovation effects of deployment support

A literature review focusing on those contributions which have analysed the impact of deployment policies on innovation has been carried out[10]. For this, a Scopus search was undertaken with the key words "innovation+renewable energy+policies". In addition, we looked into the most relevant energy and innovation journals. The key words "renewable energy", "solar" and "wind" were included in the search engines of the innovation journals, whereas the key words "innovation" and "patents" were included in the search engines of energy journals. A large number of papers (96) resulted. Their titles and abstracts were read and this led to an initial selection of contributions which a priori were within the scope of this study. Snowballing allowed us to identify other potentially relevant papers. We read all these papers and only kept those which we deemed relevant in this regard.

We ended up with 28 papers. 17 of them have used econometric modeling, whereas the rest are either theoretical or use qualitative analysis, including case studies. Table A1 in Annex 1) provides details on their geographical, temporal and technological scope as well as the method used. We also identified the aim of each paper, their main results, the policy variables which were considered in those papers, whether the impact of auctions on innovation was analysed and whether the influence of the design elements of different deployment-support instruments was taken into account[11].

The purpose of most of the finally selected papers is to directly analyse the impact of deployment support on innovation in RETs, but a few do so in an indirect manner, i.e. they provide interesting insights on this topic although their focus is not exactly on such influence.

Several insights can be derived from this literature review. First, the contributions have been both theoretical, methodological and empirical. The empirical papers differ with respect to their geographical, temporal and technological coverage, although some common patterns emerge. There is a dominance of studies in OECD countries. A technology focus on wind and PV can be observed, although many papers have also a general technological scope (i.e., all RETs). Interestingly, even if the papers were recently published, the periods covered in these studies are relatively old, and refer to about a

---

[10] There are only two literature reviews on the topic: Groba and Breitschopf (2013) and Bourgeois et al. (2017). However, the former is relatively old (and carried out at a time when the implementation of auctions was not widespread), whereas the second does not pay an explicit attention to the impact of auctions or design elements of policies on innovation. In Burgeois et al (2019), auctions are included in the "quantity-based" policy category, together with quotas with TGC schemes and, thus, it is difficult to isolate the effect of auctions on innovation.

[11] The complete table is not included here for reasons of space, but it is available from the authors upon request.

decade ago (Pitelis et al., 2019), using data up to 2014, and Matsuo and Schmidt (2019) using 2017-2018 data are two exceptions). This is particularly the case with those empirical contributions using patent data (Hille et al., 2020), with data up to 2016, is an exception).

Most empirical contributions use econometric modeling and all of these use patent data as their dependent variable. A few empirical papers use comparative case studies. The empirical contributions, however, focus on the comparison between deployment policies and public R&D support, and the consideration of deployment support is often aggregated at a very high level, i.e., either as "deployment support" generically (not taking into account that distinct deployment instruments may affect innovation differently) or only comparing administratively-set support in the form of FITs and FIPs with quantity-based support in the form of quotas with tradable green certificates (TGCs) or renewable portfolio standards (RPS). The inclusion of the different deployment instruments in econometric models is often done through dummy variables, although some also include the quantity of support provided by each instrument.

The literature on the impact of auctions or auction design elements on innovation is very scarce. Only a few papers compare the impact of auctions with respect to other deployment instruments (del Río and Bleda (2012); Finon and Menanteau (2003); Hille et al. (2020), and Ang et al. (2017)). The first two papers are theoretical ones (or use a qualitative method) and reach the conclusion that auctions would lead to fewer innovation incentives compared to administratively-set remuneration[12]. The two quantitative studies broadly confirm this finding. Hille et al. (2020) examine how different renewable energy support policies, including auctions, affect innovation in solar and wind power technologies and conclude that, although all RES support policies foster patenting activity, this inducement effect is strongest for public RD&D programs, targets, and fiscal incentives. Patenting applications are driven by FITs and FIPs and competitive bidding is estimated to have no significant effect on innovation. Ang et al. (2017) aim to identify the impact of several explanatory variables on innovation in RETs. They find that FITs and public RD&D spending stimulate patenting activity in renewable-power technologies across OECD and G20 countries and across all geographic sub-samples, whereas tenders do not stimulate patents and innovation in RETs.

The dearth of quantitative studies on the impact of auctions on innovation is probably related to the period covered in these studies (mostly the 2000s) and the relative scarcity of auctions implemented in such period around the world[13]. In addition, studies with

[12] In addition, Butler and Neuhoff (2008) do not focus on the innovation effects of different RES support policies, although the article provides some insights in this regard. Among other issues, they examine the level of competition between project developers, and also between suppliers and project developers in Germany and the U.K. The former country had a FIT and the latter country had an auction scheme (the Non-Fossil Fuel Obligation, or NFFO) in the analysed period. The authors show that long and unpredictable time lags between NFFO auctions inhibited the development of a competitive market. This stop–go cycle is also likely to have impeded both innovation and domestic industry.

[13] For instance, in their analysis, Schleich et al. (2017, 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

econometric modeling do not include an analysis of the design elements of specific instruments and their potential impact on the dependent variable (patents).

In contrast, the *theoretical literature and qualitative analyses* generally provide a more disaggregated analysis of the impact of different policies on innovation and they often consider the design elements of different policies and their potential influence on such variable. However, they still do not take into account the potential effects of auctions (with respect to other instruments) in this context (with the notable exception of Finon and Menanteau (2003)). The results of this literature on the impact of different instruments on innovation are limited, but they all point to the same direction: price-based instruments in the form of FITs or FIPs generate more innovation effects than quantity based instruments in the form of quotas with TGCs or RPS). They also indicate that design elements of the instruments may make a change in this regard (e.g., del Río (2012)).

In general, the findings of studies on the comparison of the innovation effects of the instruments (both quantitative, qualitative and theoretical) focus on four issues: 1) The innovation impact of deployment support 2) the comparative impact of public R&D with respect to deployment support, 3) the effects of FITs (usually with respect to quotas with TGCs) and 4) technology differences, i.e., different innovation effects depending on the technology.

The contributions to the literature reviewed supports our starting point that support policies for diffusion, e.g., deployment support (including auctions) can influence innovation. These demand-pull instruments are complementary to supply-push (direct public R&D) support. The latter is a crucial driver of RET innovation, most often to a greater extent than deployment support, although the effect of public R&D is stronger on the less mature technologies. The need to complement both types of support (demand-pull and supply-push) is usually stressed.

The literature on the innovation effects of deployment support also shows that those effects depend on the type of instrument being applied as well as on the maturity of the technology being considered. FITs are often shown to have a greater impact on innovation than other instruments, particularly quotas with TGCs (also called renewable energy certificate (REC) scheme)[14]. Palage et al. (2019) and Kim et al. (2017) interpret the results of the more positive effects of FITs on innovation as follows. Although Palage et al. (2019) recognizes that FITs do not induce strong competition across technologies, "technical progress increases the producers' surplus and in this way induces them to innovate. Within a REC scheme, the surplus attributed to the producers may be more limited, since the marginal price could decrease as a result of technological advances" (Palage et al., 2019, p. 242). Similarly, Kim et al. (2017) find that the renewables obligations have an insignificant effect on the invention of solar PV and even have a negative effect on wind power. The authors argue that in the case of the renewable obligation, a virtual competitive

a tender system for renewable wind power for five years only (1997–2001)".

[14] The limited innovation impacts of REC schemes have been argued by Bergek and Jacobsson (2010) in their assessment of the Swedish REC policy.

market for renewables is created. And more intensive competition in the renewable obligation may bring up more transactions and related costs between renewable producers, electric utilities and regulator[15]. The authors further argue that "the electricity utilities and renewable energy producers tend to import cheaper technologies under the renewable obligations because they do not distinguish technology and are dependent on the bidding system. In this way, renewable energy firms establish short-term goals to reduce their cost instead of investing in uncertain R&D." (Kim et al., 2017, p. 224). They conclude that "FITs provide a stable condition for technology and the market by guaranteed prices, investors fund in R&D to maximize profit, resulting in increased patent applications. The renewable obligation (RO) discourages renewable producers from investing in R&D activity due to high pressure to reduce costs, weakening the long-term innovation engine" (Kim et al., 2017, p. 223).

An interesting finding of the literature is that the impact of deployment support is different for different technologies. For the least mature ones, public R&D is a must. The finding that price-based demand-pull instruments (administratively-set support in the form of FITs or FIPs) will lead to greater innovation effects than quantity-based instruments (such as quotas with TGCs or auctions) especially applies to the less mature technologies (solar PV which, when these studies were carried out, had much higher cost and was less mature than it is today). In contrast, quantity-based instruments support innovation in the more mature technologies (such as wind on-shore). An interesting issue is the interaction between public R&D support and the type of deployment instrument. According to Palage et al. (2019), the impact of public R&D support on innovation is greater if used jointly with FITs for PV. A corresponding interaction effect is harder to detect for public R&D support and TGC schemes.

Finally, the contributions to the literature also conclude that the analysis of innovation in RETs is a very complex topic which does not only depend on the existence of policies, but which is affected by both other policies (such as public R&D and other instruments in the policy mix) and non-policy factors (such as domestic innovation capabilities).

A main problem with quantitative studies is that, quite often, the instruments pertaining to the deployment support category are aggregated and this prevents a differentiated and comparative analysis of each of them. For example, Pitelis et al. (2019) claim that differences between policy instruments (and how they are used) matter and should not be overlooked and argue that aggregating across policy types may mask important differences in terms of effectiveness and misinform the design of energy policy[16]. Often, only two broad types of policies are included (demand-pull vs. supply push) but not the

[15] The transaction costs include information and searching costs, cost of proving and bargaining costs between chosen renewable producers and electric utilities (or regulator) (Kim et al., 2017).

[16] The authors further criticize that "the current literature provides some, albeit limited, conclusions regarding which types of policy instruments work better, especially when it comes to targeting these instruments to achieve maximum return in innovation activity. The limitations of the conclusions result from the narrow focus of the studies, either in terms of the policy classification, the RET, and/or the countries examined" (Pitelis et al., 2019, p. 1165).

possibly different effect of distinct demand-pull instruments. Or only one deployment support instrument is considered[17].

Furthermore, when considered, the influence of demand-pull instruments on innovation in econometric models is often captured through dummy variables. This neglects the importance of support levels of the instruments and other design elements. Indeed, the previous studies do not descend to the design elements within demand-pull instruments[18]. The analysis of the impact of the different design elements of auctions on innovation is missing (whether for the quantitative or the qualitative studies). To the best of our knowledge, not a single contribution to the literature pays attention to this topic. This is despite the well-known finding in the RES literature that the design of instruments matter as much as the choice of the instrument for their success (IEA, 2011).

This neglect of design elements as factors influencing innovation is not an exclusive feature of auctions, but of the literature on the innovation effects of deployment support generally. The differential effects of design elements of deployment instruments on innovation in RETs have not been analysed, with the exception of the theoretical/qualitative analysis of del Río (2012) and Matsuo and Schmidt (2019). The design elements of the instruments are most often not taken into account in the quantitative analyses and, when they are, they refer to only one aspect, i.e., the level of stringency or technology-neutral vs. technology-specific support. An additional problem is that in the few cases that those aspects are included in the analysis, they are captured with very imperfect proxies, e.g., using "the renewable energies' share in total electricity generation" or "policy duration" as measures of regulation intensity (e.g., in Hille et al. (2020)).

Notwithstanding, several authors acknowledge the importance of design elements in this regard. For example, Böhringer et al. (2017, p. 547) state that "the impact of a policy instrument hinges on the stringency, predictability as well as other aspects of the design and implementation, which are all difficult to measure and compare across different countries". Peters et al. (2012, p. 1305) argue that "while this study focused on the aggregate level of policy determinants, the effect of specific policy instruments, their particular design features, and their combination also needs to be analyzed". Pitelis et al. (2019, p. 1171) reach a similar conclusion: "we considered the effect of multi-technology policy instruments on innovation for solar PV, we found no significant effect for this type of technology. However, this result changes when more targeted policy instruments are used. Indeed, (…), solar-specific demand pull instruments have had a positive and highly significant effect on the innovation activity of these technologies. This result highlights how differences in the intrinsic design of RE policy instruments may have a significant effect on the effectiveness of each type of technology". Likewise, Schleich et al. (2017, p.

[17] For example, He et al. (2018), compare public R&D support and FITs and state that "in this paper we cannot control for variables of various policy instruments, such as feed-in-tariffs, investment subsidies, tax credits, support tax policy, tendering systems, renewable energy portfolio standard and tradable green certificates" (He et al., 2018, p. 8).

[18] According to Kim et al. (2017, p. 216), "the heterogeneity of demand-pull policy features across nations with respect to level, duration, degression, and other features (IEA 2004) makes it very difficult to even crudely operationalize market-pull policies on an instrument level as independent variables".

691) state that “arguably, the dummy variable employed to reflect the impact of FITs in our econometric analysis does not adequately capture design features which are relevant for patenting activities such as the duration or level of support (the stringency), or digression in FIT rates.”. Similarly, Palage et al. (2019, p. 230) comment that they do not take into account design elements: “there are several policy design features that we are not able to take into account”.

Thus, the existing literature on the impact of deployment instruments on innovation provides some albeit limited insights in the context of this report, since it lacks the required level of granularity. The empirical analyses performed are two broad (R&D support vs. deployment support) and usually do not descend to the level of the effects of different types of deployment instruments. When they do, they often carry out a simple comparison between price-based and quantity-based instruments, usually by including a dummy variable in econometric models. Furthermore, the influence of different design elements is only addressed to some extent (but never with respect to auctions) in the theoretical literature, and it is absent in the empirical one. In particular, up to our knowledge, there isn’t any analysis (whether theoretical, qualitative or quantitative) on the impact of different auction design elements on technological innovation.

Finally, the aforementioned literature provides a main recommendation regarding the application of instruments: it suggests applying specific instruments to given technologies (e.g., technology-specific instruments)[19].

4.2 The literature on technological innovation systems (TIS)

An approach which has been used to analyse the drivers and barriers to innovation and diffusion of RETs and which provides some implications for policy in this regard is the technological innovation systems (TIS). A TIS is defined as “…network(s) of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology…” (Carlsson & Stankiewicz, 1991, p. 21). This approach can inform us about how innovation occurs in relation to particular technologies, which system failures may be occurring, and how innovation may be influenced by incentives and policies. It stresses that innovations are not developed and implemented in isolation but within a technological and socio-cultural context. It focuses on the importance and interdependencies of actors, networks, institutions, cumulative learning processes and spatial and technological characteristics. The conceptual starting point of this approach is that a well functioning TIS is a requirement for the technology in question to be developed and widely diffused. In turn, a well functioning TIS depends on the alignment of the elements which make up its structure (structural perspective): technology and related knowledge and skills, actors, networks of actors and institutions (Jacobsson & Bergek, 2004; Malerba, 2004). An analysis of the TIS in terms of its structure is a first stage in the assessment of the TIS. However, these TIS structures are mainly

[19] For example, Huenteler et al. (2016, p. 117) argue that “Few people would support a ‘one-size-fits-all’ innovation policy approach for the semiconductor, machinery, biotechnology, oil and gas, and chemical industries. The findings of this paper indicate that it may be equally misleading to lump together solar PV systems, wind turbines, biomass gasification, carbon capture and storage, and fuel cells when designing policy instruments to stimulate innovation in clean energy technologies”.

static; i.e. their existence and/or composition changes slowly, sometimes over a year or longer (Suurs & Hekkert, 2009). While different innovation systems may have similar structural elements, they may function in an entirely different way (Reichardt et al., 2016)). Jacobsson and Karltorp (2013, p. 1184) argue that, although a central proposition in the innovation system literature is that weaknesses in any of the structural elements may obstruct the development of the system, sometimes it is difficult to evaluate the appropriateness of a structure[20]. This is why a functional perspective emerged.

The functional perspective in the TIS allows the TIS to be assessed with specific system functions (table 3). However, both approaches (structural and functional) are deemed complementary, in so far as alterations in functional strengths may feed back to the structural components (Jacobsson & Karltorp, 2013). Structural factors and activities (functions) influence each other mutually (Negro et al., 2007).

Table 2: Functions of TIS.

Function	Description
1. Knowledge development and diffusion.	This function captures the breadth and depth of the current knowledge base of the TIS, and how knowledge is diffused and combined in the system. Various types of knowledge serve as inputs for innovation, including R&D and learning effects.
2.- Guidance of the search.	This refers to activities that can affect the visibility of specific needs among technology users and the incentives for the organizations to enter the TIS.
3.- Entrepreneurial experimentation	Entrepreneurial experimentation implies a probing into new technologies and applications, with successes and failures.
4.- Market formation	Market formation normally goes through three phases with quite distinct features: nursing, bridging and mass markets (see text).
5.- Legitimation	Legitimacy refers to social acceptance and compliance with relevant institutions. The new technology needs to be considered desirable by relevant actors in order for resources to be mobilized, for demand to form and for actors in the new TIS to acquire political strength. This process is complicated by competition from adversaries defending the existing TIS. The purposeful creation of legitimacy by lobbying networks counteracts resistance to change.
6.- Resource mobilization	This refers to the extent to which the TIS mobilizes competence/human capital, financial capital and complementary assets in order to make the various processes in the innovation system possible.

Source : Bergek et al. (2008)), Hekkert et al. (2007), Coenen and López-Díaz (2010) and Negro et al. (2008).

[20] As put by Jacobsson (2008, p. 1495), "there is no 'recipe' that identifies the precise attributes of actors, networks and institutions in a well-performing innovation system. Explaining the causal mechanisms between structure and performance requires, therefore, a systematic analysis of intermediate variables (…). This may be done by introducing a second level of key processes in industrial development, which addresses directly what is being achieved in the TIS—bridging the gap between structure and performance. These key processes are here referred to as "functions of innovation systems".

Functions allow for assessing of what works well and what does not within the TIS. By identifying where the problems are within the system, these problems can more easily be addressed by policy makers (Reichardt et al., 2016, p. 12). Functions are related to the interactions between the aforementioned elements of the TIS. The focus of policy in this framework is hence to identify and address problems that prevent the fulfillment of functions and to intervene to make sure that they are fulfilled. The lower the maturity of technologies, the greater the requirement for the fulfillment of system functions. More novel innovations require greater change in all system functions.

The literature on the TIS has focused on the analysis of the emergence and diffusion of technologies and has considered the influence of different types of drivers and barriers on such emergence and diffusion. Policy is one of those drivers, although its role is not isolated from the rest of factors, but interacts with them. This is a consequence of the systemic approach adopted by the TIS, with different drivers and barriers at different levels and with a wide array of stakeholders playing a role.

Therefore, two issues justify the focus on the insights derived from the TIS approach in this report:
1) Analysis of drivers and barriers to RETs. The TIS framework has been widely used to investigate the adoption or development of RETs in different geographic regions and for different RETs. Contributions using this approach have mostly focused on the first stages of the technological change process (development) although some of them have also been used to analyse diffusion. Indeed, innovation and diffusion are usually interrelated and not considered in isolation in this approach.
2) Consideration of policy measures which mitigate the weaknesses or system failures that threaten the performance of the TIS. Relevant insights on the types of policies that should be applied to encourage the development or diffusion of RETs can be derived from the TIS approach applied to RETs. Gandenberger and Strauch (2018, p. 2) even argue that "the main objective of TIS analysis is to identify relevant policy issues and to set goals for the future development of the TIS".

Thus, an in-depth review of the empirical literature on the TIS approach applied to RETs has been performed. Overall, 59 papers were identified (table A2 in Annex 2) and their useful insights regarding policy implications for the topic of this report have been considered. We focused on the insights of such literature regarding the link between policies and innovation/diffusion and the impact of different types of instruments as well as other factors. We have paid special attention to the influence of deployment policies (including auctions) on innovation and diffusion.

To the best of our knowledge, there are only a few references on the influence of auctions on market creation in the TIS literature, which is deemed a negative one del Río and Bleda (2012); (Palm, 2015; van der Loos et al., 2020). This negative effect of auctions on market creation is a consequence of this instrument being, by definition, a quantity-based scheme for which deployment is capped (del Río & Bleda, 2012). But it is also the result of auctions entailing greater transaction costs for entrepreneurs and delays as it has been the case of

PV systems on public buildings in Sweden (see Palm (2015))[21] or technology-neutral auctions discouraging the award for less mature technologies, as it was the case with wind off-shore in the Netherlands in 2010, reported by van der Loos et al. (2020, p. 7). However, van der Loos (2020a) argues that tenders positively affected the "market creation" and "guidance of the search" functions in the Dutch off-shore wind TIS after 2015 through attractive design of the tenders for potential investors[22]. It should be taken into account that the functioning of auctions in the policy mix has not been the focus of research in the TIS literature, and should be investigated in the future. Therefore, those negative effects should be regarded as preliminary and taken with caution.

To sum up, regarding the findings of studies using the TIS approach which are related to this report, it should be mentioned that no comparative analysis of the impact of instruments on innovation is performed and only a few contributions mention auctions. In addition, there are also very few contributions which mention the impact of the design elements of deployment instruments on innovation in RETs and a systematic analysis of those design elements is missing. However, this literature is relevant to identify drivers and barriers to innovation in RETs as well as the role of policy instruments to trigger those innovation effects, beyond deployment instruments. Therefore, it provides an overarching analytical framework for the analysis of policy measures on diffusion and innovation.

---

[21] According to one of the turnkey entrepreneur interviewed in Palm (2015), "his firm has refrained from tendering because this law makes it too time consuming" (op.cit., p.140).

[22] According to van der Loos et al. (2020, p. 7) "the Dutch government reformulated the permitting system for the third time, shifting to a government-administered tendering system, thus making it simpler, easier and clearer for developers to construct offshore wind farms (…). The government agreed to determine the locations for new offshore wind farms, guarantee permits and subsequently tender bids to potential developers. In addition, the government still arranges all preliminary work, including conducting wind resource assessments and geological surveying. Finally, it took responsibility for grid connectivity, including the offshore substation, thus dramatically reducing the costs and risks for offshore wind developers".

5 Relating RES auctions and innovation effects on RETs

This section provides the analytical framework for the analysis of the impact of auctions and auction design elements on technological innovation. It connects the impact of different deployment instruments (with a focus on auctions and auction design elements) on innovation in RETs through their impact on innovation mechanisms. In addition to those contributions with an exclusive focus on policies for diffusion and innovation in RETs, some papers have identified and analysed one of the links which are relevant to relate the different relevant variables. We integrate these literatures in the analysis, since they provide either the theoretical link or the empirical confirmation of some of the relevant relationships. Some of the streams of the literature which are relevant in this regard include the literature on the role of competitive pressure as a source of innovation (see section 3.3.4), the literature on learning effects and, particularly on double-rate learning effects (see section 3.3.1), the literature on auctions design elements (see section 2 and del Río (2017); IRENA (2015); Mora et al. (2017), the literature on the importance of market creation (effectiveness in investment) as a source of innovation (see section 3.3.2), the literature on the technological innovation system (TIS) and its functions (see section 4.2) and the literature on R&D spillovers (see section 3.3.5).

The analytical framework is described in subsection 5.1. The following two subsections provide a theoretical discussion on the possible relationship between auctions and innovation. Subsection 5.2 discusses how auctions may lead to different innovation effects than administratively-set support as each instrument can be expected to have different impacts on the diffusion-innovation mechanisms mentioned in section 3 and included in 5.1. Subsection 5.3 assesses how the alternatives of auction design elements activate those innovation mechanisms in different ways. The influence on RET innovation of other factors is discussed in subsection 5.4. This section concludes with a set of research proposals derived from the analytical framework (5.5).

5.1 Analytical framework: mechanisms linking auctions and the innovation effects of RET diffusion

Innovation is driven by several factors, such as the willingness to reduce the costs of production, improve existing products or create new products. This report focuses on the diffusion-related effects on innovation, which are linked to deployment and deployment policies. Demand-pull (deployment) policies in general, and auctions in particular, are one of the factors influencing innovation in RETs (new or improved products and processes). The impact on innovation activities and thus on cost reductions may differ depending on the support scheme chosen (Menanteau et al., 2002) (Söderholm & Klaassen, 2007).

The contributions to the literature reviewed in section 4 are based on a chain-linked model of innovation which recognizes the feedback effects between stages in the innovation process and, particularly, from diffusion to innovation and invention. They assume that: 1) diffusion can influence innovation in RETs; 2) Support policies affect diffusion in different ways. This supports our starting point that support policies for diffusion (including auctions) can influence innovation.

Based on the findings of the innovation literature on the drivers of innovation as a result of diffusion (section 3), and the findings of the empirical literature on diffusion-related innovation (section 4), the main assumption in this analytical framework is that auctions and auction design elements affect innovation indirectly, i.e., through their impacts on the R&D decisions of equipment manufacturers, who are the ones investing in R&D. Their initial impact is on project developers, who are the ones buying the renewable energy equipment.

In the case of auctions, the relevant effects can be compared to their alternative, i.e., administratively-set remuneration (ASR) in the form of FITs or FIPs. For design elements, the comparison is between different design options. Deployment support in general, and auctions and auction design elements in particular, may affect project developers since they influence the economic conditions (the risks, revenues and costs) to invest in new renewable energy projects. Obviously, project developers have an inherent incentive to increase their revenues (annual energy production, or AEP) and to reduce their costs (CAPEX and OPEX) and risks, and this is the case whatever the type of deployment instrument is being used. However, as suggested by the literature reviewed in section 4, different instruments and design elements are likely to have a different influence on those variables.

Therefore, project developers would face different levels profit margins (revenues and costs) and risks under different deployment instruments and design elements. It is often argued that auctions lead to higher risks compared to uncapped ASR (Menanteau et al., 2002). In addition, one of the alleged advantages of auctions is that their competitive nature reduces the level of support compared to the alternative (ASR). This reduction in profit margins as a result of lower revenues puts pressure on project developers to maximize those revenues (i.e., to increase the annual electricity production or AEP) and to minimise their costs (whether CAPEX or OPEX). Different design element choices have also different impacts on those economic conditions, leading to differences in risks, revenues and costs.

In turn, the differential economic conditions faced by project developers under auctions and different auction design elements, and their incentives to increase the revenues and reduce the costs of electricity generation could be expected to influence previous stages of the value chain, including equipment manufacturers. This influence occurs through the purchases of equipment (turbines, modules…) by project developers.

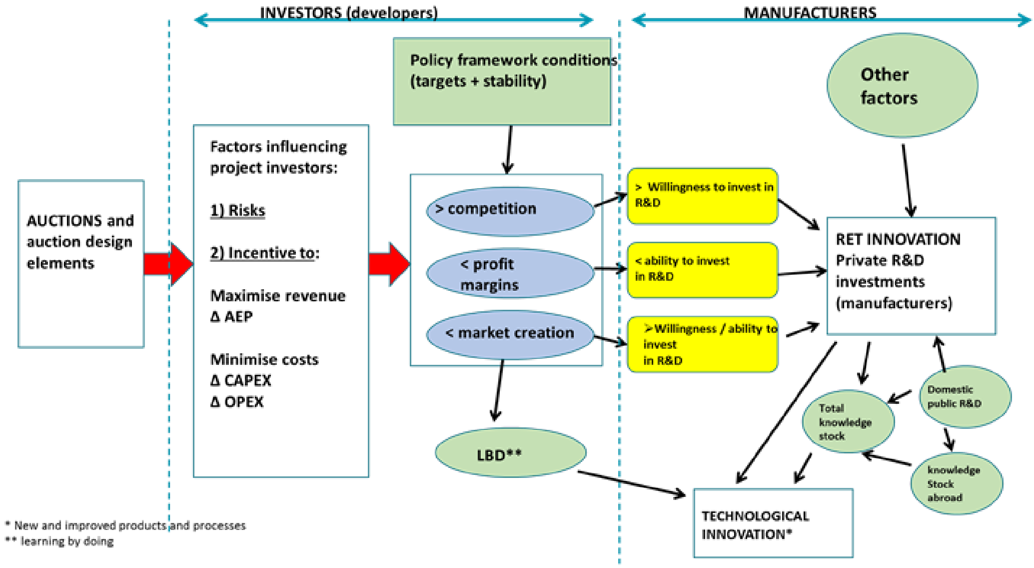
As mentioned in section 3, five types of influences of deployment instruments on innovation can be expected: learning effects, competition, profit margins, market creation and spillover effects. Arguably, these influences are interrelated and affect the willingness and ability to invest in R&D. In the following paragraphs, we discuss the possible influence of auctions on those five sources of innovation with respect to ASR, whereas the next section focuses on the influence of different design elements.

First, auctions are likely to lead to a greater level of competitive pressure than ASR. This could be expected to increase the willingness to invest in R&D and, thus, induce innovation. The greater competitive pressure would lead to lower revenues and, thus, profit margins. In addition, lower levels of market creation would result from the quantity caps (volumes auctioned) in auctions. Together with the lower profit margins, this could be expected to influence the R&D investment decisions of equipment manufacturers, i.e., their willingness and ability to invest in R&D. In addition, market creation effects influence a main source of innovation through deployment: learning-by-doing. Private R&D investments, which are influenced by the willingness to invest in R&D (competition) and the ability to do so (profit margins and market creation), contribute to the knowledge stock. In turn, learning effects would also contribute to the knowledge stock through knowledge spillovers (section 3.5). This knowledge stock, which finally ends up in innovative activities (new and improved products and processes), is also enlarged by domestic public R&D investments and the knowledge stock abroad.

Obviously, such a decision to invest in R&D and technological innovation more broadly is influenced by other factors, including the policy framework conditions (i.e., the existence of targets and the stability of regulation), pre-existing innovation capabilities (EEA, 2014) and domestic as well as international investments in public R&D which contribute to the total knowledge stock (and to which the R&D investments of equipment manufacturers also contribute). There are also other factors which put pressure to innovate and particularly on equipment manufacturers to invest in R&D. For example, in addition to auctions in the country (e.g., Spain), auctions abroad (and their design) influence the demand of renewable energy equipment by foreign actors. This foreign demand may also stem from non-auction promotion policies (for example, administratively-set FITs or FIPs in, e.g., China). In general, this is a globalised sector with high levels of international competition which pushes equipment manufacturers to improve their products and processes (or launch new ones). Furthermore, innovation is also encouraged by knowledge collaboration and involvement in networks, which may be encouraged privately or publicly through support for technology platforms or grants for consortia. Finally, the broader energy transition, and the shift towards increased electrification and sector coupling providing new opportunities for renewables-based solutions in sector-specific contexts would also influence innovation.

The following figure illustrates the mechanisms and linkages in our analytical framework.

Figure 2: Mechanisms on the influence of auctions on innovation.



Source: Own elaboration.

In this report, we focus on the policy-related influence on technological innovation stemming from private R&D investments by the equipment manufacturers, being aware that there are two other sources of technological innovation in this sector which can be influenced by deployment (and, thus, demand-pull policies), i.e. learning effects as a result of deployment (and, thus, demand-pull instruments) and contributions to the knowledge stock stemming from public R&D support (knowledge spillovers).

The reason to focus on R&D investments and not on learning effects and knowledge spillovers is related to the fact that, while the decisions of the firms can influence R&D investments, its influence on the learning effects (both learning-by-doing and learning-by-using) and spillovers is much more limited or indirect. This is because the latter are not the result of a deliberate decision of the firm, but just the outcome of the aggregation of the decisions of many firms, whereas the decision to invest in R&D is. As argued by Böhringer et al. (2017, p. 546), production and deployment of RETs could trigger learning-by-doing and R&D spillovers which are external to the individual firm. Notwithstanding, since learning effects are also related to demand pull policies, including auctions (both domestic and abroad), the potential influence of auctions and their design elements on these learning effects is relatively straightforward to analyse through their impact of auctions on deployment (market creation). The following sections provide a theoretical analysis of the innovation effects of auctions and auction design elements, illustrating this discussion with insights from empirical analyses.

5.2 The innovation effects of auctions vs. administratively-set support: insights from the empirical literature

Theoretical links between the different variables proposed in section 3 and 5.1 as well as the literature review carried out in section 4, which provides some insights on the relevant relationships, allow us to propose some a priori theoretical linkages between auctions and auction design elements and innovation.

The literature reviewed in section 4 shows that the extent to which deployment support impacts on innovation depends on the type of instrument being applied as well as on the maturity of the technology being considered. In general, price-based instruments (administratively-set support in the form of FITs or FIPs) will lead to greater innovation effects than quantity-based instruments (such as quotas with TGCs or auctions). It should be recalled that only a few papers include auctions in the analysis and, thus, such results on quantity-based instruments mostly applies to quotas with TGCs.

The assessment of the impact of auctions on innovation compared to administratively-set support should take into account several aspects.

On the one hand, auctions have some differential features with respect to administratively-set remuneration (ASR), which might be relevant when studying their respective innovation impacts in a comparative way: 1) Auctions include inherent capacity caps. This means that not all the capacity that would like to receive support will be able to receive it, which is precisely the case with administratively-set support (except if there is a capacity cap and support is granted on a first-come-first-served basis); 2) the price signal and competition in auctions can be expected to lead to lower levels of support than ASR, since the asymmetric information problem when setting such support is addressed; 3) auctions generally lead to greater risks, sunk costs and transaction costs (before the auction) than administratively-set support. 4) One of the weaknesses of auctions has been the frequent delays and non-compliance in building the awarded projects (see, e.g., del Río and Linares (2014); IRENA (2019); Jacobs et al. (2020)).

On the other hand, but related to the previous point, different technologies are in different stages of the innovation process and, thus, they are likely to be affected by auctions in a different manner. For the less mature technologies, which need to be supported in order to cover the cost gap with other technologies and need to advance along their learning curves, auctions would lead to lower levels of innovation in those RETs, since they have lower opportunities to be supported.

Therefore, the analysis should compare the a priori expected innovation impacts of auctions vs. administratively-set support in general, but should also take into account that RETs have different maturity levels.

We assume a "baseline" auction and a standard administratively-set support scheme. This is a "technology-neutral" auction whereby all technologies can participate, the awarded volume is based on capacity, with standard prequalification requirements and remuneration based on the electricity generated with a FIT. The administratively-set support to which we compare the outcome of the auction would also be based on a FIT, without a capacity cap but with support differentiated per technology (as it has usually been the case with this instrument).

The key question is: Compared to ASR, can auctions (designed in the aforementioned manner)[23] be expected to lead to greater competition, more market creation and higher profits which can be reinvested in R&D?
To answer this question we could use the theoretical analysis carried out above and the empirical results of other studies.

- *Competition*. The environmental economics literature argues that quantity-based regulation (e.g. renewable obligations) is better suited to promoting positive externalities from innovation in climate-friendly technologies, because it incentivises competition between technologies and, thus, reduces costs (Groba & Breitschopf, 2013). Additionally, as the competition with other energy sources becomes less intense with the high price, innovation activities aimed at reducing costs would become less attractive with FITs compared to quotas with TGCs (Söderholm & Klaassen, 2007). Since, under quotas with TGCs there is generally no safe floor in the form of a tariff incentive and there is competition between renewables and other energies, generators are likely to put greater pressure on equipment producers for lower prices and on developers for the best available location (Lauber, 2004). Given the lack of auction-based schemes in the past, most of the conclusions on "quantity" vs. "price" instruments were based on one quantity-based instrument (quotas with TGCs). A priori, competitive pressure would be greater under auctions, 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)[24]. The U.K. NFFO has often been used to argue that competitive pressures are greater under auctions (see, e.g., Mitchell Mitchell (2000)). Finon and Menanteau (2003, p. 28) argued that "in the bidding system, competitive pressure has indisputably forced the developers/producers to cut their costs down, in order to remain competitive" and also referred to the cases of England and Wales. However, other authors were more critical of this conclusion on the greater innovation effects of quantity-based schemes due to greater competition. For example, Huber et al. (2005) argued that competition between manufacturers to provide better technologies is ensured regardless of the type of RES-E support scheme used. This authors claim that ASR in the form of FITs facilitates the implementation of high quality components, as the objective of the investor is not only the minimisation of generation costs, but, rather, the maximisation of revenues gained from the tariff over the entire period (Huber et al., 2005).

[23] As it will be shown in the next section, the way that both auctions and ASR are designed is likely to have a considerable impact on innovation outcomes and, thus, the conclusions reached in this section.
[24] As argued by Söderholm and Klaassen (2007, 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".

- *Market creation*. The literature suggests that (ASR) FITs might lead to a higher level of innovation than other mechanisms because they have a stronger effect on demand (Lauber, 2004; Schleich et al., 2017, p. 685) observed that FITs facilitated the development of the turbine industry by creating security and encouraging market participants to adopt a long-term perspective. Hoppmann et al. (2013) argued that FITs helped to create markets, first in Germany in the 1990s, then in Italy, Spain, the United States, China and India by the 2010s and provided the guaranteed scale-up needed for global supply chains. ASR has proven to be an effective instrument to spur RES deployment according to REN21 (2019). Butler and Neuhoff (2008, p. 1863) noted that "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". In addition, Finon and Menanteau (2003, p. 28) argued that "the objectives initially set by the governments that opted for competitive bidding systems (UK, Ireland, France) were much less ambitious at the outset than those of the German, Danish and Spanish governments, which chose the feed-in tariffs". In contrast to ASR FITs and FIPs, auctions have had a poorer degree of effectiveness in the past, with delays and realization rates below 100%, sometimes even much lower than that (del Río & Linares, 2014; IRENA, 2019; Jacobs et al., 2020). Some papers identify the comparative effects of auctions vs. ASR FITs on capacity additions (Ang et al., 2017; Bolkesjø et al., 2014; Jenner et al., 2013; Kilinc-Ata, 2016) and found that those additions would be greater under ASR than under auctions. Therefore, both market creation and learning effects would be triggered by ASR FITs more than by auctions.
- *Reinvestment of profits into R&D*. To the best of our knowledge, there isn't an empirical analysis in the literature on the existence of higher profits under ASR (compared to auctions) and, thus, on the use of those higher profits to fund R&D activities. The proposition below is, thus, based on theoretical insights (see, e.g., Finon and Menanteau (2003)). Söderholm and Klaassen (2007, p. 182) argue that, under ASR FITs, technical progress increases the producers' surplus and, in this way, encourages them to innovate. In a competitive bidding system, however, the surplus that is attributed to producers is normally more limited. According to Menanteau et al. (2002), the competition for support under auctions as well as the greater transaction costs and risks (before the auction takes place) would tend to squeeze profit margins throughout the whole supply chain and lead to lower private R&D investments. Finon and Menanteau (2003, p. 17) argue that "competition imposes reduction of every static cost. However, as this involves restricting their profit margins (by eliminating the differential rent derived from technological progress) despite important risk projects, initiating the innovation process through investment in R&D may be difficult". According to these authors, "the wider diffusion observed in countries with FITs, and the more favourable sharing of surpluses, has been profitable to RES 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" (Finon & Menanteau, 2003, p. 30). However, it should be recognized that there is always the risk that technologies become over-supported through the use of deployment policies, which, in turn, can create a disincentive to innovate in the less mature technologies or applications (see section 3.3.4).

Therefore, the next question would then be: Given that the aforementioned three drivers have opposing effects on innovation, what is the net effect of innovation of ASR compared to FITs? Söderholm and Klaassen (2007) try to answer this question. The authors added an interactive slope-dummy variable for the feed-in price variable and the UK dummy, and a corresponding coefficient to the learning curve equation. The result from this test indicates that the "impact on investment costs of a marginal increase in the feed-in price does not differ across countries with different wind energy support systems" (Söderholm & Klaassen, 2007, p. 182). Therefore, according to their results, the net effect of these two opposing impacts appears to be more or less zero, i.e., auctions would not necessarily lead to lower (or higher) levels of innovation compared to ASR[25].

Although these innovation effects would happen for all the technologies, they could be expected to differ for different types of technologies. Auctions could probably discourage innovation in the less mature technologies compared to more mature ones, given the lower possibility to be awarded in auctions (del Río & Linares, 2014; IRENA, 2019; Wigan et al., 2016). The literature reviewed in section 4 shows that, in general, price-based instruments (administratively-set support in the form of FITs or FIPs) will lead to greater innovation effects than quantity-based instruments and this applies especially to the less mature technologies[26]. In contrast, quantity-based instruments would drive innovation in the more mature technologies (such as wind on-shore).

The following table summarises the assessment. Lower impacts on the more mature technologies (PV and wind on-shore) could be expected, since these technologies are already competitive at wholesale market prices in some places or are expected to be so in the near future. Therefore, an auction could not substantially worsen the situation for these technologies. They could even lead to positive innovation effects compared to the absence of support (see below and section 7).

---

[25] The authors call for further research into this issue. In particular, they note that their "analysis only incorporates one country with a competitive bidding system. It would, for instance, be useful to include also Ireland and France – both which have (or have had) competitive bidding systems for wind power – in the model estimations" (Söderholm & Klaassen, 2007, p. 182).

[26] This is the case of solar PV which, when these studies were carried out, was in much higher cost and less mature state than it is today.

Table 3: Summarising the assessment of the effects of auctions on innovation with respect to administratively-set support.

Innovation mechanisms		General assessment
Learning effects		<
Willingness and ability of equipment manufacturers to invest in R&D	Profit margins	<
	Market creation	<
	Competitive pressure	>
Total		?

Note: where < means that the auction reduces the impact of the particular innovation mechanism with respect to administratively-set remuneration (ASR).

To sum up, technological innovation in RETs depends (at least to some extent) on the R&D investments of equipment manufacturers. Auctions indirectly influence these R&D investments through their effects on both the willingness (which may respond to a need) and ability of equipment manufacturers to invest in R&D. However, compared to administratively-set remuneration, it is difficult to tell a priori if auctions would provide an incentive or a disincentive to innovate, since this depends on the net impact of opposing effects[27]. On the one hand, auctions activate the willingness to innovate through their competitive pressure on project developers (competition). However, equipment manufacturers are also encouraged to innovate when they expect the existence of a larger market in which they can sell their products. If auctions put a limit on the renewable energy capacity which can be built (compared to uncapped ASR FITs or FIPs) or if they are less effective than alternative instruments as a result of non-compliance or delays (related to underbidding), then equipment manufacturers will have a smaller market to sell their products and thus, a smaller incentive to innovate. It is also not clear that auctions are superior to other instruments regarding the ability to innovate. If they lead to lower profit margins, this results in a lower capacity to reinvest them in R&D and, thus, lower R&D investments. While the impacts of auctions on most innovation mechanisms are negative in this regard, we can also observe contradictory effects between one mechanism (competitive pressure) and the rest, which warrants further empirical research in order to quantify the net effects of auctions on innovation.

However, "standard" auctions have been considered in the previous analysis, but in reality auctions can be designed in different ways. In fact, the impact of those two instruments is

[27] Söderholm and Klaassen (2007, p. 182) also suggest this tension and trade-off: "For new technologies some kind of feed-in tariffs are necessary as they encourage diffusion, learning-by-doing activities and ultimately cost reductions. However, apart from this they also restrict competition and thus induce higher-cost windmills to come into operation".

mediated by the effects of the different design elements. This issue is addressed in the next section.

It should be mentioned that the above analysis has focused on the comparison of ASR FITs/FIPs and auctions in the past. However, for the future, and given the impressive cost reductions of RETs in the last years and the fact that they are cost-competitive with other technologies in many locations, the appropriate comparison may not be between ASR and auctions, but between auctions and lack of support. In some countries, it is increasingly argued that "support is not needed" and that RETs could compete with other technologies on the basis of the wholesale electricity price alone (IEA, 2020). Indeed, these "merchant plants" have captured non-negligible shares of the market in some countries. For example, according to the Renewables 2020 report from the IEA "annual solar PV additions in Spain are expected to slow in 2020 after a record-breaking 2019 caused by a commissioning deadline for projects awarded in 2017 auctions. Still, utility-scale additions in 2020 are expected to demonstrate the second-highest growth, and further increases are forecast for 2021-22. Expansion is mainly in unsubsidised projects supported by corporate PPAs, bilateral contracts with utilities, or by combining either with a merchant tail. Average annual growth is forecasted to decelerate during 2023-25 due to uncertainty over future power demand, potentially challenging the financing for new unsubsidised projects. More than half of the growth in this period will result from the resumption of competitive auctions after a three-year break to meet newly raised 2030 targets" (IEA, 2020, p. 57).

With respect to a lack of support, auctions could be expected to lead to higher innovation rates since they ensure the creation of a market and higher R&D investments, although, as with the comparison between ASR and auctions, there would also be opposing effects (negative competition effects, and positive profit margins and market creation effects).

5.3 The innovation effects of different auction design elements

The impact of different design alternatives on innovation can be analysed a priori by identifying the theoretical effects of those alternatives on the different innovation mechanisms. In this section, a preliminary discussion of the possible influences of different design elements on technological innovation is provided. For this, we consider the design elements included in section 2.

5.3.1 Volume auctioned

The learning effects are expected to be higher when deployment takes place. Therefore, they should be higher when the volume auctioned is set in generation or in capacity terms, whereas a given amount of deployment is not ensured under a budget-based metric. Therefore, also a given level of market creation can not be ensured under this metric. On the other hand, it is unlikely that this metric has substantial effects on either profit margins or competitive pressure.

The volume auctioned can be published or not before the auction. In case it is published, this creates trust for potential investors and, thus, encourages participation (Mora et al

2017). In turn, a greater level of investor confidence would incentivize effectiveness in deployment and, thus, learning effects. The greater visibility associated to the publication of the volume would have positive effects on the supply chain, with a clearer signal on market creation, which would encourage R&D investments by equipment manufacturers. On the other hand, publishing the volume makes strategic behaviour and collusion more likely. This can be expected to reduce the competitive pressure of the auction and, thus, it would discourage R&D investments. It may also increase profit margins and, thus, R&D investments. However these last two effects are highly uncertain and the impact is likely to be very small in this regard.

5.3.2 Schedule

The existence of a schedule of auctions, with a predefined date for auction rounds, is likely to have a positive impact on innovation. The reason is that this would provide a stronger signal to equipment manufacturers on the potential market for their products. It would also induce the participation of potential investors which, in turn, would positively affect effectiveness. In contrast, it is unclear how potential profit margins would be affected. The impact on competitive pressure is also uncertain. On the one hand, publication of future auction rounds encourages participation and, thus, competition. This would increase competitive pressure. On the other hand, a stand-alone, ad-hoc auction would generate a stronger incentive to be awarded. This would encourage lower bids, lower profit margins and a greater competitive pressure. This pressure on bidders and project developers would encourage equipment manufacturers to innovate in order to produce equipment which allows capturing higher revenues or manufacturing cheaper machines to reduce the costs for project developers/bidders, because project developers would press them to produce cheaper machines. The impact of this design element can be expected to be high, since it directly affects the expected market and revenues for equipment manufacturers. On the other hand, if there is (only) a single and stand-alone auction, competition would be more intense (e.g. to capture market share in a market where market share is not often "up for grabs"), and hence prices could be especially low, thus squeezing margins and meaning that in the mid-term there is little available funds available for funding ongoing / further R&D for tech innovation.

In the past, auctions have usually been conducted on an irregular, discontinuous basis. However, this may be more an issue of design elements in auctions (existence of an schedule of auctions conducted frequently on a regular basis) than of auctions themselves. Survey data suggests that long and unpredictable time lags between NFFO auctions inhibited the development of a competitive market. This stop–go cycle is also likely to have impeded both innovation and domestic industry (Butler & Neuhoff, 2008, p. 1863). Ang et al. (2017) argue that the lack of visibility for future tenders may be one of the reasons for the lack of statistical significance of auctions in their study[28]. Nemet (2009) found that uncertainty in the longevity of policies dampened the incentives for the most

[28] "These results can probably be explained by the fact that feed-in tariffs have been generous in the past across OECD and G20 countries, and that these price-based instruments provide long-term incentives and visibility to innovators, unlike tenders that are quantity-based tools that can be used on a one-off basis, without visibility for future tendering procedures" (Ang et al., 2017, p. 52).

radical inventions, i.e., those that are likely to take several years to pay off (Nemet, 2009, p. 700).

5.3.3 Diversity

Compared to technology-specific auctions, technological neutrality would favour the more mature technologies (e.g., PV and wind on-shore) to the detriment of less mature ones. This means that technology-specific auctions would lead to a greater deployment of the less mature technologies, whereas technology-neutral ones would make it more likely that the more mature would be awarded and deployed. Therefore, compared to technology-neutral auctions, technology-specific ones would trigger all the positive innovation effects for less mature technologies (LBD, market creation and profit margins) and would possibly offset the negative effect (less competition). The opposite would be the case for more mature technologies (which still have some potential for innovation and cost reductions). Therefore, technological neutrality would trigger innovation in the more mature technologies, but not in the less mature ones. The innovation in these technologies would be positively triggered by technology-specificity.

In general, the innovation impacts of deployment policies is likely to differ depending on whether the policy is technology-specific or technology-neutral (Palage et al., 2019). There is a widespread view in the academic literature that the technology-specific instruments or technology-specific designs would favour a greater technological diversification and encourage the less mature technologies (del Río & Bleda, 2012; del Río & Linares, 2014; Matthäus, 2020). Similarly, Hoppmann et al. (2013, p. 989) conclude that, when designing deployment policies, great care should be taken to avoid adverse effects on technological diversity and a premature lock-in into more established technologies. In contrast, Böhringer et al. (2017, p. 550) argue 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". Referring to two papers in the literature (Johnstone et al., 2010; Nicolli & Vona, 2016), the authors argue that (technology-specific) "feed-in tariffs have either no effect or exert a negative impact on innovation in other renewable energy technologies". However, the literature review in section 4 suggests that FITs play an important role in innovation, although there are some exceptions in this regard.

Geographical neutrality. Competitive pressure would be higher with geographical neutrality but no significant differential impact of the other three innovation mechanisms (learning effects, profit margins or market creation) can be expected under geographically-neutral auctions (compared to geographically-diverse ones). In a uniform-pricing geographically-neutral auction, the awarded price is likely to correspond to a bid from a project in a location with a worse resource. This might lead to higher profit margins for projects in better places than with a geographically-specific auction.

Actor-neutrality. In this case, the activation of the different innovation mechanisms strongly depends on how the goal of actor diversity is introduced in the design of the auction. For example, an auction for small actors and another for the rest would reduce the competitive pressure compared to an actor-neutral auction. In a single auction which encourages the participation of small actors together with large ones (e.g., using less stringent prequalification requirements for small actors, for example), the possibility of collusive behavior is reduced compared to an actor neutral auction. This would lead to higher profit margins but greater competitive pressure. Thus, the influence on innovation would be uncertain, but also likely to be small compared to other design elements.

Size-neutrality. Competitive pressure would be reduced when size limits on projects (either maximum or minimum ones) are imposed. Thus, size-neutral auctions would result in a greater level of competition and lower profit margins compared to size-specific ones. On the other hand, if a maximum project size limit exists, then lower economies of scale and, thus, higher costs would result. This would not necessarily lead to lower profit margins (compared to a situation without maximum size limits) since higher bids as a result of those higher costs could also be expected. A maximum size limit may lead to more projects being awarded in the auction, which would reduce the risk of ineffectiveness if a single project fails to materialize. This would have positive effects on the market-creation mechanism. However, this effect is likely to be very limited.

5.3.4 Prequalifications

Prequalification requirements (whether financial, or material on projects or project developers) are imposed in order to ensure the seriousness of bids, with a positive effect on the effectiveness of the auction. Matthäus (2020) finds a positive and statistically significant correlation between the effectiveness of the auction and the existence of financial and material prequalification requirements and, indeed, this is the most influential design element on the effectiveness of the auction.

Although there is a general agreement in the academic literature that these requirements should be adopted, and most countries over the world have done so, their level of stringency is open to discussion. Projects awarded in the auction are more likely to be built under stringent requirements. Therefore, learning effects and the expectation on market creation would be better activated when this design element is not lenient. However, more stringent prequalifications would result in higher costs and may also knock out smaller scale actors from the bidding process, perhaps contributing to some of the effects that are mentioned in ”actor neutrality” above. Although they may also lead to higher bids, profit margins are likely to be lower (than with lenient prequalifications). If these prequalification requirements are too strong (i.e., very high economic guarantees, previous experience in building similar projects, or administrative permits or connection points for the projects), then this would limit the number of potential participants in the auction, which would reduce competition and lead to a lower competitive pressure. However, apart from this “quantitative” effect on competition, there is a “qualitative” effect. This would not be so detrimental for competitive pressure: the weaker bidders would not participate in the auctions, but stronger bidders would. Therefore, it cannot be a priori be stated whether more stringent or lenient prequalification requirements would have a net positive or negative effect on innovation.

Some specific prequalification requirements may encourage or discourage innovation, more than others. For example, a “best available technology” criterion could be included as an additional material prequalification criterion (falling on projects). This could be expected to have a positive effect on innovation.

5.3.5 Seller concentration rules (SCRs)

The impact of SCRs on innovation is uncertain and likely to be limited. On the one hand, the number of participants in the auction would be greater, which would encourage competition and lead to a greater competitive pressure as well as to lower profit margins. On the other hand, economies of scale would probably be lower, which would lead to higher costs and, thus, lower profit margins for project developers. In addition, the risk of failing to build the projects is more diversified, and, thus, effectiveness is likely to be higher. Finally, the lower volumes that are awarded to specific bidders winning in the auction means that project developers have a lower negotiation power with respect to manufacturers, compared to a situation without SCRs. This leads to a lower pressure on manufacturers to reduce the costs of their equipment. The net impact of all those effects is uncertain.

5.3.6 Local content requirements (LCRs)

LCRs may adopt different forms (Hansen et al., 2020). There are basically two options, which can be used independently from each other or can be combined. They may require that the equipment is manufactured domestically, e.g., provided by local manufacturers. There might also be a requirement to hire a certain percentage of the total staff from the area (or country) where the project is located. In both cases, the impact on innovation is uncertain, although the first one is likely to have a greater effect that the second.

In the first case, the impact on innovation depends on several aspects, including the existence of a relatively developed supply chain. If there is a local industry on the renewable energy technology, then an LCR would encourage the national industry and, eventually, lead to local innovation. However, if the local industry is underdeveloped, there might be delays in building the projects as a result of bottlenecks in the supply chain (Matsuo & Schmidt, 2019). This would lead to a lower effectiveness of the auction but, perhaps more importantly, to a high uncertainty that the projects being awarded in the auction will be deployed in the future, negatively affecting market creation.

The negative impact on effectiveness would not occur in the case of a developed supply chain. However, even under these circumstances, LCRs entail a hurdle for some project developers (specially, foreign ones) and, thus, the existence of LCRs would lead to lower levels of competitive pressure, and lower competition negatively affects innovation. However, LCRs would ensure a given market quota and higher profit margins for domestic manufacturers. Whether this would be positive for innovation is uncertain, because international manufacturers would have a lower market quota. In addition, the local equipment is likely to be more expensive than equipment bought abroad, which would lead to lower profit margins for project developers/owners and, thus, a lower likelihood to invest in R&D.

In the second case (LCRs on employment), the impacts on the whole supply chain are likely to be lower, since the manufacturing industry is not directly affected. Bottlenecks in the supply chain are less likely to occur, especially if the employment requirements are for blue-collar jobs. Local manufacturers would not have a guarantee of a minimum quota for their equipment, which would lead to a greater competitive pressure compared to LCRs on the local industry.

5.3.7 Information provision

Information on the goodness of the renewable resource has been provided by the government in some cases (e.g., India or Denmark). This encourages participation in the auction (at a cost for the government). The impacts of this design element on innovation are likely to be low, although positive. On the one hand, this design element encourages participation in the auction, which increases competition and competitive pressure. In addition, the costs of measuring the resource are not faced by project developers and, thus, this leads to a higher profit margin. Providing this information may reduce the risk of underbidding, leading to a greater certainty that bidders have not faced the "winners' curse". Thus, a lower degree of project failure and a greater effectiveness can be expected, which is positive from the point of view of the market creation mechanism.

5.3.8 Remuneration type (capacity vs. generation)

In principle, remuneration based on generation would be more innovation-friendly than remuneration based on capacity. The reason is that, under generation-based remuneration, there is a greater incentive for project developers to adopt better designed machines, i.e., which lead to higher revenues or lower costs (i.e., higher expected profit margins). This increases the competitive pressure on manufacturers to invest in R&D and innovate in order to provide such machines. In contrast, the impact of the two alternatives on market creation is likely to be similar.

5.3.9 Remuneration type (generation)

Generation can be remunerated in different ways: a FIT, a fixed FIP and a sliding FIP (one-way and two-way or CfD)(see section 2). A FIT would lead to the lowest risks and, thus, to a greater incentive to build the projects. This risk is a bit higher with sliding FIPs and even higher with a fixed FIP since, in this latter case, part of the revenues are obtained by selling the electricity in the wholesale market although, in sliding FIPs, the level of total revenues are guaranteed (with the strike price obtained in the auction). It is unclear whether the different alternatives lead to higher profit margins. However, the lower risks of FITs would lead to a greater certainty on market creation with this alternative. In contrast, the competitive pressure would be highest under fixed FIPs. In addition, the greater market exposure of FIPs (both fixed and sliding), which require that the electricity is sold in the wholesale electricity market, would encourage innovation in RETs.

5.3.10 Selection criteria

Compared to multicriteria auctions, price-only auctions would probably lead to greater innovation effects. By definition, price-only auctions lead to more competition and, thus, a greater competitive pressure than multicriteria ones. Project developers have to comply with the criteria in multicriteria auctions, and fulfilling these criteria could lead to lower profit margins. In addition, given the uncertainty on whether the awarded bidders and project developers will be able to meet the criteria, a price-only auction will lead to better expectations that there will be a market for the technologies. This greater certainty on market creation is likely to spur innovation by equipment manufacturers. In contrast, no differences can be expected a priori on the level of learning effects that could be achieved with the two alternatives. Nevertheless, it should be taken into account that a "best available technology" criterion could be included as an additional criterion in multicriteria auctions, which would then have a positive effect on innovation.

5.3.11 Auction format

Auction formats are unlikely to have a differential or even relevant effect on innovation. It is very difficult a priori to tell whether single-item auctions or multi-item auctions would be preferable in this context. The choice of these formats is usually related to the features of the technologies. For example, given their large-scale and/or the existence of large economies of scale, wind off-shore and CSP are usually auctioned in single-item auctions, since it is difficult to split these projects among different units without considerable losses in their technical or economic performance. But a greater flexibility is allowed in this regard for PV and wind on-shore, which can be split among different units without those losses. Therefore, multi-item auctions in wind off-shore and CSP would lead to lower economies of scale and, thus, lower profit margins can be expected in this case. The only innovation mechanism that could be positively activated is market creation. Since several bidders might be awarded in multi-item auctions, this would reduce the risk that a single project developer does not build the project, compared to single-item auctions.

5.3.12 Auction type

Compared to static auctions, dynamic auctions provide more information for market participants, and allow them to bid according to the information revealed by the other participants. This reduces the risk of underbidding but increases the risk of collusion. Therefore, dynamic auctions can be expected to be more effective, which would lead to greater learning effects and market creation as innovation mechanisms. Profit margins would be lower in static auctions, given the higher risks of underbidding and the lower likelihood of collusion in this alternative. For the same reason, static auctions would increase competitive pressure.

5.3.13 Pricing rule

There isn't a consensus in the academic literature on the impact of the pricing rule (uniform versus pay-as-bid, PAB) on the effectiveness of the auction. According to Anatolitis and Welisch (2017), and Matthäus (2020), uniform pricing would lead to a higher remuneration for project developers, which would lead to a greater effectiveness of the auction compared to PAB. In contrast, for Kreiss et al. (2017), Mora et al. (2017) and Haufe and Ehrhart (2018), a greater effectiveness would be achieved with PAB.

The pricing rule is unlikely to have an important effect on innovation. The direction of the effect is also unclear, because there is not a consensus in the literature on which pricing rule leads to higher bid prices for the awarded winners and which one leads to higher competition levels.

5.3.14 Ceiling prices

Similarly to the previous design element, ceiling prices are unlikely to substantially affect the incentives for innovation. They would limit the risk of very high bid prices and, thus, total support, but sufficiently high ceiling prices are unlikely to have any effect (if the auction is well designed) and, thus, they are unlikely to influence profit margins. They are also unlikely to have any impact on competition. The disclosure (or non-disclosure) of ceiling prices is also unlikely to have meaningful effects in this regard.

5.3.15 Realisation period

Establishing a deadline for building the projects awarded in the auction is a common design element in auctions from around the world. When a deadline is not set, as in the U.K. NFFO, a risk of ineffectiveness results. Therefore, market creation and learning effects would be higher with the setting of a required realization period. However, a main issue is how long this period should last for. Too long realization periods (as in the auctions in Chile) may be detrimental for effectiveness. If the time between the auction is conducted and the deadline for project construction is too long, bidders may bid too low. The reason is that bidders calculate their bids based on expectations of the reductions in the costs of the technologies. If these cost reductions do not materialize to the extent expected by the bidders, they may end up with bids which are too low, maybe even below the costs of their projects. This results in underbidding and underbuilding, negatively affecting market creation and, thus, innovation. Too short realization periods may also be detrimental for market creation and, thus, innovation if they do not allow awarded bidders to close the financing after being awarded, but before the realization period expires without having to pay substantial penalties.

5.3.16 Frequency

Auctions organized at regular intervals with a relatively high frequency (e.g., at least once per year) can be expected to positively and strongly affect one innovation mechanism (market creation), although it would probably have small effects on the others.

5.3.17 Minimum participation conditions

Minimum participation conditions, as in Colombia or Portugal, where a minimum number of bidders are required to participate in the auction, would have a positive impact on competition and, thus, competitive pressure. The rest of innovation mechanisms are unlikely to be affected.

Table 4 summarises the assessment above.

Table 4: Assessment of the impact of different design elements on innovation.

Design elements		Learning effects	Profit margins	Market creation	Competitive pressure	Expected impact on innovation	
Category	Alternatives					Net (positive) impact	Expected degree of impact
Volume	Generation, capacity or budget	GEN and CAP (+), BUD (-)	=	CAP (++), GEN (+), BUD (-)	=	Capacity (generation)	Small
	Disclosure (vs. non-disclosure)	+	Slightly -	+	Slightly -	Disclosure	Small
Schedule (vs. non-schedule)		++	=	++	?	Schedule	High
Diversity	Technology-neutral (vs. technology-specific)	+ (more mature) -(less mature)	+ (more mature) -(less mature)	+ (more mature) -(less mature)	+	Neutral (more mature) Specific (less mature)	High
	Geographically-neutral (vs. geographically-specific)	=	?	=	+	Neutral	Small
	Actor-neutral (vs. actor-specific)	=	? (depends on the specific design)	=	? (depends on the specific design)	? (depends on the specific design)	Small
	Size-neutral (vs. maximum size)	Slightly -	-	Slightly -	+	?	Small
Prequalification (stringency)	Material prequalifications on projects (vs. non-stringent)	+	-	+	-	?	Medium
	Material prequalifications on project developers (vs. non-stringent)	+	-	+	-	?	Medium
	Financial prequalifications (vs. non-stringent)	+	-	+	-	?	Medium
Seller concentration rules (vs. their absence)		?	-	+	+	?	Small
Local content rules: local industry (vs. their absence)*		=	+	?	-	?	Medium

Local content rules: local employment (vs. their absence)		-	=	=	=	?	Small
Information provision		Slightly +	+	+	+	Information provision	Small
Remuneration type: generation (vs. capacity)		=	=	+	=	Generation-based remuneration	Medium
Remuneration type (FITs, fixed FIPs, sliding FIPs)		1. FIT; 2. Sliding FIPs; 3. Fixed FIP	?	1. FIT; 2. Sliding FIPs; 3. Fixed FIP	1. Fixed FIP 2. Sliding FIPs; 3. FIT	?	Medium
Selection criteria: price-only (vs. multicriteria).		=	+	+	+	Price-only	Medium
Auction format: multi-item (vs. single-item).		=	=	+	=	Depends on technology	Small
Auction type: static (vs. dynamic)		-	-	-	+	Dynamic?	Small
Pricing rule: PAB (vs. uniform)		?	?	?	?	?	Small
Ceiling prices	Existence (vs. absence)**	=	=	=	=	?	Small
	Disclosure (vs. non-disclosure)	=	=	=	=	?	Small
Realisation period with an appropriate length (vs. their absence or too long)		+	=	+	=	Realisation period (set with an appropriate length)	Small
Frequency: high (vs. low)		=	=	+	=	High frequency	Small
Minimum participation conditions (vs. their absence)		=	?	=	+	Minimum levels of participation	Small

* Assuming a developed local value chain. ** Assuming they are not set at low levels.

Note: (+) means that a positive impact of the design element option with respect to its alternative regarding the specific innovation mechanism can a priori be identified; (-) means that a negative impact of the design element option with respect to its alternative regarding the specific innovation mechanism can a priori be identified; (=) means no clear differential impact on innovation can a priori be identified.

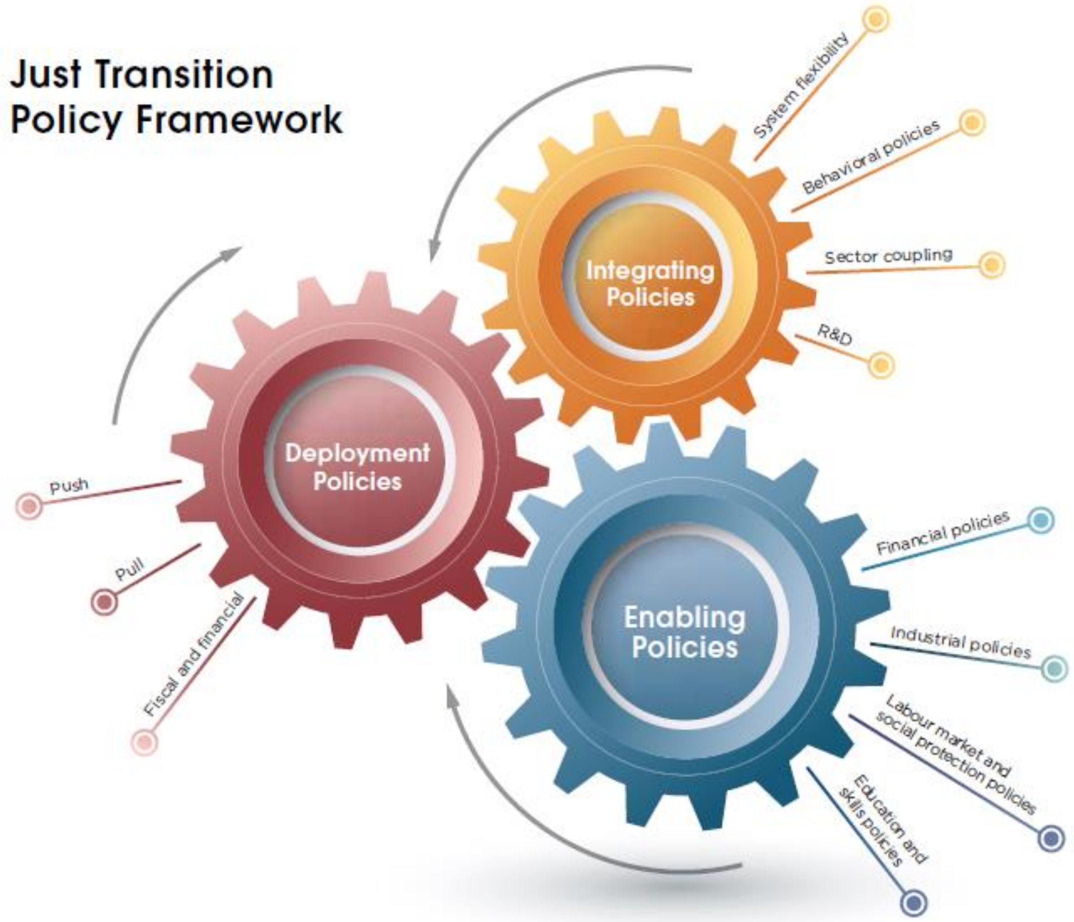
As it can be observed, not all design element categories can be expected to influence innovation in RETs. The following would be the most relevant in this context: schedule, technological neutrality, the stringency of prequalification requirements and the remuneration type. In addition, after looking closer at the potential for impacts of other design elements on innovation and discussing these with a couple of experts, other design elements are deemed relevant in this regard, including the existence of project size limits (vs. their absence), a high frequency of auctions (vs. occasional ones), price-only auctions (vs. multicriteria ones), capacity-based remuneration (vs. generation-based one) and generation-based auction volumes (vs. a capacity-based ones). On the other hand, opposite effects on innovation can be observed for most design elements, leading to an unclear a priori result, which justifies empirical research on the topic.

The design elements mentioned above would represent the lowest level of granularity of policies. However, there could be an even greater level of granularity, depending on the different choices for the specific design elements (Table 4).

5.4 The impact of other context variables

The literature reviewed in section 4 suggests that innovation in RETs is a very complex topic which does not only depend on the existence of demand-pull policies, but which is affected by other policy (such as public R&D and other instruments in the policy mix) and non-policy factors (such as domestic innovation capabilities). Therefore, auctions are not the only factor inducing innovation. Indeed, they might have a very modest impact in this regard. The comprehensive framework depicted in IRENA (2019) is very useful in this regard (see Figure 3). Thus, it should be identified whether auctions fit in this framework, whether they could be aligned with other instruments to promote innovation and whether there could be synergies, conflicts and complementarities.

Figure 3: Just transition policy framework.



Source: IRENA (2019).

Two main policy factors are public R&D and context (framework) conditions. As mentioned above, and shown by the review of the literature in section 4, public R&D is a main driver of RET innovation. It is complementary to deployment support. It can be shown that demand-pull policies that are entirely designed in isolation from supply-push support (R&D programs) are less effective in encouraging innovation. Similarly, Bointner (2014) finds that appropriate public R&D funding associated with a subsequent promotion of the market diffusion of a niche technology may lead to a breakthrough of the respective technology.

On the other hand, learning by interacting through private knowledge collaboration and involvement in networks is a relevant source of innovation in RETs. Therefore, public support for knowledge collaboration and involvement in networks, such as technology platforms or grants for consortia could be supportive of RET innovation.

Policy framework conditions refer to the existence of long-term targets and also to policy stability. Long-term targets are likely to favour innovation process as they provide long-term signals, specifically if accompanied by stable policies. Indeed, Schleich et al. (2017)

show that patenting in wind power is positively related to the presence of production or capacity targets for wind power and a more stable policy environment. Liang and Fiorino (2013) and Pitelis et al. (2019) suggest that the level of R&D support loses power to explain RET innovation to policy stability in the long run. Hoppmann et al. (2013) also stress the importance of market stability and long-term targets as drivers of R&D expenses. Uncertainty makes investors reluctant to make long-term commitments and, thus, reduces corporate investments in both exploration and exploitation (Hoppmann et al., 2013, p. 999)[29].

In addition to policy aspects, non-policy factors can also be expected to influence innovation. In the RET sector, the high level of international competition in a globalized sector may be a relevant driver in this regard. Foreign demand for domestic RET equipment (i.e., wind turbines) would trigger innovations domestically and do so to a larger extent in the future. However, Schleich et al. (2017, p. 693) do not find that export demand exhibited a statistically significant effect on patenting in most models estimated. Note that this foreign demand may be related to policy factors, i.e. triggered by auctions or ASR FITs or FIPs abroad. The trend towards a broader energy transition, and particularly the shift towards increased electrification and a greater sector coupling and new opportunities for renewables-based solutions in sector-specific contexts is also likely to encourage innovation in the RET sectors. This would be for at least two reasons: (i) A push to greater electrification will, overall, create significant increases in electricity demand at the national level. Hence there will be a bigger and attractive market, with a larger scope for making (increasingly larger scale) investments. (ii) Certain sectors may require specific ad-hoc electrification solutions as far as RETs are concerned (including more hybrid tech solutions, likely greater generation plus storage systems, automation and efficiency measures....) which could potentially be rolled out by auctions. Finally, the literatures on the economics of innovation and organizational theory stress the role of factors internal to the firm as drivers of innovation activities and also as a determinant of specific innovation activities. These would include the firms' slack and other resources or their technology portfolio (Hoppmann et al., 2013), among many other resources, competences and dynamic capabilities (Kiefer et al., 2019).

5.5 Main research proposals

The above discussion allows us to infer a set of a priori research proposals. These proposals are then shared with different types of experts in the field to check their correctness and possible omissions.

-Auctions influence innovation through their impact on manufacturers and technology developers. These innovation effects of auctions should be compared to other alternatives:

---

[29] This is particularly the case for investors / organizations that are primarily (or even exclusively) focused on one (or few) markets (as opposed to multiple markets) because they would then be more dependent / at the mercy of the prevailing conditions of one market. In contrast, organisations active in multiple markets have a higher chance of finding favourable conditions in (at least) one or few markets amongst many and, hence, the R&D / innovation push gamble would be "less risky".

administratively-set remuneration (in the past) and a lack of support (for the future). In the future, the proper comparison of auctions is not with administratively-set remuneration, especially for low-cost, mature technologies (such as PV or wind on-shore) but probably with the absence of any support, whereby RES plants only receive the wholesale electricity market price.

-The design of the auction (different design elements) may affect innovation through several channels: impact on private R&D through a greater profit margin and the expectation that there will be a market for the technology (i.e., where manufacturers and technology developers can sell their technology), impact on technology diffusion and impact on the competitive pressures faced by manufacturers and technology developers to reduce costs or increase revenues.

-The negative effects on innovation from lower profit margins in auctions and lower levels of market creation for RES compared to ASR offsets the positive effects on innovation from a greater competition in auctions. Whether this is so for all RETs and auctions depends on the technologies, the design of the auction and the details of the ASR to which the comparison is made.

-Auctions will be one of the factors influencing innovation in RETs, but probably not the main one. Many other policy and non-policy factors influence innovation. Among the former, a main one is technology-push policies. Among the latter, the pressure to reduce costs as a result of international competition in a globalised sector stands out.

-Different design elements in auctions have different impacts on the R&D expenditures or the innovation activities of equipment manufacturers. Some design elements discourage them, others encourage them and yet others are unlikely to have any impact.

6 Methodology

The empirical analysis of the influence of policy on innovation is a difficult one. Kemp and Pontoglio (2011) described three challenges in this regard: the difficulty to measure environmental policy (especially the design aspects of policy instruments), methodological problems in measuring innovation and the problem that many relevant factors cannot be observed, e.g. business expectations, institutional constraints, and innovation capabilities.

In this context, the empirical analysis of the influence of auctions and auction design elements on RET innovation is a particularly challenging task for several reasons. Some concern the dependent variable (e.g., whether to use patents, R&D expenditures or other innovation variable), others refer to the policy variable (e.g., how to include different design options in the specifications of models) and yet others are related to the control variables (how to account for other policy and non-policy factors as drivers of innovation). Data availability is an issue for the three types of variables.

The results of the literature reviewed in section 4 show that many empirical contributions to the literature on the innovation effects of deployment policies focus on a macro (country) level, using panel databases in which patents are the dependent variable and the results for several policies in several countries are compared. However, there has not been much focus on the micro-level decisions of actors directly involved in RET innovation, i.e., those who invest in R&D and produce new or improved products and processes (equipment manufacturers). How those decisions are affected by different instruments and different design elements within the instruments have not received much attention.

In addition, the focus on auctions has been rather scant. There are very few existing studies on the impact of auctions on innovation with respect to other instruments (see section 4) and, when auctions have been included in the analysis, this is usually done with a dummy variable in econometric models. Furthermore, the impact of auction design elements has been a neglected topic.

This report takes a different approach. The purpose of the empirical analysis is to confirm the insights on the possible impact of auctions (with respect to ASR or no support) and different design elements within auctions on RET innovation, i.e. to check the relationships between the variables and their direction put forward in the analytical framework. The final aim is to confirm the set of research proposals on the mechanisms linking those two sets of variables (auctions and their design elements on the one hand, and innovation in RETs on the other) and the relative importance of other (non-auction) factors in driving innovation. For this, we take into account as a first step the analytical framework built in section 5 and the literature reviewed in section 4, but complement it with a consultation to experts on the relevant relationships, i.e., on the relevant influencing factors and the role of auctions in this context.

Therefore, we try to assess 1) which main factors in addition to auctions influence innovation in RETs and what is the importance of auctions in this context; 2) how auctions affect innovation differently from other alternative policies adopted in the past (administratively-set support in the form of FITs or FIPs) and how they could be expected to influence innovation in the future (compared to the absence of public support for RETs, i.e., a "merchant approach"); 3) how different design element choices influence innovation in RETs.

The focus on the detailed mechanisms (variables and relationships between the variables) linking auctions and innovation is clearly justified because this link has not yet been explicitly addressed in previous research. In carrying out this work, we are inspired by the approach taken by Hoppmann et al. (2013), although that paper addresses a different topic. In their paper, these authors argue that, in order to investigate their research question, they use qualitative case study research for two main reasons. "First, this link has not yet been explicitly addressed in previous research. The focus of the study therefore was on scrutinizing alternative causal mechanisms in order to build well-founded theory. According to Eisenhardt (1989) qualitative case studies are particularly well suited to fulfilling this task. Second, we chose case study research because this method allows for the studying of a phenomenon in greater depth than can be achieved using quantitative methods. In using qualitative research we are able to discern alternative determinants of technological learning and provide a detailed description of the mechanisms at work" (Hoppmann et al., 2013, p. 993).

The focus of the consultation is on the factors influencing innovation and R&D investments. This covers the drivers of diffusion-related innovation mentioned in section 3: reinvestment of profits into R&D activities (3.3.2), market creation (3.3.3) and competition (section 3.3.4). The other two drivers of RET innovation (learning effects and spillovers) are not directly addressed in this consultation, since they fall outside the direct realm of the decisions of the relevant actors (equipment manufacturers). In addition, there is much literature on learning effects and a recently emerging but already abundant literature on spillovers (see sections 3 and 4). This is in contrast to the extremely tiny literature on the impact of different instruments and design elements on R&D expenditures. In addition, for learning effects, which mostly depend on the evolution of capacity additions over time, a different approach should be adopted, whereby capacity additions are analysed under different support schemes (auctions vs. administratively-set remuneration).

In addition, it is important to identify the relative importance of auctions and design elements with respect to other factors influencing RET innovation. Apart from auctions, other policy factors (public investment in R&D and other measures in the policy mix) and non-policy factors (such as the domestic innovation capabilities) influence RET innovation. This represents a considerable methodological challenge, given the difficulty to isolate the effects of auctions in this context.

Two very relevant choices in this report, which are very different to the approaches taken in the literature, refer to the focus on R&D (instead of patents) and the micro-level (instead of the macro-level).

The micro-level focus is justified because innovation is generated by firms. Therefore, the impact of deployment policies on the innovation activities of firms is worth researching. Several theoretical approaches to technological innovation and diffusion exist in the literature, including environmental economics, innovation studies, the multi-level perspective (MLP), the literature on learning effects, diffusion modeling and innovation adoption approaches with a focus on the adopter (see Kiefer & del Río, 2020 for details). Each highlights crucial aspects in these processes, while neglecting or downplaying others (see Kiefer & del Río, 2020 for details).

Two particularly relevant approaches to empirically assess the drivers and barriers to RET innovation and diffusion have been environmental economics and innovation studies, including the technological innovation systems (TIS) approach. However, these two approaches have usually adopted a macro-level or system view, and have not paid specific attention to the role of actors (firms) in the process, including the effects of policies on the micro-level innovation or adoption decisions of firms (del Río, 2009). The micro-level constraints suffered by firms (in terms of the resources, capabilities or competencies of firms) are often disregarded (Kiefer & del Río, 2020). The analysis of innovation and diffusion processes should consider the views of those who are directly engaged in such process, i.e. the adopters (investors) and the innovators and their responses to institutional drivers and pressures (Horbach and Rammer 2018, Mignon & Bergek 2016, Hansen and Coenen (2017).

The level of private R&D spending can be viewed as both an input and an output measure, as it represents an input to a company's innovation strategy and the result of supportive government policies (Groba & Breitschopf, 2013). The focus on R&D investments is justified given the focus on the micro-level decision of firms to invest in R&D and due to the combined fact that there is a time lag between auctions and patent fillings and most RES auctions have occurred quite recently.

As it is well-known, innovation can be measured through input (private R&D) or output variables (patents). Both have their pros and cons (for a discussion, see e.g., Pitelis et al. (2019)). Data on private R&D are not publicly available but patent data are. However, in the context of this report, we are interested not only on a particular innovation outcome, but on the innovation efforts made by actors in the supply chain as a result of the auction and auction design elements and not at a macroeconomic level, but at a microeconomic one. We want to identify the incentive to innovate, i.e., we are interested in the incentives of those actors to invest in innovation as influenced by auctions. For this, patents represent a very crude proxy and are probably more suitable for a macro analysis, than for a microeconomic one.

In addition, if innovation is measured with patent data, there are delays in the publishing of patent information and, most importantly, there is a several years time gap between the adoption of a policy and the moment when invention/innovation shows in patent filings[30].

[30] As argued by Nicolli and Vona (2016, p. 203) "in a complex system, such as the energy sector, where renewable energy policies often target downstream distributors, which consequently indirectly demand more

Since most of the RES auctions have been organized in the last years, it may be too early to identify their potential impact on innovation as measured by patent data.

However, private R&D investments suffer from severe data availability problems. Therefore, the aim should not be to use a survey of equipment manufacturers to obtain those R&D investment data. This is likely to lead to a high non-response rate since such data are regarded as confidential by firms. The survey should try to identify the impact of auctions on R&D investments, which is a much less sensitive issue. At the end, the aim is to analyse such impact, and data on innovation (whether measured by private R&D or patents) is instrumental to achieve such aim.

To sum up, given the focus not on a particular innovation outcome, but on the micro-level innovation efforts made by actors in the supply chain as a result of the auction and auction design elements and the search for information about the factors that drive the decisions of those who innovate, i.e., those who invest in R&D, it makes sense to explore the impacts of auctions and auction design elements on private R&D investments, how they influence exploration vs. exploitation decisions, the type of innovation resulting (process vs. products, incremental vs. radical…) and also how these decisions are shaped by other factors.

The experts selected for this consultation had to meet several conditions: 1) they should be familiar with auctions for RES and the different options of auction design; 2) they should be knowledgeable of the process of innovation in RETs, either theoretically (because they are trained in innovation economics and energy) or practically (because they are practitioners in the field). This very specific profile of experts, who need to be knowledgeable of both auctions and innovation processes, is only met by a narrow set of experts, although in different areas: academic experts in energy issues with an innovation economics or innovation studies background, energy experts who are directly involved in the RET sectors (and, thus, know much about innovation processes in these sectors), equipment manufacturers, representatives of energy associations and members of technological platforms.

These groups of experts were consulted through a written questionnaire, which included the aforementioned propositions (section 5.5), asking them to identify the relevance of each aspect and, most importantly, the possible existence of missing variables or relationships. The questionnaire was structured in several blocks (box 1). These blocks could refer to all RETs or to given RETs (in particular, solar PV, CSP, wind on-shore and biomass).

---

upstream ‘green innovation’, it is reasonable to assume that the effect of the policy stimulus on patenting could take several years to be realized”.

Box 2: Structure of the questionnaire.

Block 0. Confidentiality clause, objective and definition of technological innovation. The questionnaire informs the interviewees that the answers would be strictly confidential. The names and the institutions of the participants would not be published in any place. Then, the objective of the questionnaire is stated. Technological innovation is defined as "a new or significantly improved product or production process. It includes new or significantly improved techniques, components, materials or software".

Block 1: Comparative influence of auctions with respect to other policy options.
In this block, interviewees are asked about the importance of the influence of auctions on technological innovation in RETs with respect to administratively-set remuneration (ASR), focusing in the past, and with respect to the absence of support (only the wholesale electricity price is received), focusing on auctions in the future. The interviewees, both in this block and the next ones, are asked to include other factors, items or comments regarding the drivers of innovation in RETs (both related and unrelated to auctions) which have not been included in the questionnaire.

Block 2. Influence of auctions on the deployment-related drivers of innovation.
Participants are asked to indicate the degree of agreement with some statements regarding the influence of auctions on the deployment-related drivers of innovation in RETs (competitive pressure, profit margins and market creation). This is done both with respect to auctions compared to ASR and auctions compared to the absence of support.

Block 3. Impact of different design elements.
Here, interviewees give their views on the effects of different design elements of auctions on technological innovation in RETs with respect to their alternatives (for instance, strict vs. lax prequalification requirements).

Block 4. Influence of other factors on technological innovation in RETs.
Finally, in this block, interviewees are asked to give their views on the degree of impact of several factors unrelated to auctions on technological innovation in RETs. These factors include the existence of international competition in a globalised sector, public support for R&D and collaboration and framework conditions (long-term goals and stability).

Note: the full questionnaire is available from the authors upon request.

The time focus of the analysis should be taken into account. The innovation effects of auctions can be analysed for the present and past auctions and for future auctions. This time differentiation is very relevant. In the past, the "competitors" of auctions were administratively set FITs or FIPs. This was due to the relatively lower competitiveness of RETs with respect to the conventional, fossil-fuel fired electricity generation technologies. However, it is increasingly argued that the substantial cost reductions of some RETs (and particularly, wind on-shore and PV) make those support schemes useless, and policy-makers in some countries are starting to consider whether those RETs should receive support at all (see section 5.2). This increasing trend towards a "merchant approach" is likely to intensify. Therefore, the future impact of auctions should probably be compared to the lack of support, not to administratively-set support, as in the past.

The aim of the questionnaire was not to get a definitive answer. It asks about the perception of the different stakeholders on the issues asked, so it is neither based on nor it provides hard data. The aim is to check the mechanisms identified in section 5 and if some relevant relationships or variables had been omitted. This would allow us to derive testable research propositions, following an inductive approach[31]. This kind of explorative approach is justified given the micro-level focus of the study and for a topic for which there is a lack of research on the innovation effects of auctions and on the mechanisms linking auctions and innovation, and for which qualitative aspects (related to the design of the auctions) play a very relevant role.

[31] According to Dudovskiy (2020), "the inductive approach, also known in inductive reasoning, starts with the observations and theories are proposed towards the end of the research process as a result of observations. Inductive research "involves the search for pattern from observation and the development of explanations – theories – for those patterns through series of hypotheses". No theories or hypotheses would apply in inductive studies at the beginning of the research and the researcher is free in terms of altering the direction for the study after the research process had commenced. It is important to stress that inductive approach does not imply disregarding theories when formulating research questions and objectives. This approach aims to generate meanings from the data set collected in order to identify patterns and relationships to build a theory; however, inductive approach does not prevent the researcher from using existing theory to formulate the research question to be explored. Inductive reasoning is based on learning from experience. Patterns, resemblances and regularities in experience (premises) are observed in order to reach conclusions (or to generate theory)".

7 Results of the case study

This section reports the results of the case study on the influence of auctions in technological innovation in Spain. First, an overview of the statements made by renewable energy associations and technology platforms in this country is provided (7.1). The results of the questionnaires to experts are included in section 7.2. Section 7.3 takes a closer look at the view of one equipment manufacturer.

7.1 An overview of the statements of renewable energy associations and technology platforms

In order to identify the views of relevant stakeholders with respect to innovation, its drivers and the role of auctions in this context, we have taken a look at the statements made by two types of technology-specific organizations (technological platforms and renewable energy associations) which are publicly available in their respective websites.

The technological platforms for RETs in Spain include the different actors which are relevant in innovation processes in the different renewable energy technologies. We have paid attention to the public statements made by the following technological platforms: wind (REOLTEC), solar PV (FOTOPLAT), CSP (SOLARCONCENTRA), biomass (BIOPLAT) and geothermal (GEOPLAT). Their objectives are the integration and coordination of the research, development and innovation actions of the Spanish wind energy sector (REOLTEC), to group all the firms and institutions involved with the challenge to maintain Spain and the Spanish firms at the forefront of research and industrialisation of the PV energy systems, looking for synergies between the different institutions and implementing coordinated strategies (FOTOPLAT), to implement the promotion of R&D in this sector and to favour the innovation and technological development of CSP in Spain (SOLAR CONCENTRA), to provide the framework under which all the sectors involved in the development of the biomass can work jointly and in a coordinated manner in order to achieve the commercial implementation of bioenergy (BIOPLAT) and to be the framework under which all the sectors involved in the development of geothermal energy can work jointly and in a coordinated manner in order to achieve the commercial implementation of geothermal energy (GEOPLAT)[32].

For the purposes of this report, we have looked for information on their views regarding the impact of deployment support, and particularly auctions, on innovation. However, as expected, the mention to auctions and their relationship with innovation is very scarce in the analysed documents. In general, these platforms put the emphasis on public R&D support, support for demonstration, support for public-private collaboration (a greater integration of university, research centers and firms) and for the maintenance and reinforcement of the local industrial supply chain. The role of deployment instruments is

[32] These statements can be found in the respective websites: REOLTEC (https://reoltec.net/), FOTOPLAT (https://fotoplat.org/), SOLARCONCENTRA (http://www.solarconcentra.org/), BIOPLAT (https://bioplat.org/) and GEOPLAT (https://www.geoplat.org/).

usually considered in this latter context, i.e., as a way to maintain a local industry which, in turn, can be involved in innovation processes.

When mentioned, auctions are regarded as an additional incentive to encourage innovation in the respective sectors and RETs. For example, with respect to the wind energy sector, REOLTEC (2020) argues that in very competitive sectors and very competitive auctions it will be necessary to increase the annual energy production as well as to reduce CAPEX, OPEX and LCOE. "In this scenario, the wind energy sector needs to reduce the LCOE, in addition to maintain the availability of plants, the contribution to the security and reliability of electricity supply and the lengthening of the lifetime of the installations. All this sets the innovation of the sector" (REOLTEC, 2020, p. 3). However, in an analysis of the evolution of patents in climate change mitigation technologies, it also argues that in this context of the need to reduce costs, firms do not patent more, but rather the opposite is true (in order to save money on intellectual property rights) (REOLTEC, 2020).

On the other hand, the renewable energy associations include organizations which cover all the RETs (APPA) as well as those which are focused on specific technologies: wind (AEE), PV (UNEF and ANPIER), CSP (Protermosolar), biomass (AVEBIOM) and geothermal (AEG)[33]. In general, these organizations celebrate the calls for auctions and regard deployment support as a crucial requirement for the growth of their sectors.

The auctions have reactivated some of these sectors, at least this is regarded to be the case for PV and wind (the ones awarded in the 2016-2017 auctions) and it is also considered to be the case with the future auctions by the CSP association (PROTERMOSOLAR, 2019). For example, UNEF emphasises the importance "to introduce mechanisms in order to keep stable the deployment of new capacity, such as auctions" (UNEF, 2020b, p. 28). It is argued that "technological development and the dragging effect of new installed capacity have allowed PV to maintain a cost-reduction trend in the last years" (UNEF, 2020a, p. 21). "Auctions allow a stable deployment of the new capacity, favouring the development of an industrial and technological sector, as long as there is a pre-set schedule" (UNEF, 2020b, p. 57). Recently UNEF has praised the five-year auction schedule published by the government since "it will give visibility to the sector and will favour the industrial development and R&D investments" (UNEF, 2020c).

Regarding the wind energy association (AEE) the last annual report of the AEE mentions that "the strong competition of wind energy technology with other forms of electricity generation, and even the competition between the manufacturers of this sector, forces to reduce the cost of generation (LCOE)" AEE (2020, p. 84). Auctions have likely encouraged such competition and, thus, innovation to reduce those costs. It is also mentioned that "the wind sector has been for a long time defending the need to coordinate the decisions in energy, industrial, climate and R&D policy among the different institutions" (AEE, 2020, p. 5).

[33] Their websites are, respectively: AEE (https://www.aeeolica.org/), UNEF (https://unef.es/), ANPIER (https://anpier.org/), Protermosolar (https://www.protermosolar.com/), AVEBIOM (https://www.avebiom.org/) and AEG (https://geotermia.ch/).

The annual reports of the AEE include a chapter on R&D of the wind sector, with insights from the analysis of patents carried out in REOLTEC. In the 2018 edition of that report, it is mentioned that "reducing the LCOE is one of the priorities of the sector in order to maintain a competitive position. In addition, auctions have led to the cost of generation being very relevant. In order to achieve the reductions in costs, practically all the manufacturers have increased the diameter of the wind turbines which, although it has some impact on the cost increase of the machines, it also leads to a clear increase in production." (AEE, 2018, p. 81). Similarly, in the 2019 edition, it is mentioned that "the main drivers of innovation are linked to the current auctions, which are leading to the development of turbines with a greater diameter in order to capture more energy from the wind" (AEE, 2019, p. 74). It also argues that public investments in R&D have experienced a decreasing trend since 2011 (AEE 2019, p.76). An analysis of the European patent fillings of Spanish origin of the climate change mitigation technologies in the 2005-2017 period reveals a decreasing trend, except for the year 2017, when an increase was observed. According to AEE (2019, p. 83) this increase "can be linked to the dynamism of the market due to the result of the auctions".

7.2 Results of the questionnaires to experts

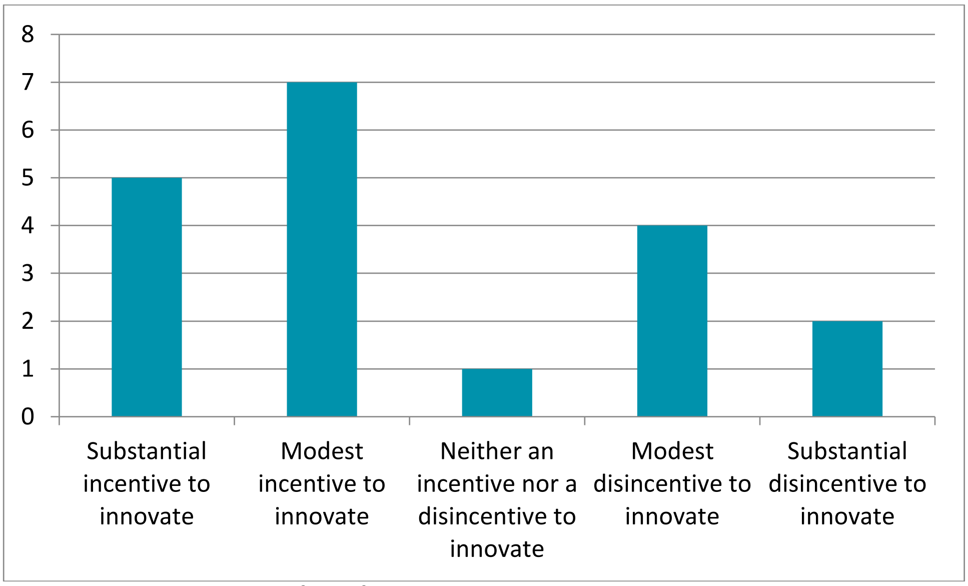
A questionnaire was sent to main experts knowledgeable of the link between auctions and innovation in RETs to know their perception on the topic and the relationships between the different variables. 19 experts completed the questionnaire and sent it back to the authors between November and December 2020. Different types of experts were contacted. Per type of stakeholder, 2 experts belong to a technology platform, 5 belong to different Spanish renewable energy associations, 1 belongs to a think tank, 3 are project developers, 6 are academic experts, one is a non-academic expert and there is one manufacturer. The questionnaire focused on either RETs in general (8 completed questionnaires) or specific technologies (3 for wind, 3 for PV, 4 for CSP and 1 for biomass). The rest of this section provides and discusses the results.

Block 1: Comparative influence of auctions with respect to other policy options.

Regarding the perceived influence of RES auctions on technological innovation in RETs in Spain with respect to ASR, most interviewees believe that auctions (in general, i.e., whether conducted in Spain or in the rest of the world) provide an incentive to innovation (with respect to ASR)(Figure 4). However, this incentive is modest for many of those stating that such a positive impact would exist. In addition, a non-negligible share of interviewees believes that auctions discourage innovation.

Those which argue that auctions have discouraged innovation are mostly those focusing on specific technologies which were not awarded in the auction procedures or which were not eligible to participate (such as CSP). In addition, many interviewees emphasise that the devil lies in the details and suggest that the innovation impacts of auctions depend on the way they are designed (such as technology-neutral vs. technology-specific auctions). This is also the case for ASR. For example, one interviewee argues that "if a ASR with sufficiently adjusted award prices (to the LCOE) had been organized, it would have also encouraged innovation in order to benefit from such price". Framework conditions (long-term support frameworks) would also play a role in this regard. Another interviewee states that auctions are for large plants, "whereas innovation is in distributed generation". Finally, a couple of interviewees argue that auctions may generate a competitive pressure to innovate, but at the expense of reducing the incentive to develop innovations due to "too much pressure" and low profit margins throughout the whole value chain (this issue is addressed further below). One interviewee mentions that there might be a conflict in auctions between the short-term incentive to have low support prices and the incentives for innovation.

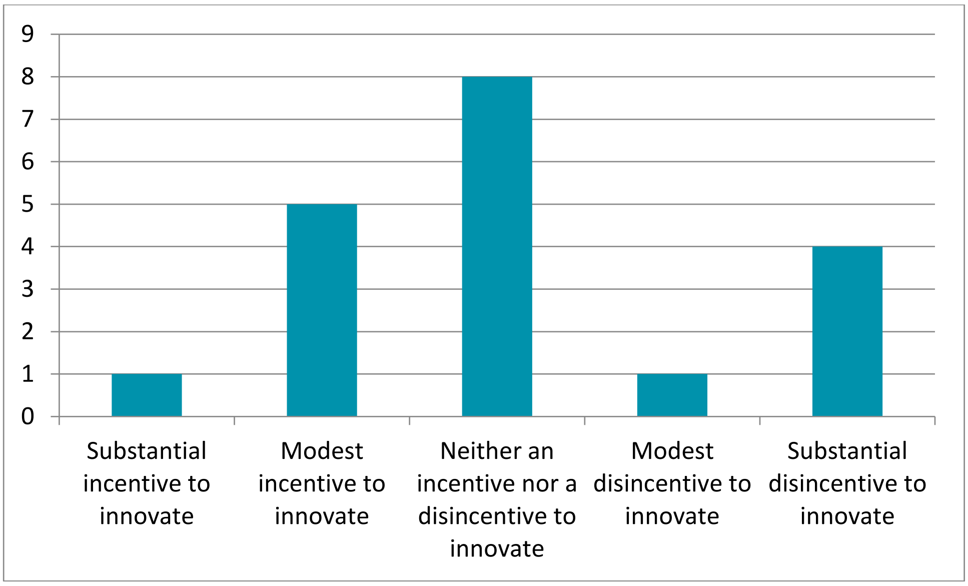
Figure 4: The impact of RES auctions on technological innovation in RETs in Spain with respect to ASR.



Note: in this and the rest of the figures, unless otherwise stated, the numbers in the y-axis refer to the number of interviewees who have provided the respective answer.

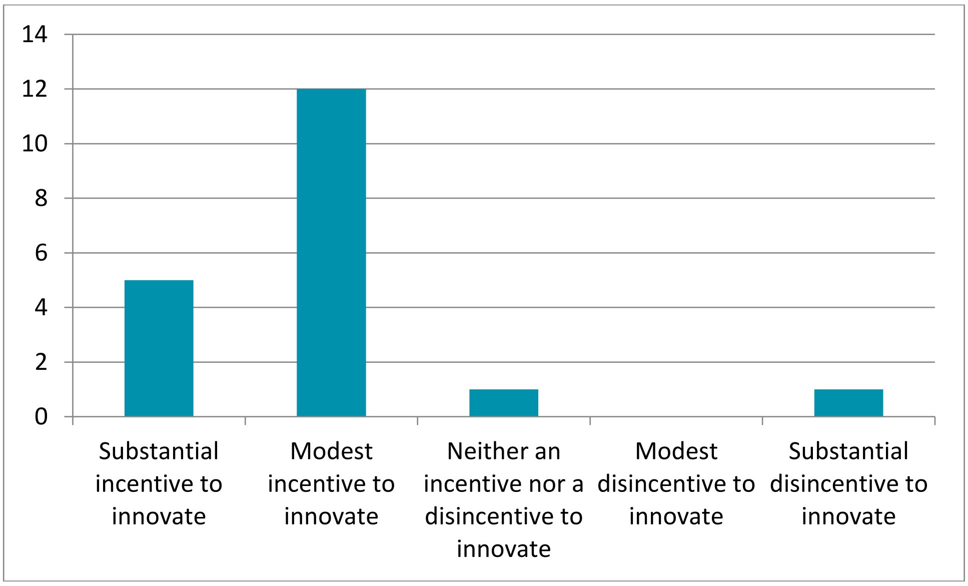
When interviewees were asked about the perceived influence of past auctions in Spain (i.e., those conducted in 2016 and 2017) on technological innovation in RETs in Spain, most argued that those auctions have neither encouraged nor discouraged technological innovation (Figure 5). The rest of interviewees had opposing opinions in this regard, with balanced views on whether auctions encourage or discourage technological innovation. Whereas some argued that the auctions would encourage innovation due to the stronger need to reduce costs, others mentioned that the auctions in Spain in 2016 and 2017 did not encourage innovation either because the design was not favourable in this respect (being conducted at short notice, being price-only ones, some technologies not being eligible to participate or auctions being conducted with a small volume). A few claimed that the auctions were only aimed to encourage a "speculative" renewable energy model.

Figure 5: The impact of past RES auctions in Spain on technological innovation in RETs in Spain (with respect to ASR).



Finally, as illustrated in figure 6, when asked about the expected influence of future auctions on technological innovation (with respect to the absence of support), there seems to be a widespread agreement that auctions will encourage technological innovation in the next decade, although this impact will be modest for an overwhelming majority of interviewees. On the one hand, those mentioning that auctions would encourage innovation with respect to the lack of support, focused on higher-cost technologies in terms of LCOE (biomass or CSP), arguing that those technologies could not compete on the basis of wholesale prices alone and that auctions would provide a price floor which would be beneficial for the deployment and, thus, innovation in those technologies.

Figure 6: Expected impact of RES auctions on technological innovation in RETs in Spain in the future with respect to the absence of support.

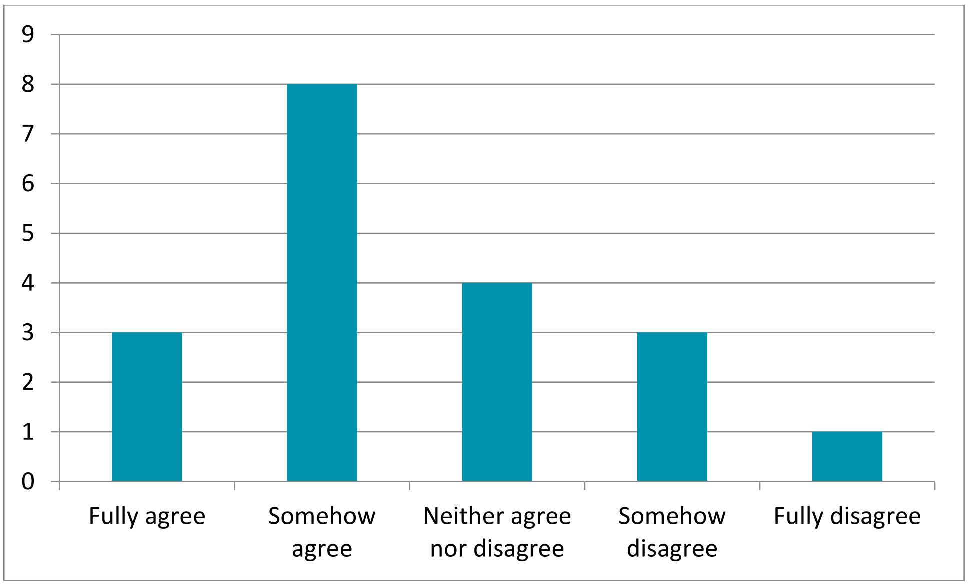


Block 2. Influence of auctions on the deployment-related drivers of innovation.

Participants were asked to indicate the degree of agreement with some statements regarding the influence of auctions on the deployment-related drivers of innovation in RETs (competitive pressure, profit margins and market creation). This was done both with respect to auctions compared to ASR and auctions compared to the absence of support. The results are shown in the next figures (Figures 7 to 12).

1) Competitive pressure. There seem to be a favourable opinion on the influence of auctions on technological innovation (with respect to ASR) through the competitive pressure exerted on project developers, which encourages equipment manufacturers to innovate (e.g., to spend more on R&D). Again, the influence of some design elements (the level of remuneration under ASR and auctions, the dispatch profile and a long-term schedule) and framework conditions (long-term targets and stability of regulation) were mentioned.

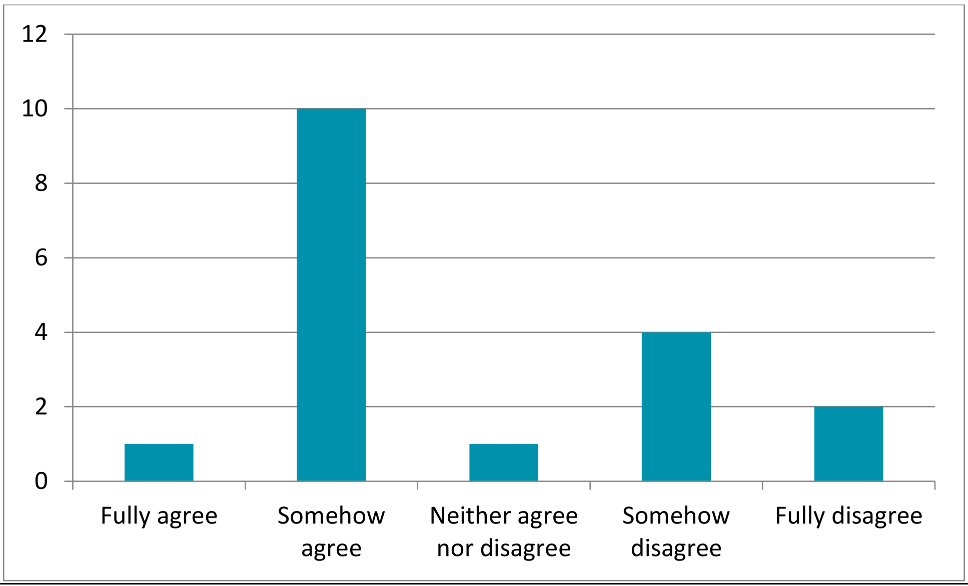
Figure 7: The influence of auctions on the "competitive pressure" deployment-related driver of innovation (with respect to ASR).



Note: the full question was: "Do you agree with the following statement? Compared to ASR, the competitive pressure exerted by auctions on project developers leads equipment and component manufacturers to innovate (increase their R&D expenditures)".

On the other hand, the experts seemed to agree on the negative influence of auctions on the aforementioned competitive pressure with respect to the absence of support, suggesting that auctions would not induce technological innovation as much as the absence of support. However, a non-negligible number of interviewees had the opposite view and argued that, without support (through the auction), some RETs could not compete with other technologies on the basis of wholesale market prices alone.

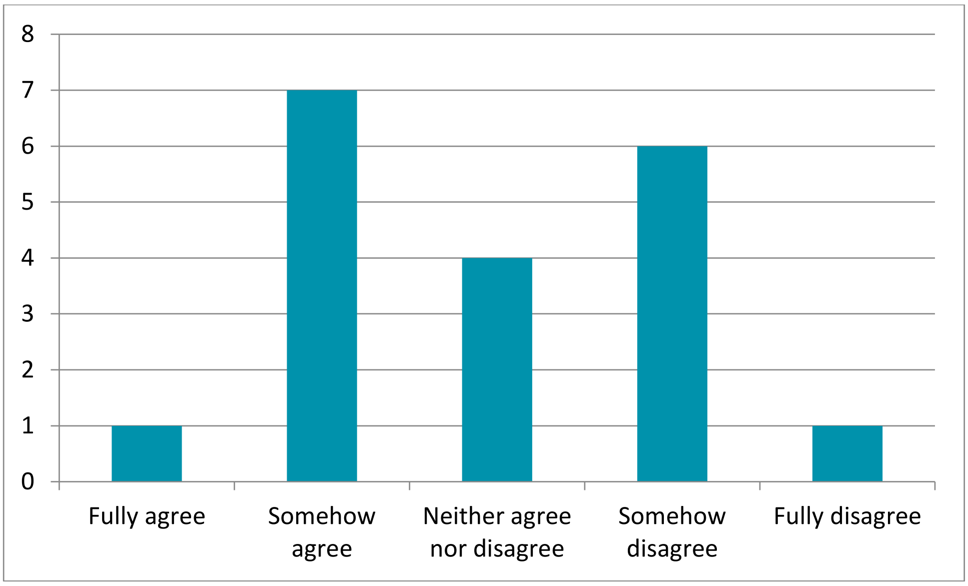
Figure 8: The influence of auctions on the “competitive pressure” deployment-related driver of innovation (with respect to the absence of support).



Note: the full question was: “Do you agree with the following statement? Compared to auctions, the competitive pressure exerted by the absence of support (only the wholesale market electricity price is received) on project developers leads equipment and component manufacturers to innovate (increase their R&D expenditures)”.

2) Profit margins. There were opposing views on the statement that “R&D expenditures of manufacturers of renewable electricity generation equipment and components, which partly depend on the existence of profit margins which can be reinvested in R&D by project developers, are negatively influenced by auctions, which lead to lower margins compared to ASR”. Almost the same number of interviewees agreed and disagreed on such statement, whereas some interviewees (4) neither agreed nor disagreed.

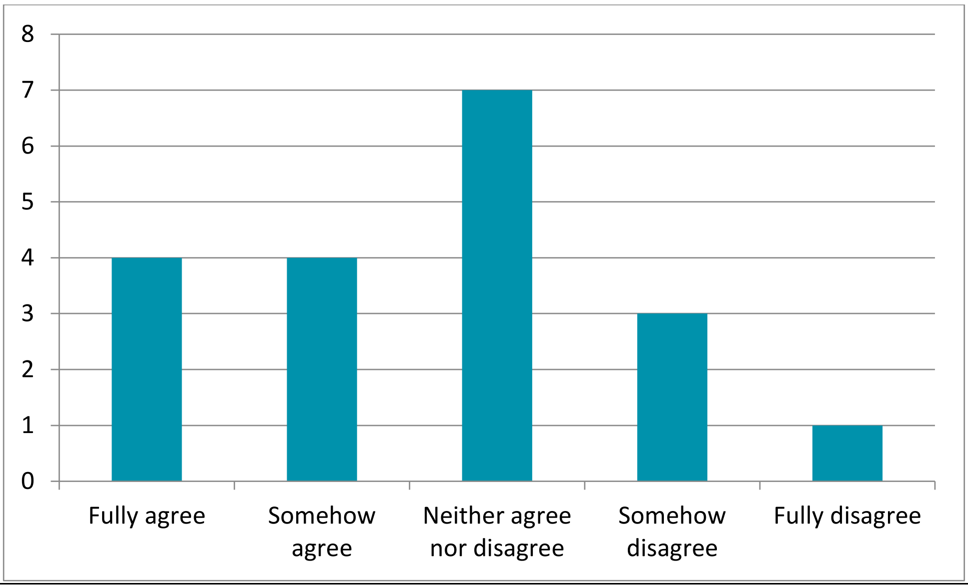
Figure 9: The influence of auctions on the “profit margins” deployment-related driver of innovation (with respect to ASR).



Note: the full question was: “Do you agree with the following statement? The R&D expenditures of RET equipment and component manufacturers, which partly depend on the existence of profit margins which can be reinvested in R&D by project developers are negatively affected by auctions, which reduce those margins compared to ASR”.

In contrast, there was some agreement on the positive influence of auctions on technological innovation with respect to the absence of support through their impact on higher profit margins that can be reinvested in R&D. Therefore, auctions can be expected to influence technological innovation with respect to the absence of support. A couple of interviewees suggested that auctions would be an appropriate instrument to achieve short-term cost reductions, leading to cost effectiveness, but not necessarily to innovation in the long-term.

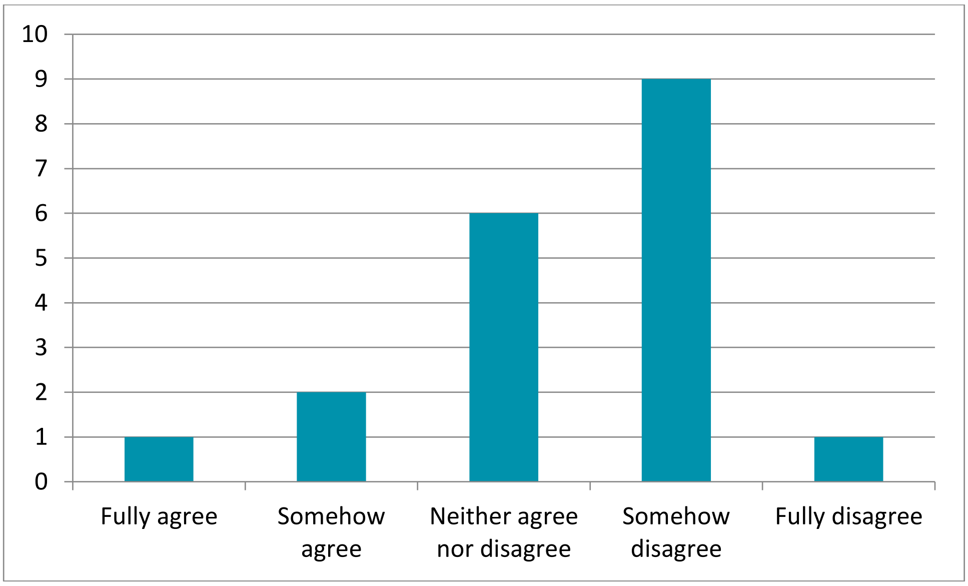
Figure 10 The influence of auctions on the "profit margins" deployment-related driver of innovation (with respect to the absence of support).



Note: the full question was: "Do you agree with the following statement? Compared to auctions, the absence of support reduces the profit margins which can be reinvested on R&D by project developers, which has a negative effect on the R&D expenditures of RET equipment and component manufacturers".

3) Market creation. Finally, most interviewees disagreed with the statement that "with respect to ASR, auctions reduce the ability of the manufacturers to invest in R&D, given that the installed capacity would be lower with auctions than with ASR and, thus, the amount of products that manufacturers can sell in Spain is lower with auctions than with ASR". Therefore, the interviewees mostly seemed to reject the existence of a market creation effect on technological innovation.

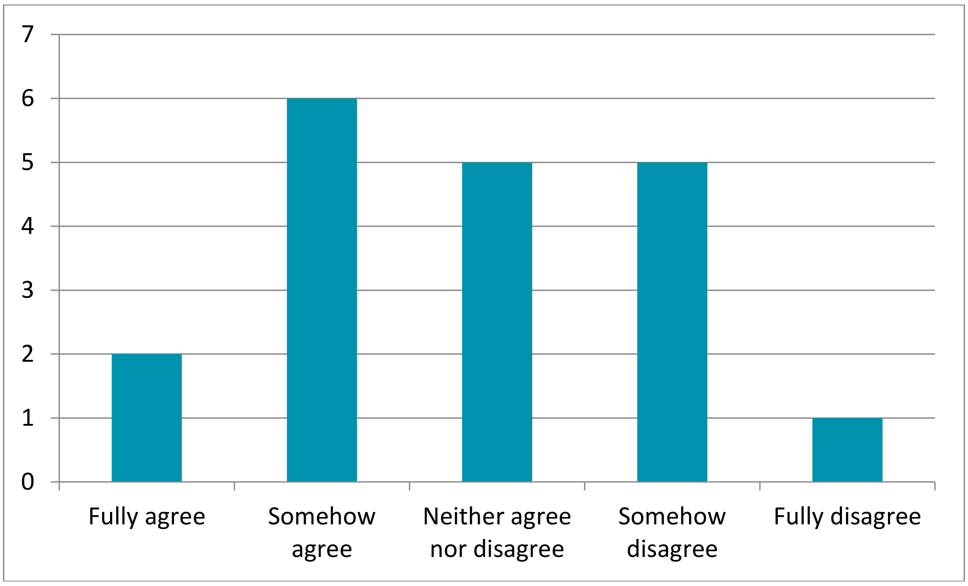
Figure 11: The influence of auctions on the "market creation" deployment-related driver of innovation (with respect to ASR).



Note: the full question was: "Do you agree with the following statement? Compared to ASR, auctions reduce the ability of RET equipment and component manufacturers to invest in R&D. The reason is that the installed capacity would be lower with auctions than with ASR and, thus, the quantity of products that manufacturers can sell in Spain would also be lower with auctions".

In contrast, the views of interviewees seem to be highly divided regarding the impact of auctions with respect to lack of support through their effects on market creation.

Figure 12: The influence of auctions on the "market creation" deployment-related driver of innovation (with respect to the absence of support).



Note: the full question was: "Do you agree with the following statement? Compared to auctions, the absence of support reduces the ability of RET equipment manufacturers to invest in R&D. The reason is that the installed capacity would be lower without support and, thus, the amount of products that manufacturers can see in Spain would also be lower without support".

The results for this block suggest that, according to the perceptions of the experts, and compared to ASR, auctions are likely to have a positive impact on technological innovation through the positive effect on the competitive pressure driver and their non-negative effect on profit margins and market creation. With respect to the absence of support, auctions are unlikely to affect technological innovation significantly through any of the drivers (and could even be negative concerning the competitive pressure driver).

Block 3. Impact of different design elements.

The views of the interviewees with respect to the effects of different design elements of auctions on technological innovation in RETs are provided in this block (see Figure 13).

According to those views, stringent prequalification requirements would encourage technological innovation (compared to laxer or inexistent ones), although this effect could be expected to be modest.

Compared to technology-specific auctions, technology-neutral ones would discourage technological innovation in RETs in Spain, according to the perception of the respondents.

The perceived influence of project size limits on technological innovation is more balanced, although there tends to be an agreement that those limits would encourage innovation (modestly) with respect to their absence.

Compared to the absence of a schedule of future auctions, its existence would have a clear positive effect on technological innovation as perceived by virtually all interviewees. This is the design element with the highest level of agreement on its substantial influence.

The interviewees agreed on the positive influence of a high frequency of auctions (compared to infrequent ones) on technological innovation in RETs.

In contrast, the opinions of the interviewees are split between those who think that price-only auctions would encourage technological innovation (compared to multicriteria ones) and those who think that the opposite would be true. There is a slightly more shared view that multicriteria auctions would be positive for technological innovation.

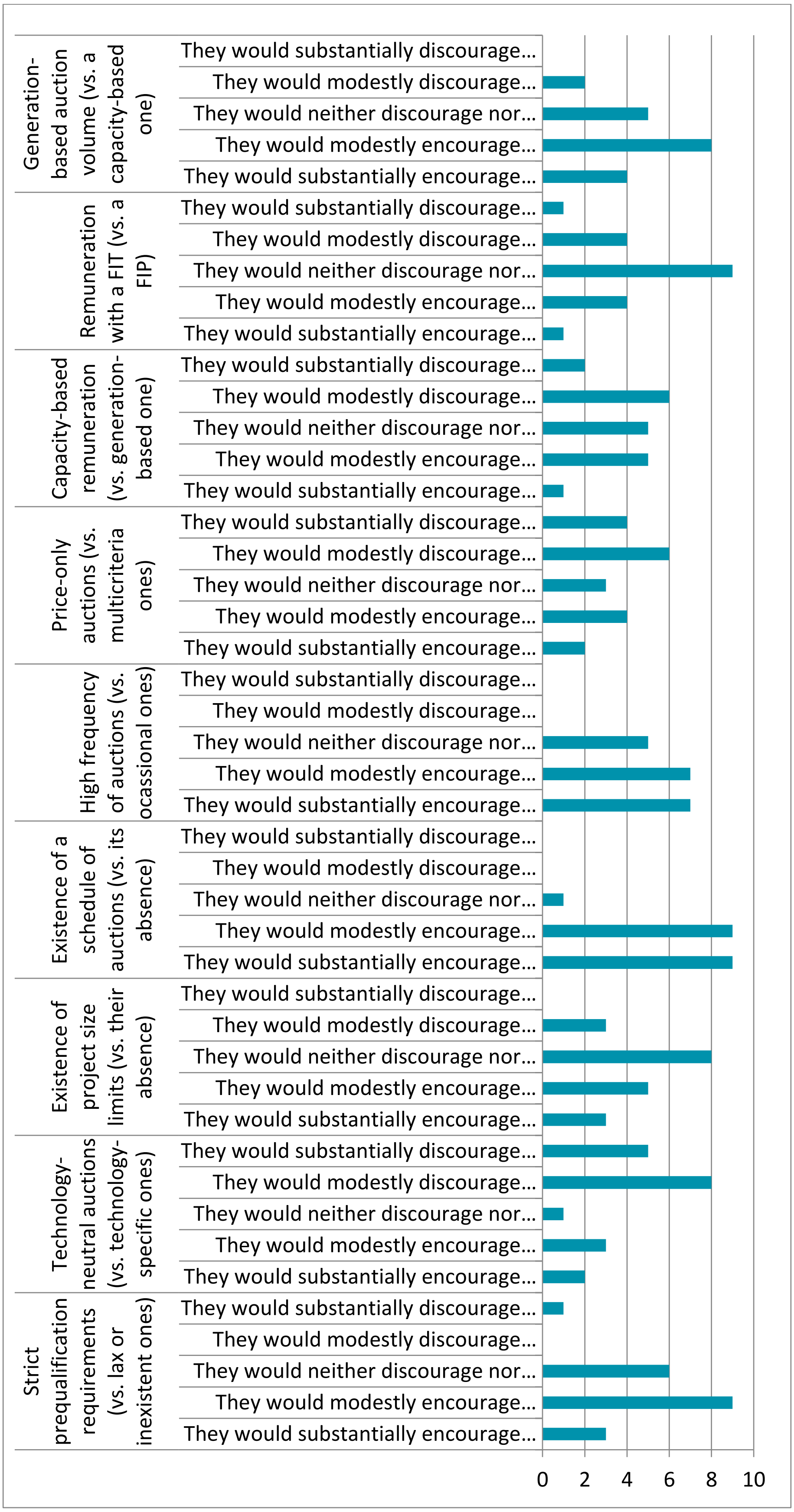
The views are even more balanced in the case of the type of remuneration, with almost the same number of interviewees sharing the view that capacity-based remuneration would encourage technological innovation to a greater extent than generation-based remuneration and those thinking that the opposite would be more likely (and a relatively large number of interviewees stating that they would neither encouraged nor discouraged technological innovation).

The views on the influence of the remuneration form (FIT vs. FIP) on technological innovation were also split, with a relatively large number of interviewees believing that this choice would have neither a positive nor a negative effect on technological innovation.

Finally, an auction volume set in terms of generation would have a more positive effect on technological innovation than a capacity-based volume, according to the views of the interviewees, with a significant number of interviewees believing that the effect would be neutral. This positive influence of generation-based volumes on technological innovation was a priori not expected.

Overall, the most influential design elements on technological innovation seem to be the stringency of prequalification requirements, technological neutrality, a schedule of auctions, highly frequent auctions and generation-based auction volumes.

Figure 13: The perceived impact of different design element options on technological innovation in RETs. Which is the influence of the design element (with respect to the alternative) on technological innovation in RETs in Spain?


Generation-based auction volume (vs. a capacity-based one)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Remuneration with a FIT (vs. a FIP)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Capacity-based remuneration (vs. generation-based one)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Price-only auctions (vs. multicriteria ones)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
High frequency of auctions (vs. ocassional ones)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Existence of a schedule of auctions (vs. its absence)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Existence of project size limits (vs. their absence)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Technology-neutral auctions (vs. technology-specific ones)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
Strict prequalification requirements (vs. lax or inexistent ones)
They would substantially discourage…
They would modestly discourage…
They would neither discourage nor…
They would modestly encourage…
They would substantially encourage…
0
2
4
6
8
10

The interviewees were asked about other design elements which had not been considered in the list above and which may have a relevant impact on RET innovation. There were no further additions to the list, except an important one: Some of them stressed that auctions should include elements which allow taking into account the indirect generation costs (profile, grid and balancing), and not only the direct costs (LCOE). This consideration of the indirect costs would induce technological innovation. For example, a given dispatch profile, hourly discrimination of prices or storage capacity could be required. In particular, some argued that the dispatchability of some technologies (CSP and biomass) should be included in the design of the auction in order to encourage their uptake and induce innovation in those technologies. Design elements which would encourage distributed generation would also be important in this regard, since "distributed generation is the one which can provide more innovation through the development of distributed energy resources".

Interviewees were asked if they had any comment on the list above. In addition to the inclusion of the aforementioned dispatchability issue, one interviewee stated that auctions could include requirements directly related to innovation, "such as prequalifications which require innovation in projects or a higher remuneration for more innovative projects". Another interviewee (referring to biomass) mentioned that the selection criteria should include "the positive impact of those plants on the electricity system and the environment as well as the positive socioeconomic effects".

Block 4. Influence of different factors on technological innovation in RETs.

Finally, the views on the degree of impact of several factors unrelated to auctions on technological innovation in RETs are provided in this block (Figure 14).

There was a widespread agreement that auctions (whether conducted in Spain, in the rest of the EU or in the rest of the world) would have an impact (albeit a rather small one) on technological innovation in RETs in Spain. Large differences on the impact on technological innovation of auctions conducted in different places could not be observed, which is probably related to the globalised nature of the RET sector. However, other factors seem to play a more important role in this context.

Foreign demand of components manufactured in Spain, which is not related to the organization of auctions, was regarded to have a considerable impact on innovation in RETs in Spain. This is in line with the importance attached to "international competition in a globalised sector" also as a driver of technological innovation in RETs.

As mentioned in previous sections, technological innovation is also contingent upon public investments in R&D. The importance of these investments (both in Spain and elsewhere) in RET innovation was also perceived to be very high by the respondents. They also attached a high relevance to public support to collaboration and knowledge networks (e.g. support for technological platforms)[34].

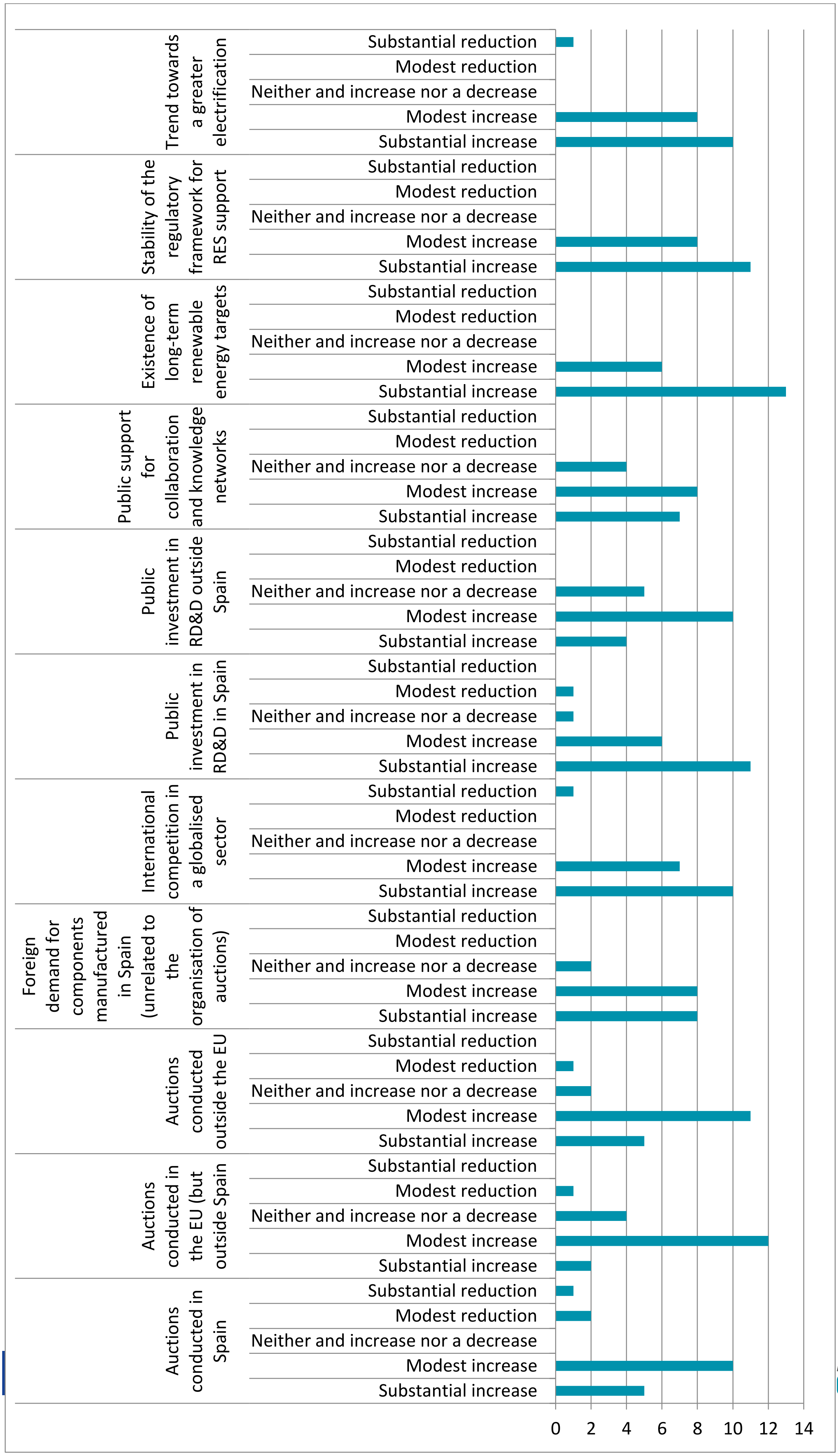
The expected relevance of framework conditions on innovation mentioned in the preceding sections also shows in our results. This is the case for both the existence of long-term renewable energy goals and the stability of the renewable energy regulatory framework. There was a broad consensus among the interviewees that both factors encourage innovation, with a majority of interviewees believing that they do so substantially.

Finally, the trend towards a higher level of electrification (including sector coupling) was believed to substantially encourage technological innovation in RETs also by most respondents.

Overall, the perceptions of the interviewees seem to suggest that auctions play a limited role in driving technological innovation in RETs compared to other factors. The impact of auctions in this regard is rated as modest. This contrasts to the perception on the effects of other factors, which are deemed to have a substantial impact on technological innovation in RETs. The most influential factors driving technological innovation in RETs, according to the views of the interviewees are unrelated to auctions and refer to three sets of factors: the existence of international competition in a globalised sector, public support for R&D and collaboration and framework conditions (long-term goals and stability).

Figure 14: The perceived impact of different factors on technological innovation in RETs. Which is the degree of influence on technological innovation in RETs in Spain and the rest of the world of the following factors?

[34] Interviewees were asked about the degree of influence of all the aforementioned factors on technological innovation in RETs both in Spain and the rest of the world. Only the results for innovation in RETs in Spain are reported here. However, the results for innovation in RETs in the rest of the world did not differ much with respect to those for Spain except for one factor: public RD&D investments. RET innovation in the rest of the world would not be much affected by public RD&D investments in Spain, but they would be influenced by RD&D investments in the rest of the world.


Trend towards a greater electrification
Stability of the regulatory framework for RES support
Existence of long-term renewable energy targets
Public support for collaboration and knowledge networks
Public investment in RD&D outside Spain
Public investment in RD&D in Spain
International competition in a globalised sector
Foreign demand for components manufactured in Spain (unrelated to the organisation of auctions)
Auctions conducted outside the EU
Auctions conducted in the EU (but outside Spain
Auctions conducted in Spain
Substantial reduction
Modest reduction
Neither and increase nor a decrease
Modest increase
Substantial increase
0
2
4
6
8
10
12
14

Interviewees were then asked to mention other factors and how they would influence innovation in RETs in Spain. They mentioned some items, but these were already explicitly or implicitly included in the list above.

Finally, interviewees were asked to provide any comment which they deemed relevant regarding the influence of the aforementioned factors on technological innovation in RETs. One stressed the need to strengthen the collaboration between firms, universities and research centers, which has been "very scarce in our country". Another stressed the importance of European support through the Horizon 2020 or the Innovation Fund. Finally, another one emphasized that innovation occurs predominantly in decentralized electricity generation rather than in large installations.

7.3 In focus: the view of equipment manufacturers

A questionnaire was sent to wind energy manufacturers in Spain to identify their views on the impact of auctions on their R&D investments. Unfortunately, we only received one questionnaire from those firms. Its results were included in the previous figures.

The questions asked in this questionnaire were the same as those included in the questionnaire for experts, and this is why we have included the answers in the figures above. Since equipment manufacturers are the ones carrying out innovation in this sector, their views are deemed very relevant in this context and this is why, despite having only one questionnaire being fulfilled, we focus on those responses in this subsection.

Regarding the answers to the questions which were similar to the expert questionnaire, the wind manufacturer is quite skeptical about the role of auctions in encouraging innovation. Basically, it argues that auctions in general and also those taking place in Spain in 2016 and 2017 led to a reduction in its R&D expenditures. Their general assessment is that "aggressive and price-only auctions discourage innovation since they put so much pressure on the value chain that they do not allow firms to develop new solutions". However, it also believes that they will not encourage innovation compared to the absence of support. It is particularly critical with the idea that the competitive pressure exerted by auctions on project developers will lead to an increase in the R&D expenditures of equipment manufacturers. "Auctions encourage cost reductions (and, thus, delocalization in many cases) and not R&D expenditures". They also strongly agree with the idea that "the R&D expenditures of equipment manufacturers, which depend in part on the existence of profit margins which can be reinvested in R&D by the project developers are negatively affected by auctions, which reduce those margins with respect to ASR". However, it does not agree with the aforementioned negative effect of auctions on market creation. It also does not agree that the absence of support will lead to greater R&D expenditures through a greater competitive pressure on project developers.

Regarding the design elements, only one of them (stringent prequalification requirements) would lead to a substantial increase in the R&D expenditures of the firm, whereas technological neutral and price-only auctions and would lead to a strong reduction in those expenditures. A schedule of auctions would lead to a modest increase in the R&D expenditures.

Regarding the most relevant factors that influence the R&D expenditures of the firm, auctions are regarded to have a small (negative) influence on those expenditures compared to other factors: foreign demand for components, long-term renewable energy targets and a stable regulatory framework (strong positive influence) and international competition (strong negative influence).

Additional questions were also made regarding three sets of issues: 1) the influence of auctions on R&D investments per innovation category; 2) the impact on exploration or exploitation activities; 3) the economic factors faced by project developers which have induced equipment manufacturers to invest in R&D.

<u>1) The influence of auctions on R&D investments per innovation category.</u>

We were interested to know the opinion of equipment manufacturers on the current and future impacts of auctions on R&D expenditures of their firms dedicated to the different categories of wind energy innovation (Table 5)[35]. Therefore, the firm was asked the following two questions: 1) "Compared to administratively-set remuneration (in the form of a FIT or a FIP), without a cap on the capacity which is eligible for support, how do you think the remuneration being set in auctions conducted in Spain influences the R&D expenditures of your firm?"; 2) "Compared to the absence of public support to wind energy in which the project developer receives the wholesale market price of electricity, how do you think the remuneration being set in an auction will influence the R&D expenditures of your firm in the future (the period to 2030)?". The results, suggest that auctions have and will have a strong reduction effect on the R&D investments in several categories of innovation ("Wind, improvement of knowledge on the behaviour of wind and flows near the wind farms, reduction of uncertainties", "Blades in order to reduce the LCOE", "Mechanical transmission, oriented to the reductions of costs and loads, given the greater size", "Control", "Converters, which respond to the reduction of loads and the new grid codes", "Towers and foundations, modularity, reduction of weight and ease of assembly", "Maintenance, oriented to the control of costs, guarantee of availability and supply of components" and "Repowering") and a modest reduction in the category "Optimisation of industrial processes, logistics and BOP". An increase can only be observed for the category "Lifetime extension, beyond the useful lifetime envisaged in its design".

[35] These categories were taken from the Spanish Wind Energy Technology Platform (REOLTEC, 2020).

Table 5: Innovation categories in wind energy.

INNOVATION CATEGORIES
1. Wind, improvement of knowledge on the behaviour of wind and flows near the wind farms, reduction of uncertainties
2. Blades (for example, a greater diameter), in order to reduce the LCOE.
3. Mechanical transmission, oriented to the reductions of costs and loads, given the greater size.
4. Digitalization
5. Control
6. Converters, which respond to the reduction of loads and the new grid codes.
7. Towers and foundations, modularity, reduction of weight and ease of assembly.
8.Maintenance, oriented to the control of costs, guarantee of availability and supply of components.
9. Lifetime extension, beyond the useful lifetime envisaged in its design.
10. Optimisation of industrial processes, logistics and BOP
11. Repowering
12. Grid integration, compliance with grid codes and possible solutions which may entail an improvement of the technical operation of the system
13. Environment (including noise reduction), mitigation of the effects on the environment with respect to other technologies.

Note: REOLTEC (2020).

2) The impact on different types of R&D activities (exploration or exploitation).

On the other hand, following Hoppmann et al. (2013), we were interested to know the impact of auctions on the type of R&D activities carried out by equipment manufacturers, focusing on exploitation vs. exploration. Exploration is defined as all innovation activities pertaining to the generation of new technological options for the firm's product portfolio, whereas exploitation is defined as innovation activities related to the execution of a firm's existing product portfolio (Hoppmann et al., 2013). Therefore, the firm was asked the following question: "As a consequence of auctions, and compared to administratively-set remuneration, the R&D expenditures of your firm have mainly focused on exploration or exploitation activities?" The firm was given five possible answers (exclusively exploration, mostly exploration, both exploration and exploitation, mostly exploitation and only exploitation). It answered that it mostly focused on exploitation. This suggests that auctions can be expected to influence incremental rather than radical innovation, although this is certainly a preliminary conclusion which has to be confirmed with more research in the future.

3) The economic factors faced by project developers which have induced equipment manufacturers to invest in R&D.

Finally we were interested to know the economic factors faced by project developers which have induced equipment manufacturers to invest in R&D. Therefore, "the firm was asked the following question: which of the following economic factors which are faced by project developers induce your firm to change the R&D expenditures of your firm?" It was given the following possible answers: "1) Need of project developers to increase their annual energy production (AEP), 2) Need of project developers to reduce their CAPEX, 3) Need of project developers to reduce their OPEX; 4) Need of project developers to improve the availability of the plant in the hours with a higher electricity price, 5) Need of project developers to integrate their production into the grid". The firm answered that all the factors were important, with the need of project developers to reduce their CAPEX, OPEX and grid integration being rated as "very important".

8 Conclusions

Technological innovation will be a crucial component of the energy transition. It will allow advancing in such transition and do so at the lowest cost. On the other hand, the use of an instrument to support the deployment of RETs (auctions) has been widespread in the world and, particularly, in the EU. Although the main aim of auctions is not to support innovation, its innovation effects cannot be disregarded, as the literature on innovation shows that different stages of the technological change process are connected and, thus, instruments supporting diffusion of the technologies may also influence previous stages of such process. In the case of RETs, there is some analysis of this feedback from deployment to innovation for other instruments, but the literature on the innovation effects of auctions is extremely tiny. This report has covered this gap in knowledge. Its aim has been to provide an analytical framework on the mechanisms linking diffusion-driven technological innovation and auctions and their design elements and to carry out a preliminary empirical analysis which allows us to identify the perception of key stakeholders on the topic and, based on theory and those perceptions, to put forward some research proposals to be investigated in future research. This report also highlights the methodological challenges that will be faced by those aiming to undertake future in-depth empirical analyses on this topic.

The exploratory approach followed in this report is based on a literature review and a exchange of views on the main aspects (variables, relationships between variables and causal links) with different relevant stakeholders knowledgeable of both innovation processes in RETs and auctions (and their design elements). The literature review and the preliminary analysis suggest a small effect of auctions on innovation. In addition, the preliminary analysis indicates that different design elements of auctions may have a different degree of impact on innovation. Therefore, the following research proposals, to be further investigated in the future have been put forward:

- Auctions influence innovation through their impact on manufacturers and technology developers. These innovation effects of auctions should be compared to other alternatives: administratively-set remuneration (in the past) and a lack of support (for the future).
- Different design elements in auctions have different impacts on the R&D expenditures or the innovation activities of equipment manufacturers. Some design elements discourage them, others encourage them and yet others do not have any impact.
- The design of the auction (different design elements) may affect innovation through several main channels: impact on private R&D through a greater profit margin and the expectation that there will be a market for the technology (i.e., where manufacturers and technology developers can sell their technology), impact on technology diffusion and impact on the competitive pressures faced by manufacturers and technology developers to reduce costs or increase revenues.
- The negative effects on innovation from lower profit margins in auctions and lower levels of market creation for RES compared to administratively-set FITs may offset the positive effects on innovation from a greater competition in auctions. Whether

this is so for all RETs and auctions depends on the technologies, the design of the auction and the details of the ASR to which the comparison is made.

- Auctions will be one of the factors influencing innovation in RETs, but probably not the main one. Many other policy (e.g., technology-push policies) and non-policy factors (e.g., the pressure to reduce costs as a result of international competition in a globalised sector) influence innovation.

A survey to was distributed to 19 experts on both auctions and innovation in Spain (including an equipment manufacturer) in order to identify their views on this topic, and also if some elements of our analytical framework had been missing.

The questionnaires received broadly confirm the variables and the relationships put forward in the analytical framework. However, the relatively short empirical base and its focus on a single country does not allow us to generalize our findings and further research will be required. This should be done by asking those which innovate in this sector (equipment manufacturers) with a survey in different countries and for different technologies, since the impact of auctions and their design elements may differ depending on the institutional context and the features of the different RETs. Internal variables of the firms should also be considered in this analysis (such as the existence of a given level of financial and human resources within the company, i.e., their resources, dynamic capabilities and competences). Different analytical approaches can be used, including the technological innovation systems approach, which may provide relevant insights in this context. The combination of approaches would shed more light on the interactions and interrelationships between the innovation mechanisms identified in this report.

In addition to qualitative analyses with a focus on R&D expenditures, quantitative analyses with an output measure of innovation (patents) should also be performed in the future. Furthermore, the focus should be broadened to include not only technological, but also other types of innovation (e.g., organizational).

Finally, future analyses should explore the combination of framework conditions, (supply-push and demand-pull) instruments and design elements of those instruments which are more likely to steer innovation in RETs.

9 References

AEE. (2018). *Anuario eólico 2018*.

AEE. (2019). *Anuario eólico 2019*.

AEE. (2020). *Anuario eólico 2020*.

Anadon, L. D., Chan, G., Harley, A. G., Matus, K., Moon, S., Murthy, S. L., & Clark, W. C. (2016, Aug 30). Making technological innovation work for sustainable development. *Proc Natl Acad Sci U S A, 113*(35), 9682-9690. https://doi.org/10.1073/pnas.1525004113

Anatolitis, V., & Welisch, M. (2017). Putting renewable energy auctions into action – An agent-based model of onshore wind power auctions in Germany. *Energy Policy, 110*, 394-402. https://doi.org/10.1016/j.enpol.2017.08.024

Ang, G., Röttgers, D., & Burli, P. (2017). *The empirics of enabling investment and innovation in renewable energy* (OECD Environment Working Papers, Issue.

Arrow, K. J. (1962). The economic implications of learning by doing. *The review of economic studies, 29*, 155-173.

Bergek, A., & Berggren, C. (2014). The impact of environmental policy instruments on innovation: A review of energy and automotive industry studies. *Ecological Economics, 106*, 112-123. https://doi.org/10.1016/j.ecolecon.2014.07.016

Bergek, A., & Jacobsson, S. (2010). Are tradable green certificates a cost-efficient policy driving technical change or a rent-generating machine? Lessons from Sweden 2003–2008. *Energy Policy, 38*(3), 1255-1271.

Functions in Innovation Systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers, Innovations for a Low Carbon Economy: Economic, Institutional and Management Approaches (Edward Elgar 2008).

Böhringer, C., Cuntz, A., Harhoff, D., & Asane-Otoo, E. (2017). The impact of the German feed-in tariff scheme on innovation: Evidence based on patent filings in renewable energy technologies. *Energy Economics, 67*, 545-553.

Bointner, R. (2014). Innovation in the energy sector: Lessons learnt from R&D expenditures and patents in selected IEA countries. *Energy Policy, 73*, 733-747.

Bolkesjø, T. F., Eltvig, P. T., & Nygaard, E. (2014). An econometric analysis of support scheme effects on renewable energy investments in Europe. *Energy Procedia, 58*, 2-8.

Bourgeois, G., Mathy, S., & Menanteau, P. (2017). L'effet des politiques climatiques sur les énergies renouvelables: une revue des études économétriques. *Innovations*(3), 15-39.

Braun, F. G., Schmidt-Ehmcke, J., & Zloczysti, P. (2010). *Innovative Activity in Wind and Solar Technology: Empirical Evidence on Knowledge Spillovers Using Patent Data*.

Bush, V. (1945). Science: The endless frontier (Reprint). *North Stratford, NH: Ayer.*

Butler, L., & Neuhoff, K. (2008). Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *Renewable Energy, 33*(8), 1854-1867.

https://doi.org/10.1016/j.renene.2007.10.008

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of Evolutionary Economics, 1*, 93-118. https://doi.org/10.1007/BF01224915

Coenen, L., & López-Díaz, F. (2010). Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. *Journal of Cleaner Production, 18*, 1149-1160.

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and learning: the two faces of R & D. *The economic journal, 99*(397), 569-596.

del Rio, P. (2004). Public policy and clean technology promotion. The synergy between environmental economics and evolutionary economics of technological change. *International Journal of Sustainable Development, 7*(2), 200-216.

del Río, P. (2009). The empirical analysis of the determinants for environmental technological change: A research agenda. *Ecological Economics, 68*, 861-878. https://doi.org/10.1016/j.ecolecon.2008.07.004

Del Río, P. (2011). Climate Change Policies and new Technologies. In E. Cerdá & X. Labandeira (Eds.), *Climate change policies: global challenges and future prospects* (pp. 49-68). Edward Elgar.

del Río, P. (2012). The dynamic efficiency of feed-in tariffs: The impact of different design elements. *Energy Policy, 41*, 139-151. https://doi.org/10.1016/j.enpol.2011.08.029

del Río, P. (2017). Designing auctions for renewable electricity support. Best practices from around the world. *Energy for Sustainable Development, 41*, 1-13. https://doi.org/10.1016/j.esd.2017.05.006

del Río, P., & Bleda, M. (2012). Comparing the innovation effects of support schemes for renewable electricity technologies: A function of innovation approach. *Energy Policy, 50*, 272-282. https://doi.org/10.1016/j.enpol.2012.07.014

del Río, P., & Linares, P. (2014). Back to the future? Rethinking auctions for renewable electricity support. *Renewable and Sustainable Energy Reviews, 35*, 42-56. https://doi.org/10.1016/j.rser.2014.03.039

del Río, P., & Peñasco, C. (2014). Inventory of RES-E policy challenges towards 2030. Report for the EU-Funded project Towards 2030.

del Río, P., Ragwitz, M., Steinhilber, S., Resch, G., Busch, S., Klessmann, C., de Lovinfosse, I., Nyszen, J., Fouquet, D., & Johnston, A. (2012). *Key policy approaches for a harmonisation of RES(-E) support in Europe - Main options and design elements. A report compiled within the European research project beyond2020 (work package 2). Supported by Intelligent Energy - Europe, ALTENER (Grant Agreement no. IEE/10/437/SI2.589880)* www.res-policy-beyond2020.eu.

del Río, P., Wigan, F., & Steinhilber, S. (2015). *Assessment criteria for RES-E Auctions* (Report of the EU-funded AURES project, Issue. http://auresproject.eu/

Dosi, G., & Orsenigo, L. (1988). Coordination and transformation: an overview of structures, behaviours and change in evolutionary environments. *Technical change and economic theory*, 13-37.

Dudovskiy, J. (2020). Inductive Approach (Inductive Reasoning). *Business Research Methodology*. https://research-methodology.net/research-methodology/research-approach/inductive-approach-2/

EEA. (2014). *Energy support measures and their impact on innovation in the renewable energy sector in Europe* (EEA Technical report No 21/2014, Issue.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of management review, 14*(4), 532-550.

ETH. (2014). *Expert statement on the impact of the German Renewable Energies Act (EEG) on innovation and climate protection: In response to the annual report of the "Expert Commission Research and Innovation" to the German Chancellor*.

EU. (2019). *What is the European Green Deal?* https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6714

Finon, D., & Menanteau, P. (2003). The static and dynamic efficiency of instruments of promotion of renewables. *Energy Studies Review, 12*(1), 53-82.

Gandenberger, C., & Strauch, M. (2018). Wind energy technology as opportunity for catching-up? A comparison of the TIS in Brazil and China. *Innovation and Development, 8*(2), 287-308.

Groba, F., & Breitschopf, B. (2013). Impact of renewable energy policy and use on innovation: A literature review.

Hansen, U. E., Nygaard, I., Morris, M., & Robbins, G. (2020). The effects of local content requirements in auction schemes for renewable energy in developing countries: A literature review. *Renewable and Sustainable Energy Reviews, 127*. https://doi.org/10.1016/j.rser.2020.109843

Haufe, M.-C., & Ehrhart, K.-M. (2018). Auctions for renewable energy support – Suitability, design, and first lessons learned. *Energy Policy, 121*, 217-224. https://doi.org/10.1016/j.enpol.2018.06.027

He, Z.-X., Xu, S.-C., Li, Q.-B., & Zhao, B. (2018). Factors That Influence Renewable Energy Technological Innovation in China: A Dynamic Panel Approach. *Sustainability, 10*(1), 124. https://www.mdpi.com/2071-1050/10/1/124

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change, 74*, 413-432. https://doi.org/10.1016/j.techfore.2006.03.002

Hille, E., Althammer, W., & Diederich, H. (2020). Environmental regulation and innovation in renewable energy technologies: Does the policy instrument matter? *Technological Forecasting and Social Change, 153*, 119921.

Hoppmann, J. (2015). The role of deployment policies in fostering innovation for clean energy technologies: Insights from the solar photovoltaic industry. *Business & Society, 54*(4), 540-558.

Hoppmann, J., Peters, M., Schneider, M., & Hoffmann, V. H. (2013). The two faces of market support - How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. *Research Policy, 42*, 989-1003. https://doi.org/10.1016/j.respol.2013.01.002

Huber, C., Faber, T., Haas, R., Resch, G., Green, J., Ölz, S., White, S., Cleijne, H., Ruijgrok, W., & Morthorst, P. E. (2005). Green-X. Deriving optimal promotion strategies for increasing the share of RES-E in a dynamic European electricity market. Final report of the project Green-X-a research project within the fifth framework programme of the European Commission, supportedby DG Research.

Huenteler, J., Schmidt, T. S., Ossenbrink, J., & Hoffmann, V. H. (2016). Technology life-cycles in the energy sector—Technological characteristics and the role of deployment for innovation. *Technological*

Forecasting and Social Change, 104, 102-121.

IEA. (2008). Energy Technology Perspectives.

IEA. (2011). *Deploying Renewables*.

IEA. (2020). *Clean energy innovation*. https://www.iea.org/reports/clean-energy-innovation

IRENA. (2015). *Renewable Energy Auctions: A Guide to Design*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/Jun/IRENA_Renewable_Energy_Auctions_A_Guide_to_Design_2015.pdf

IRENA. (2017). Renewable Energy Auctions : Analysing 2016. *Renewable Energy Auctions : Analysing 2016, 1*, 28.

IRENA. (2019). *Renewable energy auctions: Status and trends beyond price*.

Jacobs, D., Grashof, K., del Río, P., & Fouquet, D. (2020). *The Case for a Wider Energy Policy Mix in Line with the Objectives of the Paris Agreement. Shortcomings of Renewable Energy Auctions Based on World-wide Empirical Observations*.

Jacobsson, S. (2008). The emergence and troubled growth of a 'biopower' innovation system in Sweden. *Energy Policy, 36*, 1491-1508. https://doi.org/10.1016/j.enpol.2007.12.013

Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: The evolution of technological systems in renewable energy technology. *Industrial and Corporate Change, 13*, 815-849. https://doi.org/10.1093/icc/dth032

Jacobsson, S., & Karltorp, K. (2013). Mechanisms blocking the dynamics of the European offshore wind energy innovation system - Challenges for policy intervention. *Energy Policy, 63*, 1182-1195. https://doi.org/10.1016/j.enpol.2013.08.077

Jaffe, A., Newell, R., & Stavins, R. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics, 54*, 164-174. https://doi.org/10.1016/j.ecolecon.2004.12.027

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2002). *Environmental policy and technological change* (09246460). (Environmental and Resource Economics, Issue.

Jenner, S., Groba, F., & Indvik, J. (2013). Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. *Energy Policy, 52*, 385-401. https://doi.org/10.1016/j.enpol.2012.09.046

Johnstone, N., Hascic, I., & Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics, 45*, 133-155. https://doi.org/10.1007/s10640-009-9309-1

Junginger, M., Faaij, A., & Turkenburg, W. C. (2005). Global experience curves for wind farms. *Energy Policy, 33*, 133-150.

Kahouli-Brahmi, S. (2008). Technological learning in energy-environment-economy modelling: A survey. *Energy Policy, 36*, 138-162. https://doi.org/10.1016/j.enpol.2007.09.001

Kemp, R., & Pontoglio, S. (2011). The innovation effects of environmental policy instruments - A typical case of the blind men and the elephant? *Ecological Economics, 72*, 28-36. https://doi.org/10.1016/j.ecolecon.2011.09.014

Kiefer, C. P., & del Río, P. (2020). Analysing the barriers and drivers to concentrating solar power in the European Union. Policy implications. *Journal of Cleaner Production, 251*. https://doi.org/10.1016/j.jclepro.2019.119400

Kiefer, C. P., del Río, P., & Carrillo-Hermosilla, J. (2019). Drivers and barriers of eco-innovation types for sustainable transitions: A quantitative perspective. *Business Strategy and the Environment*, 155-172. https://doi.org/10.1002/bse.2246

Kilinc-Ata, N. (2016). The evaluation of renewable energy policies across EU countries and US states: An econometric approach. *Energy for Sustainable Development, 31*, 83-90.

Kim, K., Heo, E., & Kim, Y. (2017). Dynamic Policy Impacts on a Technological-Change System of Renewable Energy: An Empirical Analysis. *Environmental and Resource Economics, 66*, 205-236. https://doi.org/10.1007/s10640-015-9946-5

Kline, S. J., & Rosenberg, N. (1986). An Overview of Innovation. In R. Laudan & N. Rosenberg (Eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth* (pp. 275-305). National Academies Press.

Kreiss, J., Ehrhart, K.-M., & Haufe, M.-C. (2017). Appropriate design of auctions for renewable energy support – Prequalifications and penalties. *Energy Policy, 101*, 512-520. https://doi.org/10.1016/j.enpol.2016.11.007

Lauber, V. (2004). REFIT and RPS: options for a harmonised Community framework. *Energy Policy, 32*(12), 1405-1414.

Liang, J., & Fiorino, D. J. (2013). The Implications of Policy Stability for Renewable Energy Innovation in the U nited S tates, 1974–2009. *Policy Studies Journal, 41*(1), 97-118.

Lundvall, B. A. (1988). Innovation as an interactive process: from user-producer interaction to the national system of innovation. In G. Dosi (Ed.), *Technical change and economic theory*. Pinter London.

Malerba, F. (2004). Sectoral systems of innovation: basic concepts. In F. Malerba (Ed.), *Sectoral systems of innovation: concepts, issues and analyses of six major sectors*. Cambridge University Press.

Matsuo, T., & Schmidt, T. S. (2019). Managing tradeoffs in green industrial policies: The role of renewable energy policy design. *World Development, 122*, 11-26. https://doi.org/10.1016/j.worlddev.2019.05.005

Matthäus, D. (2020). Designing effective auctions for renewable energy support. *Energy Policy, 142*. https://doi.org/10.1016/j.enpol.2020.111462

Menanteau, P., Finon, D., & Lamy, M.-L. (2002). Feed-in tariffs versus quotas: how to promote renewable s and stimulate technical progress for cost decrease?

Menanteau, P., Finon, D., & Lamy, M.-L. (2003). Prices versus quantities: choosing policies for promoting the development of renewable energy. *Energy Policy, 31*(8), 799-812.

Mitchell, C. (2000). The England and Wales non-fossil fuel obligations: History and lessons. *Annual Review of Energy and the Environment, 25*, 285-312. https://doi.org/https://doi.org/10.1146/annurev.energy.25.1.285

Mora, D., Kitzing, L., Rosenlund, E., Steinhilber, S., del Río, P., Wigand, F., Klessmann, C., Tiedemann, S., Amazo, A., Welisch, M., Kreiß, J., Fitch Roy, O., & Woodman, B. (2017). *Auctions for renewable* *energy support - Taming the beast of competitive bidding* (Final report of the EU-funded AURES project, Issue.

Negro, S. O., Hekkert, M. P., & Smits, R. E. (2007). Explaining the failure of the Dutch innovation system for biomass digestion-A functional analysis. *Energy Policy, 35*, 925-938. https://doi.org/10.1016/j.enpol.2006.01.027

Negro, S. O., Hekkert, M. P., & Smits, R. E. H. M. (2008). Stimulating renewable energy technologies by innovation policy. *Science and Public Policy, 35*, 403-416. https://doi.org/10.3152/030234208X323334

Nemet, G. F. (2009). Demand-pull, technology-push, and government-led incentives for non-incremental technical change. *Research Policy, 38*, 700-709. https://doi.org/10.1016/j.respol.2009.01.004

Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management, 67*(3), 396-411.

Nicolli, F., & Vona, F. (2016). Heterogeneous policies, heterogeneous technologies: The case of renewable energy. *Energy Economics, 56*, 190-204.

OECD. (2018). *Oslo Manual 2018 Guidelines for collecting, reporting and using data on innovation*. http://oe.cd/oslomanua

Palage, K., Lundmark, R., & Söderholm, P. (2019). The innovation effects of renewable energy policies and their interaction: the case of solar photovoltaics. *Environmental Economics and Policy Studies, 21*(2), 217-254. https://doi.org/10.1007/s10018-018-0228-7

Palm, A. (2015). An emerging innovation system for deployment of building-sited solar photovoltaics in Sweden. *Environmental Innovation and Societal Transitions, 15*, 140-157.

Peters, M., Schneider, M., Griesshaber, T., & Hoffmann, V. H. (2012). The impact of technology-push and demand-pull policies on technical change – Does the locus of policies matter? *Research Policy, 41*(8), 1296-1308. https://doi.org/10.1016/j.respol.2012.02.004

Pitelis, A. T., Vasilakos, N., Chalvatzis, K., & Pitelis, C. N. (2019). Can industrial policy foster innovation in renewable energy technologies in the OECD and in EU regions? *Cambridge Journal of Regions, Economy and Society, 12*(2), 271-292.

Popp, D. (2010). *Innovation and climate policy*.

Popp, D. (2019). *Environmental policy and innovation: a decade of research* (CESifo Working Paper, Issue. http://hdl.handle.net/10419/198904

PROTERMOSOLAR. (2019). *PNIEC y Estabilidad Retributiva*.

Reichardt, K., Negro, S. O., Rogge, K. S., & Hekkert, M. P. (2016). Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany. *Technological Forecasting and Social Change, 106*, 11-21. https://doi.org/10.1016/j.techfore.2016.01.029

REOLTEC. (2020). *Innovación en el sector eólico. Período 2018-2019.* . https://reoltec.net/wp-content/uploads/2020/07/REOLTEC_-INNOVACION-EN-EL-SECTOR-E%C3%93LICO_2018_2019.pdf

Schleich, J., Walz, R., & Ragwitz, M. (2017). Effects of policies on patenting in wind-power technologies.

Energy Policy, 108, 684-695. https://doi.org/10.1016/j.enpol.2017.06.043

Schmookler, J. (1962). Changes in Industry and in the State of Knowledge as Determinants of Industrial Invention. In N. B. o. E. Research; (Ed.), *The Rate and Direction of Inventive Activity* (pp. 195-232). Princeton University Press.

Söderholm, P., & Klaassen, G. (2007). Wind power in Europe: a simultaneous innovation–diffusion model. *Environmental and resource economics, 36*, 163-190.

Suurs, R. A. A., & Hekkert, M. P. (2009). Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands. *Energy, 34*, 669-679. https://doi.org/10.1016/j.energy.2008.09.002

Taylor, M. R., Rubin, E. S., & Hounshell, D. A. (2005). Control of SO2 emissions from power plants: A case of induced technological innovation in the US. *Technological Forecasting and Social Change, 72*(6), 697-718.

UNEF. (2020a). *El sector fotovoltaico hacia una nueva era. Informe anual UNEF*.

UNEF. (2020b). *Propuestas para una estrategia industrial fotovoltaica*.

UNEF. (2020c). *UNEF aplaude la propuesta de la Orden Ministerial de Subastas a cinco años*.

UNEP. (2015). *Global Trends in Renewable Energy Investment 2015. United Nations Environment Programme*. http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2015

van der Loos, H. A., Negro, S. O., & Hekkert, M. P. (2020). International markets and technological innovation systems: The case of offshore wind. *Environmental Innovation and Societal Transitions, 34*, 121-138.

Watanabe, C., Wakabayashi, K., & Miyazawa, T. (2000). Industrial dynamism and the creation of a virtuous cycle between R&D, market growth and price reduction. The case of Photovoltaic Power Generation (PV) development in Japan. *Technovation, 20*, 299-312.

Wigan, F., Förster, S., Amazo, A., & S., T. (2016). *Auctions for renewable energy support: lessons learnt from international experiences* (Report of the EU-funded AURES project, Issue.

ANNEX 1

Table A1. Contributions in the literature on the innovation effects of deployment policies.

	Geographical scope	Period	Technologies	Method
ECONOMETRIC MODELLING				
1. Emodi et al 2015	12 OECD countries	1997-2011	PV and wind	Panel data econometric model (fixed effects model).
2. Palage et al 2019	13 OECD contries	1978-2008	PV	Econometric modeling. Reduced form of negative binomial (NB) regression models. Innovation dependent variable: patents.
3. Kim et al 2017	16 OECD countries (PV) 13 OECD countries (wind)	1992-2007 (PV) 1991-2006 (wind)	PV and wind	Simultanoeus econometric model with panel data (three-stage least squares). Innovation dependent variable: patents.
4. Johnstone and Hascic 2010	25 OECD countries	1978-2003	Wind, solar, ocean, geothermal, biomass and waste-to-energy	Econometric analysis with panel data (negative binomial model). Dependent variable: patents.
5. He et al (2018)	China (29 provinces)	2006-2013	Wind, solar, geothermal, ocean, biomass	A dynamic panel approach with patent data.
6. Watanabe 2000	Japan	1976-1995	Solar PV	Econometric analysis.
7. Peters et al (2012)	15 OECD countries	1978-2005	PV	Panel data econometric model with patent data.
8. Pitelis (2019)	21 OECD countries	1990-2014	All RETs	Econometric modeling (negative binomial regression model) using data on policy intervention, innovation activity (patent counts per type of renewable technology) and performance.
9. Soderholm and Klaassen (2007)	Denmark, Germany, Spain and the United Kingdom	1986-2000	Wind	A simultaneous model of wind power innovation and diffusion, which combines a rational choice model of technological diffusion and a learning curve model of dynamic cost reductions. These models are estimated using pooled annual time series data.
10. Hille et al 2019	194 countries and territories	1990-2016	All RETs	Econometric modeling with patent data.
11. Walz et al 2008	Ten OECD countries	1991-2004	Wind	Econometric modeling (Feasible Generalized Least Squares).
12. Schleich et al 2017	12 OECD countries	1991-2011	Wind	Patent counts were used as an indicator for innovation. Count data econometric model were used for the estimations.

13.Ang et al 2017	46 OECD and G20 countries	2000-2012	All RETs	A negative binomial fixed effects regression on patent counts.
14.Böhringer et al 2017	Germany	1990-2014	All RETs	Fixed effect negative binomial and Poisson panel data regression models with patent data.
15. Nicoli and Vona 2016	19 EU countries	1980-2007	All RETs	Negative binomial model with patent data.
16. Gao and Rai (2019)	China	2005-2014	Distributed PV	Fixed effects and random effects regression models using a database of PV balance-of-system (BOS) patents in the distributed PV market.
17. Dechezleprêtre and Glachant (2014).	28 OECD countries	1991-2008	Wind	Poisson model and negative binomial estimation (fixed effect estimator) with patent data.
THEORETICAL, QUALITATIVE ANALYSIS, CASE STUDIES, OTHER				
18. Finon and Menanteau 2004	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	Theoretical analysis. Graphic analysis and the results are checked with empirical observations.
19. Groba and Breitschof 2013	Focus on (some) European countries and U.S.	Studies reviewed until 2013	All	Literature review.
20. Del Río 2012	Several countries from around the world with FITs, but focus on Spain	1990-2011	All RETs	Theoretical analysis, literature review, qualitative.
21. Del Río and Bleda 2012	Several countries from around the world	1990-2011	All RETs	Theoretical analysis, literature review, qualitative.
22. Hoppmann et al 2013	European, US, Chinese and Japanese firms	2012	PV	Comparative case studies with a global sample of 9 firms producing PV modules, complemented by in-depth interviews with 16 leading PV industry experts.
23. Huenteler et al (2016)	World	1963-2009	PV, wind	It provides a novel, patent-based methodology to study how the focus of innovation changes over the course of the technology life-cycle. The authors analyze patent-citation networks in PV and wind power.
24. Matsuo and Smichdt (2019)	Mexico and South Africa	2017-2018	PV, wind	Comparative case study. Data on the involvement of local and foreign actors in Mexican and South African RE projects, policy documents, and interviews with

				public and private stakeholders in the two countries.
25. Nemet (2009)	California	1980-2005	Wind	Case study.
26. EEA 2014	Czech Republic, the Netherlands, Spain and Switzerland	2006-2010	All RETs	Descriptive statistics based on the number of patent applications to the European Patent Office (EPO) for various RETs.
27.Samant et al (2020)	Turkey, India, Brazil, and China	2000-2015	All RETs	A comparative case study of four emerging economies with information on policy initiatives and renewable energy patents.
28.Butler and Neuhoff 2008	Germany, U.K.	2003 (survey)	Wind	Case study, with a survey to project developers and manufacturers.

Source: Own elaboration.

ANNEX 2

Table A2. Studies using the TIS approach to analyse the drivers and barriers to RETs.

Paper	Scope (technology, period, country, stage)
1. Darmani et al (2014)	W, S, B, WV Until 2012 7 EU countries.
2. Eleftheriadis and Anagnostopoulou (2015)	Wind and PV 2013 Greece
3.Reichardt et al (2017)	W (off-shore) Germany
4. Wieczorek et al 2013	Wind (off-shore) 2011 4 EU countries
5. Huang et al (2016)	PV (manufacturing industry, not electricity generation) 1985-2012 China
6.Wieczorek et al 2015	W (off-shore) 2010-2011 North-Western Europe
7. Jacobsson and Karltorp 2013	W (off-shore) 2011 5 EU countries
8. Karltorp et al 2017	Wind 2012 China
9. Gosens and Lu 2013	W 2012 China
10.Kebede and Mitsufuji 2017	PV 2016 Ethiopia
11.Bento and Fontes 2015	Portugal Wind 1988-2013
12.Tigabu et al 2015a	Biogas (biodigesters) 1957-2010

	Kenya and Rwanda
13.Tigabu et al 2015b	Biogas 2000-2011 Rwanda
14. Anderson et al 2017	Marine energy 1975-2014 Sweden
15. Al-Saleh 2011	Saudi Arabia All RES 2008-2009
16. Malonzo and Posadas 2016	Phillipines Undefined period PV, W, H, B.
17. Tigabu et al 2017	Biogas Rwanda, Kenya 1950-2011
18. Chikezie and Luke 2017	Sierra Leone Renewable energy technologies
19. Vidican et al 2010	Abu Dhabi 2010 Solar (PV + CSP)
20.Walz et al 2016	China, Germany Wind 2014
21.Jacobsson and Lauber 2006	Germany Wind, PV 1974-2003
22. Jacobsson 2008	Sweden Biopower 1990-2007
23.Zou et al 2017	China PV (manufacturing) 2014
24.Vasseur et al 2013	PV The Netherlands and Japan 2000-2011
25. Mignon and Bergek 2016	RETs (PV, W, B, H)

	Sweden, France
26. Edsand 2016	Wind Colombia
27.Quitzow 2015	PV China and India 1999-2011
28.Dewald and Truffer 2012	PV, Germany 1990s-2011
29.Bergek et al 2008	Renewable energy technologies Sweden 2000s
30.Hansen and Coenen 2017	Biorefineries Sweden/Finland
31.Hanson 2017	PV Norway 1980-2014
32. Dewald and Truffer 2011	PV Germany 1990s – 2010
33. Simensen 2012	RETs Norway 2007-2012
34.Dewald and Fromhold-Eisebith 2015	PV Germany 1983-2012
35 Negro et al 2007	Bioma ss digestion 1974-2004 The Netherlands
36 Karltorp 2016	Biomass gasification +off-shore wind Europe 2012
37 Markard et al 2009	Biomass Switzerland 2006 (but focus on future variants)
38 Negro et al 2008	Biomass gasification The Netherlands 1980-2004

	Development
39 Reichardt et al 2016	Wind off-shore Germany 1993-2013
40 Gosens and Lu 2014	Wind China 2005-2011
41 McDowall et al 2013	Wind China, U.K., Germany, USA. 1974-2010
42 Jacobsson and Bergek 2004	Wind, solar Germany, Norway, Sweden 1990-2001
43 Hellsmark and Jacobsson 2012	Gasified biomass EU 2010
44 Del Río et al 2018	CSP Spain 2016
45 Klagge et al 2012	China Wind (manufacturers) 2010-2016
46. del Río and Bleda (2012)	Several countries from around the world, all RETs, 1990-2011
47. Nevzorova and Karakaya 2020.	TIS for biogas in a systematic literature review on seven mature biogas markets: Austria, France, Germany, Italy, Sweden, the Czech Republic and the United Kingdom
48. Esmailzadeh et al 2020	Iran, PV, 2019
49. Potts and Walwyn (2020)	South Africa, CSP, 2019
50. Gandenberger and Strauch (2018)	Brazil and China, wind, 2000-2013
51. Hanson (2018)	Norway, PV, 1980-2010
52. Andersson et al 2017	Tidal kyte, Sweden
53. Van der Loos et al (2020a)	The Netherlands and Norway, wind off-shore
54. Shubbak (2019)	China, PV, 1995-2015
55.Van der Loos et al 2020b	Offshore wind, the Netherlands, 2018-2019
56. Palm 2015	building-sited PV systems, Sweden

57. Karanasios and Parker 2018	Canada (remote indigenous communities in Northwest Territories (NWT) and Ontario), all RETs, 2000-2016
58. Vidican et al 2012	UAE, solar, 2009
59. Kiefer and del Río (2020)	EU, CSP, past and future (up to 2030)

AURES II is a European research project on auction designs for renewable energy support (RES) in the EU Member States.

The general objective of the project is to promote an effective use and efficient implementation of auctions for RES to improve the performance of electricity from renewable energy sources in Europe.

www.aures2project.eu

AURES II has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817619