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Auctions for the support of renewables: when and how?

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Auctions for the support of renewables: when and how?

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Abstract: The objective of this report is to provide a conceptual background to identify when competitive bidding mechanisms are useful and how they can be designed to deliver their full potential in the context of support for renewables. The first part of the report clarifies the potential role of auctions in pinning down support and determining which technologies to support, and reviews general principles of policy design that apply whether or not aid is granted through a competitive mechanism. The second part of the report describes the different design dimensions of auctions and their contributions to auction success. Case studies are provided to illustrate these concepts.

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1. Background, objectives and overview of report

The new guidelines on state aid for environmental protection and energy (henceforth EEAG) published in April 2014 emphasize the role of competitive mechanisms in ensuring that state aid is reduced to its minimum (proportionality principle).

The objective of this report is to provide a conceptual background to identify when competitive bidding mechanisms are useful and how they can be designed to deliver their full potential. While the EEAG cover aid for different types of activities, this report focuses, for the sake of concreteness, on aid for energy from renewable sources.

The report starts by distinguishing different policy objectives that can motivate subsidies for renewables, namely restoring economic efficiency (in the presence of market failures) and cost effectiveness (in the presence of a policy target). The type of technology (or set of technologies) to support depends on the policy objective. However, a basic principle across policy objectives is that the level of support should not be larger than the amount needed to turn the investment project into a positive net present value (NPV) project for the investor, the so-called “funding gap”. We demonstrate that, when technologies are sufficiently comparable, auctions can serve to both:

1. Help select the technologies to support, and
2. Bring the level of support as close as possible to the funding gap.

To deliver these benefits, auctions need to be designed appropriately. This means, among other things, accounting for the specificities of the auction objectives and the market environment. In section 3, we first review general principles about policy design in the context of support for renewables. These considerations apply whether or not aid is granted through a competitive mechanism. This section provides the background for the discussion in section 4 of the different design dimensions of auctions and their contributions to auction success. Section 5 illustrates the discussion through several case studies.

2. Rationale for support to renewables

In this section, we briefly review the two potential reasons to subsidize renewables, market failures and policy targets, and their associated policy decision criteria, efficiency and cost effectiveness.

2.1. Market failures and the efficiency criterion

Private investment incentives in renewables are driven by private costs and benefits (i.e. the costs and benefits effectively incurred by the investor). Given that costs and benefits do not accrue at the same time, an investor will furthermore discount future costs and benefits to reflect his/her cost of capital. The cost of capital depends on the financing structure of the project as well as the perceived risks. Investment will be profitable if it has a positive net present value (NPV). In the context of electricity generation, this roughly means that the implied levelized cost of energy is smaller than the expected price at which the investor will be able to sell the energy produced.

Social investment incentives differ from private investment incentives in two respects. First, *social* costs and benefits are taken into account.[1] Private costs and benefits will typically differ from social costs and benefits when there are unpriced externalities (i.e. impacts that are not reflected in prices) or imperfectly competitive markets. In the case of immature technologies, the experience of early adopters can benefit future investors in a way that is not fully captured by those early adopters. Likewise, the fact that conventional electricity production technologies do not bear their full social costs (for example because allowance prices in the EU ETS do not reflect the social cost of carbon or because nuclear risk is not fully insured) means that wholesale electricity prices do not reflect the full social cost of electricity.[2] Incorrect electricity prices imply that investment in renewable energy source (RES) may not be privately profitable even though it would be privately profitable if electricity prices reflected all costs and benefits of the existing electricity mix.

Economic versus financial logic

Economic logic characterizes decision processes that account for all social costs and benefits of investment projects, and not only those accruing to investors. It is associated with the efficiency criterion for public decisions. Financial logic characterizes decision processes that only account for investors' costs and benefits. It is useful to determine the funding gap.

The second dimension in which social and private investment incentives differ relates to the way future costs and benefits are discounted. The social rate of discount, which captures the inter-temporal social opportunity cost of money, is typically lower than the financial rate of discount used by private investors (this may result from market power in the long term finance market or simply differences in risk attitudes). The final result is a cost benefit analysis (CBA), with the project deemed socially desirable when the net present value of future benefits is higher than the net present value of costs.

Table 1: Private vs. social incentives to invest in renewables and rationale for support

		Private investment incentives	
		NPV > 0	NPV < 0
Social investment Incentives	CBA > 0	Investment happens and socially desirable → no need to intervene	Investment does not take place although socially desirable → need support to happen
	CBA < 0	Investment happens and is socially undesirable → need to prevent it	Investment does not happen and is not desirable socially → no need to intervene

Situations where private and social incentives differ are characterized by market failures: a situation when market forces alone do not deliver efficient outcomes. Given that projects are not evaluated in

[1] Social costs and benefits refer to the full economic costs and benefits, i.e. the sum of the private costs and benefits borne by private decision-makers and the external costs and benefits borne by other parties outside of the decision.

[2] On assessment of external costs of electricity, see also European Environmental Agency (2008), EN35: External costs of electricity production, available at: http://www.eea.europa.eu/data-and-maps/indicators/en35-external-costs-of-electricity-production-1

the same way, the "go/no go" decisions for investment in renewables will also typically differ. Table 1 summarizes the 4 possible cases. The top right cell of table 1 is the case of interest as far as aid for renewables is concerned: investment in the renewable energy source (RES) is socially desirable (efficient) but not privately profitable. The amount of money needed to bring the net present value (NPV) of the project to a positive value is referred to as the "funding gap": support equal to the funding gap will make the investment just profitable for a private investor.

An important implication of the discussion so far is that "getting prices right", i.e. accounting for all social costs and benefits, is essential to determine *which* projects and/or technologies to support (more on this in section 3) and restore efficiency. However, what matters for the decision about *how much support* to provide to the investor is the private investment incentives constraint, i.e. the funding gap.[3]

2.2. Policy targets and the cost effectiveness criterion

Policy targets provide a second rationale for support to renewables. Of course, in principle, such policy targets would be based on an analysis of the full costs and benefits of these targets and therefore they are unlikely to diverge much from the recommendations of a policy seeking to correct for market failures. However, they do induce a different decision criterion, namely cost effectiveness: is the option pursued the cheapest (where "cheap" can be denominated in different ways, including the amount of public financing or the full social costs) to reach the target? Cost-effectiveness in terms of the impact on public finances is an especially attractive decision criterion when the support mechanism is funded through (distortive) taxation.[4] We illustrate these concepts in the next section.

3. Policy choices

When discussing support for renewables, policymakers face two basic questions: Which technology should be supported? And how? In this section, we review each question separately, highlighting the key considerations to take into account when choosing between technologies and deciding on the form of support. The discussion serves both to illustrate where competitive mechanisms can contribute and provide background for the discussion in section 4 on the design of competitive mechanisms.

3.1. Technology choice and the role of competitive bidding

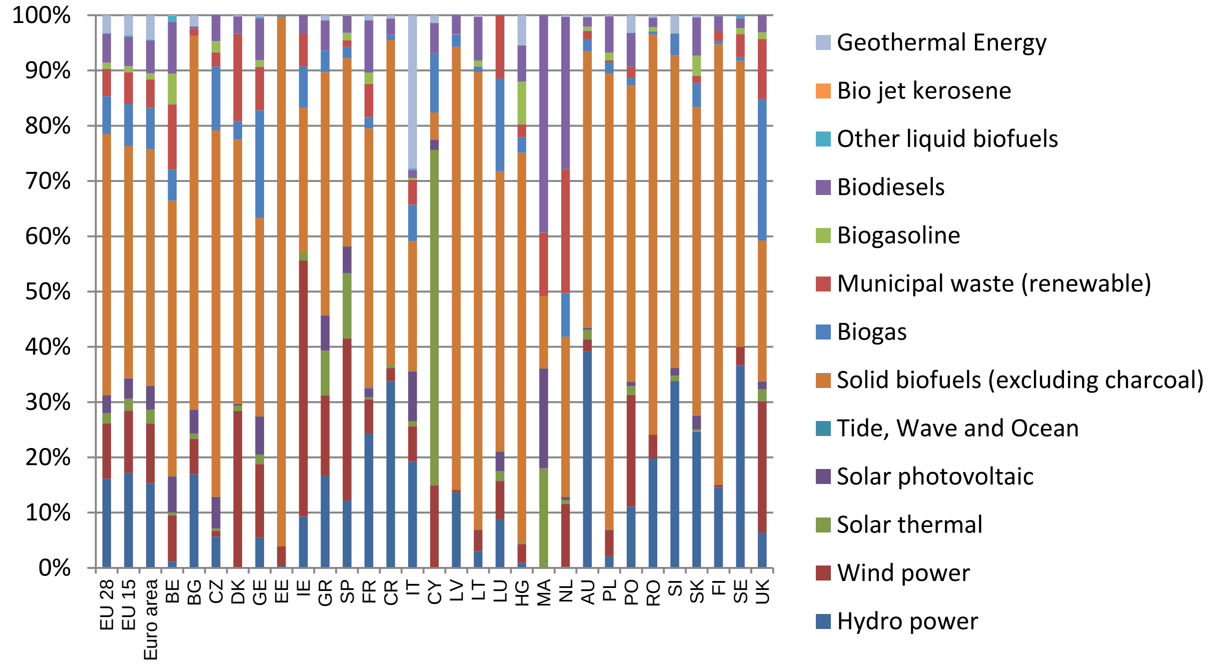
There are many sources of renewable energy. Figure 1 shows the current renewable energy mix in the EU. It is important to recognize that these technologies are not all perfect substitutes: some are relevant for electricity generation, some for transport, and some for heating. Therefore the decision about which renewable technology or technologies to support should be taken at two levels, first within each category of energy use (electricity generation, transport, etc.), then across categories.

[3] When the market failure at the origin of the discrepancy between private and social investment incentives arises from distortions in the market for non-renewables (leading to electricity prices that do not reflect the true social costs), removing such distortions will be a cheaper alternative to restore private investment incentives in renewables than subsidies.

[4] Different countries have different degrees of distortions built in their tax systems. This means that the exact same support mechanism funded through taxation in two different countries can imply different levels of distortion and costs.

Competitive mechanisms can mostly contribute when the technologies under consideration are sufficiently close substitutes so it is useful to have one specific application in mind for the rest of this section. We will use electricity generation as the leading example.

Figure 1: Renewable Energy mix in Europe - 2012 (source: Eurostat)



3.1.1. Choosing among technologies that are perfect substitutes

To develop intuition regarding the decision about which technology to support and how much subsidy to provide, let us consider the following example. Suppose electricity can be produced from renewable sources using three different technologies: technology 1, technology 2 and technology 3. Suppose further that all three technologies are currently unprofitable investment opportunities (their NPV is negative). Technology 1 is quite mature and the main reason why it is not profitable is because electricity wholesale prices do not reflect the full social cost of electricity. Investment in technologies 2 and 3 additionally generates positive externalities in terms of learning from experience. Figure 2 illustrates (in Figure 2, CBA_i refers to the net present value of all social costs and benefits of technology i and Δ_i refers to the difference between the private NPV of the project and its social NPV).

To begin, let us ignore electricity mix considerations and thus consider these 3 technologies as perfect substitutes. Which technology should we support? The answer depends on the policy objective pursued. Ignoring the costs of public funds, efficiency implies choosing the technology that yields the **highest social value** based on cost-benefit analysis.[5] At the other extreme, cost effectiveness implies investing in the technology that requires the **lowest level of public funds**. In practice, actual policy objectives will often mix both considerations.

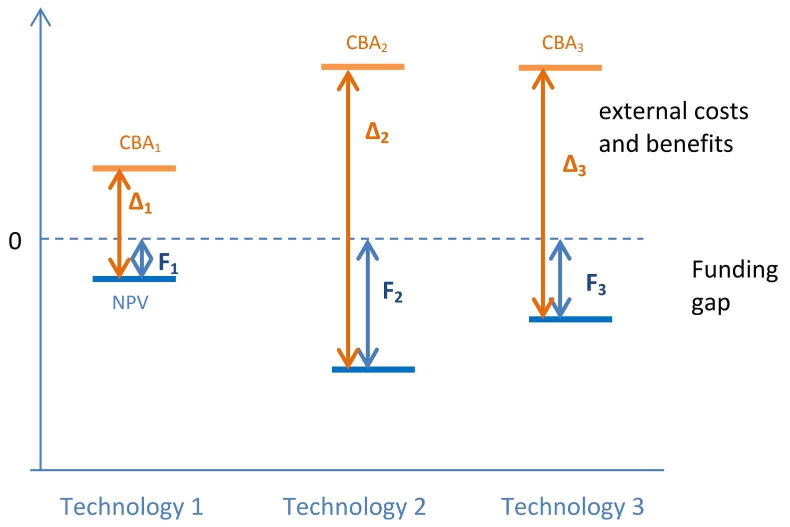
[5] In practice, budgetary considerations and the shadow cost of public funds mean that we will never exactly pursue the technology that leads to the highest social value, irrespective of costs.

Technology choice from an efficiency perspective

> Competitive mechanisms can fulfill the **dual role** of (1) choosing among technologies, and (2) deciding on the level of support.

In Figure 2, technologies 2 and 3 both yield the highest level of social surplus (again with the caveat that we ignore the cost of public funds). The minimum support needed for investors to be willing to invest in these technologies is equal to their funding gap, F_2 and F_3 respectively. So we should provide support F_2 to technology 2 and support F_3 to technology 3. This illustrates the principle introduced in section 2 according to which *social incentives* (computed from the cost-benefit analysis) drive the choice of technology but *private incentives* (measured by the funding gap) drive the level of support.

Figure 2: Technology choice



In this example, technology 2 benefits from a higher level of support than technology 3. Such support is nevertheless technologically neutral in the sense that it is putting all technologies on the same level-playing field, *once prices are corrected* for externalities and other market imperfections. At the same time, it is useful to stress that such technologically neutral support does not need to compensate each technology for their full externalities (in figure 2, this would correspond to Δ_2 and Δ_3) but simply ensure that *differences in support* are justified by *differences in external costs and benefits* (indeed $F_2 - F_3 = \Delta_2 - \Delta_3$).

Technology choice from a cost effectiveness perspective

Cost-effectiveness can lead to different decisions than efficiency because cost effectiveness only accounts for costs and not external benefits, other than those included in the target. In our example, this means that if the only difference between technologies 2 and 3, on the one hand, and technology 1, on the other hand, are external benefits from experience, then from a pure cost effectiveness perspective, we should choose technology 1 because it contributes to the target at the lowest social costs.[6] Support should again be equal to the funding gap, in this case the funding gap of technology 1, F_1. Table 2 summarizes the discussion.

Table 2: Technology choice and support as a function of the policy objective, when technologies are perfect substitutes

	Efficiency criterion	Cost effectiveness criterion
Technology choice	Technologies 2 and 3	Technology 1
Support level	F_2 (for technology 2) and F_3 (for technology 3)	F_1

Efficiency and cost effectiveness lead to different definitions of the concept of technological neutrality. From an efficiency perspective, technological neutrality will seek to correct for differences in external costs *and benefits* across technologies. From a cost effectiveness perspective, technological neutrality will at most seek to correct for differences in external costs (not benefits) across technologies (no correction will be needed if cost effectiveness from a public finance perspective is used).

Both definitions will nevertheless share two common implications. First, some technologies may need more subsidies than others. Technological neutrality does not require to give all technologies the same subsidy, nor to make all technologies "equally competitive" (i.e. compensating technologies on the basis of their funding gap), two common fallacies heard in policy discussions. Technological neutrality means correcting prices so that they reflect all relevant economic costs and benefits given the policy criterion used, and relying on these prices to select and subsidize technologies.[7] A second implication is that a technologically neutral policy may not always minimize the total amount of "out-of-pocket" aid needed to reach the renewables target, unless cost effectiveness in terms of public funds is the policy criterion used.

The concept of technological neutrality and, more broadly, non-discrimination is context-dependent.

3.1.2. The potential benefits of competitive mechanisms

Let us now consider the informational requirement to implement such decisions. To identify which technology to support from a cost effectiveness perspective, one needs information on the costs and benefits borne by the investors. To identify which technology to support from an efficiency perspective, one additionally needs to have information on the external costs and benefits. This is a difficult or even impossible task for any regulator: regulators will usually not have access to cost estimates of the same quality as project developers, and externalities are notably difficult to price precisely. Given this, it will be difficult to figure out which is the best technology, and how much subsidy to give.

[6] Though, if we take a longer term view, external benefits in terms of reduction in future costs could be considered as relevant for cost effectiveness.

[7] This is in line with the definition of technological neutrality used in the March 2013 consultation paper by the European Commission about the environmental and energy aid guidelines: "DG COMP considers that the general principle of technology neutrality is a good starting point for the development of the EAG. This would, in principle, leave it to the market to select the most efficient technologies *provided that external costs are internalized*. Eventually such technologies should prevail." (European Commission, 2013, p. 3, emphasis added)

Competitive mechanisms can help. Consider first technology choice under the cost effectiveness criterion. We can organize an auction where different technologies compete in bidding requested support levels. The technology bidding the lowest amount of support is selected and receives the support it requested. Assume that investors bid their funding gap, i.e. the minimum level of subsidies needed to make investment profitable (section 4 discusses the conditions under which competition will indeed induce bidders to submit bids not too far from their funding gap). The proposed selection criterion will then pick the technology with the lowest funding gap, which is the technology that would be selected under the cost effectiveness criterion, despite the regulator not having the necessary information about private costs and benefits to determine the project with the highest NPV. In other words, **we have just shown that a competitive bidding process is sufficient to both identify the best technology from a cost effectiveness perspective, and decide on the subsidy level**.

Competitive mechanisms can also help when the policy objective is efficiency if the procurement agency can at least pin down *differences* in external costs and benefits across technologies. This is a less daunting task than determining social costs and benefits. Indeed, these differential external costs and benefits will often be few and regulators are likely to be at least as well informed as market participants about these. In the case of our example, we can ignore factors that equally affect all three technologies, such as the fact that wholesale electricity prices do not reflect the social costs of conventional electricity and simply put a monetary value on the external learning benefits from experience in technology 2 and 3.

When this is done, we can again organize an auction where different technologies compete in bidding requested support levels but where bids are now corrected by the *differences* in external costs and benefits. The lowest corrected bid wins and is paid the support requested. To illustrate, let us go back to our example of figure 2 to see what would happen in such a competitive process. As before, assume for now that each technology bids its funding gap. The bids from technologies 2 and 3 are then discounted by Δ_2-Δ_1 and Δ_3-Δ_1 respectively to determine the winner. The regulator compares bids F_1, $F_2 - (\Delta_2 - \Delta_1)$ and $F_3 - (\Delta_3 - \Delta_1)$. Selecting the minimum of these bids is equivalent to selecting the maximum of $\Delta_1 - F_1$, $\Delta_2 - F_2$ and $\Delta_3 - F_3$, i.e. the technology with the highest CBA value. In our example, $\Delta_2 - F_2 = \Delta_3 - F_3$: both technologies 2 and 3 yield the highest social surplus and will therefore win. They will receive subsidy F_2 and F_3 respectively. **In words, competition, combined with knowledge about the *differences* in external costs and benefits, is sufficient to both, identify the best technology from an efficiency perspective, and decide on the subsidy level**. The informational requirement is also much lower than the informational requirement to administratively decide which technology to encourage and what level of support it should be given.[8]

A competitive bidding mechanism can be defined as a procedure that leverages competition to determine the price of a transaction. Auctions are a special kind of competitive mechanisms where competition takes place only on one side of the market: on the side of suppliers, in the context of procurement, or on the side of buyers in the case of a sale.

The simple example that we have just reviewed serves to illustrate two general points about the potential benefits of competitive mechanisms in the context of support for renewables. The first is

[8] However, we will see in section 4 that, in practice, regulators organizing auctions will benefit from doing some extra due diligence to set for example reserve prices appropriately to guard against situations when competition might be insufficient.

that market participants will usually have better information about their costs and investment opportunities and an auction can help reveal this information, thereby contributing to bringing the subsidy closer to the funding gap. This is related to the proportionality criterion of state aid. The second potential benefit of competitive mechanisms is that they can guide the decision about which technologies to support and therefore can contribute to policy coordination across different technologies. In the example we have just reviewed, the informational demand to figure out which technology to support is enormous, but if we can correct for differences in external costs, then the competitive mechanism can generate that decision. This is related to the appropriateness criterion of state aid.

3.1.3. Technology choice when technologies are not perfect substitutes

The discussion so far has considered that the different RES technologies were perfect substitutes. In practice, even for a single application such as electricity generation, RES technologies are far from being perfect substitutes. Different technologies will come with different cost structures, making them more suitable for some time of the day (and year) than others. Some technologies are dispatchable, others are intermittent and require back-up. This implies that the decision about which technologies to support can no longer be a single dimensional decision based on individual costs and benefits. Regulators may want to impose a cap on some technologies, a floor on others, or more generally, seek a specific technology mix. There might also be some geographical constraints.

Such technology mix considerations add constraints on the optimization problem faced by regulators concerning which technologies to support. However, the basic principles about (1) understanding social and private investment incentives, (2) using social costs and benefits to select technologies and (3) using private costs and benefits to determine subsidies, remain valid. The main difference is that the benefits of competition are likely to be reduced: floors for specific technologies ensure they get support irrespective of costs; caps on technologies limit their development even if they are cheaper, and so on. However, there is still a role for competition in selecting technologies and determining their support when these constraints are not binding. Intuitively, a bid correction of the type discussed above can be used to determine the allocation when the constraints are not binding. Competitive mechanisms that can account for these constraints are discussed in section 4.

3.2. How to support renewables

The discussion so far has considered a generic subsidy for renewables, without specifying its form. In practice, such subsidies can take many different forms. This choice affects the risk borne by investors and regulators and, eventually, the efficiency and the level of subsidies needed to reach the target. The appropriate choice of instruments is the subject of a vast literature in economics. We sketch some of the considerations that are relevant for auction design here.

3.2.1. R&D support versus deployment support

Many RES technologies are still at the development stage where R&D is crucial to reduce costs. Therefore a central question is whether R&D support rather than deployment support is more appropriate for these technologies.[9]

[9] R&D support to renewables is not covered by the EEAG. Investment subsidies and production subsidies are both deployment subsidies.

R&D support is justified if there is a market failure in the market for R&D. A common source of market failure in the R&D market is the lack of full appropriability of the returns to R&D (especially when fundamental research is involved). In presence of both a market failure in the R&D market and a market failure in the technology market of the type discussed in section 2.1, the optimal policy combines R&D support and deployment support. The use of deployment support alone will lead to higher costs and greater distortions (Acemoglu et al., 2012). In addition, deployment subsidies focused on currently cost-effective technologies may lead to lock-in and prevent the development of other technologies with better longer term potential (Frondel et al., 2010). Jasmasb (2007) and Zachmann et al. (2014) argue that there is currently too little support of R&D relative to deployment support in energy today.

3.2.2. Moral hazard and risk sharing considerations

Investment in renewables involves upfront costs and uncertain future cash-flows due to uncertainties about future output levels and prices. At the very basic level, subsidies increase the profitability of investment. Yet, the exact way these subsidies are designed affect the incentives of investors and the risks that governments, consumers and investors bear.

There are at least two sources of moral hazard in this context. First, investors may not exert the required level of diligence to bring investment projects to successful and timely completion. Second, the actual level of production or its "quality" (level of reliability, dispatchability) may depend on the quality of the engineering or the location, which are also decisions under the control of investors.

The presence of moral hazard calls for structuring support in such a way that investors bear the consequences of their actions. Practical examples of financial arrangements to increase incentives for delivery include deposits (that project developers provide upon selection and only get back when the project is completed), conditional payments upon reaching specified steps in the project, and financial penalties for delays in completion. In addition, exposure to wholesale market prices can help provide incentives for adequate production.

Making investors bear the full risks of projects is not without cost, however. Risk increases the cost of capital and, therefore, investment costs and the overall cost of support.[10] This is particularly relevant in the current regulatory context where developments in the prudential regulation of the banking sector (Basle III) and of related sectors (Solvency II) are likely to reduce the amounts available for long–term large-scale investments and increase the cost of capital for borrowers (Matsuda et al., 2012, Estache, 2014). Moreover, it is difficult in practice to target only those risks over which investors have control: contingent payments will also expose investors to market, regulatory and political risks (just to name a few) outside of their control. Making investors bear those risks increases costs without improving incentives.

The economic theory of contracting under moral hazard suggests that the optimal contractual arrangement will trade off the benefits of risk sharing and incentives: it will contain dimensions of contingent payments but not necessarily make investors bear the full risks. When possible, contractual arrangements will expose investors to those risks over which they have some control, and not to risks over which they have no control.

[10] Risky projects may also deter participation by new entrants.

This trade-off is likely to be investor, technology or size specific, calling for different types of support for different investors, technologies or sizes. To see why, consider Figure 3, which shows how investor revenue depends on production in a pure investment subsidy scheme, a pure production subsidy scheme (a fixed premium) and a hybrid format that combines both.[11] In the case of a pure investment subsidy, investor revenue increases with production only due to the resale price of the electricity produced (the slope of the blue line is equal to the electricity resale price). In case of a production subsidy, investor revenue increases with production due to both the resale price and the production subsidy. As a result, the slope of the revenue function in case of production subsidy is steeper than the slope of the revenue function in case of investment subsidies. Hybrid support combines an investment subsidy component (necessarily smaller than under a pure investment subsidy) with a production subsidy (also smaller). As a result, the slope of the revenue line lies in-between.[12]

The optimal degree of risk-sharing is likely to depend on the technology, calling for a different mix of investment and production subsidies across technologies.

Figure 3: Structure of support and revenue risk for the investor

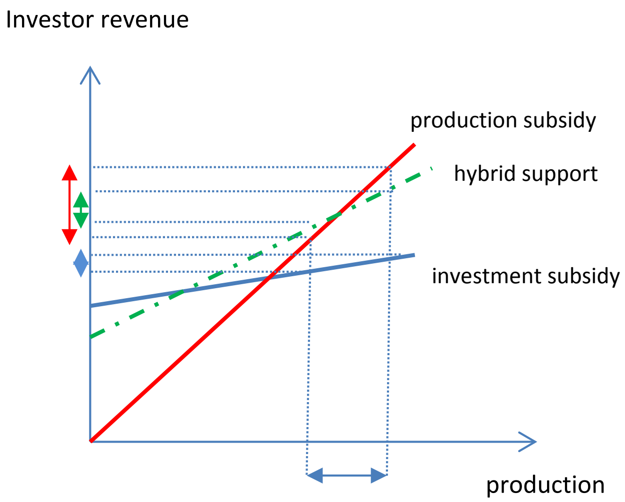


Figure 3 allows us to see how uncertainty about production converts into uncertainty about revenue under the three different support schemes. The same level of production uncertainty (captured by the interval defined by the double blue arrow on the x-axis) results in lower revenue uncertainty under investment subsidy (two-sided blue arrow on the y-axis), than under hybrid support (two-sided green arrow on the y-axis), which itself leads to lower revenue uncertainty than under pure production subsidies (two-sided red arrow on the y-axis).

Revenues are only one part of the equation, however. Investors eventually care about the profit they can make from their investment. Figure 4 adds the cost side to figure 3 to pin down how the NPV of the project depends on production. Two cases are considered: the case of a technology with very low

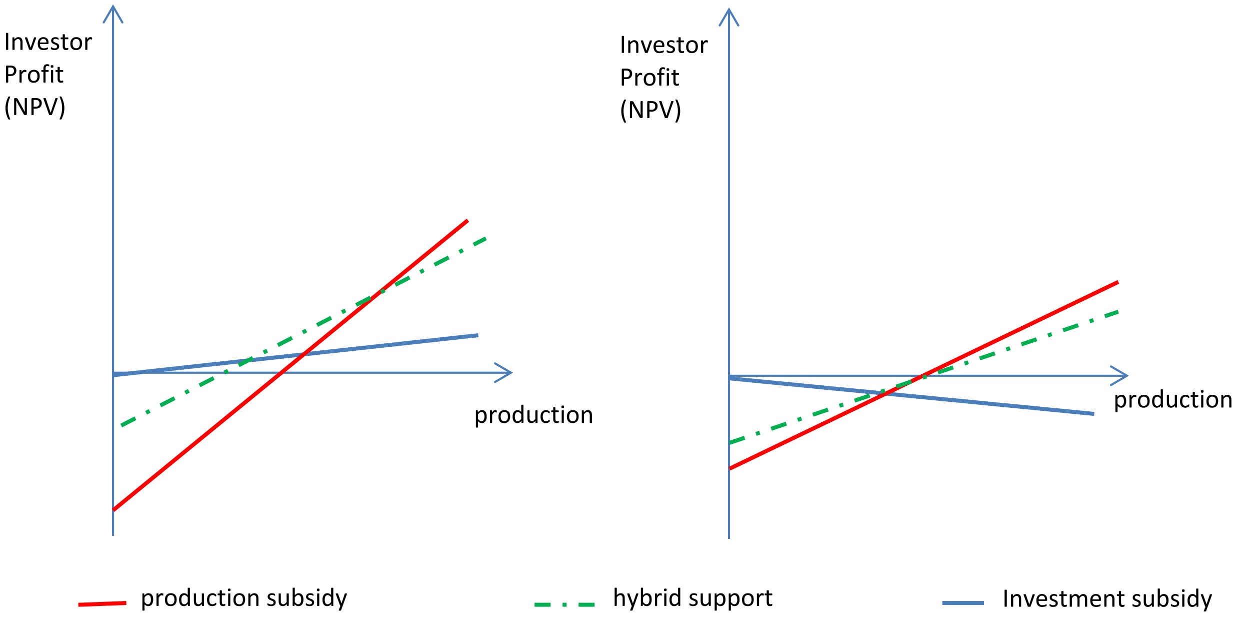
[11] Figure 3 assumes that electricity produced by the RES investment is sold in the wholesale market as imposed by the EEAG.

[12] There are many possibilities to combine investment and production subsidies. Other hybrid schemes include caps on total subsidies (so that no further subsidies are due if the plant produces more than contracted for) and floors on subsidies (to ensure a minimum level of support independent of production).

variable costs (e.g. on-shore wind) and the case of a technology with significant variable costs (e.g. biomass). In case of negligible variable costs (left panel), the NPV of the investment is simply a shift down of the revenue lines in figure 3. A high level of uncertainty about production results in a high level of uncertainty in the NPV in case of pure production support, medium level of uncertainty in case of hybrid support, and a low level of uncertainty in case of pure investment subsidies. The presence of significant variable production costs flattens the NPV curves (the NPV may even depend negatively on production in the case of investment subsidies if the variable costs are higher than the resale value of the electricity produced). This tends to reduce the impact of production uncertainty.

Current discussions about investment versus production support and discussions about the different types of production support can be seen against this background. Because high fixed costs / low variable cost technologies are more sensitive to production risks, investment subsidies or at least hybrid schemes are likely to be favored for these technologies, unless production uncertainty is limited or moral hazard is a concern.[13] Production subsidies are likely to be preferred by high variable costs technologies.

Figure 4: structure of support and investor profit risk for low variable cost technologies (left) and high variable cost technologies (right)



Production subsidies can take several forms beyond the fixed premium format (feed-in premium) assumed in Figures 3 and 4. Each variant mitigates or exacerbates the advantages or disadvantages of production subsidies. Feed-in-tariffs set the price at which the electricity produced is remunerated. It leaves production as the only source of risk for investors. Contracts-for-differences are a variant of feed-in tariffs that result in the same outcome for investors: a guaranteed price for their electricity. With feed-in premia, investors are exposed to price movements in the wholesale market on top of production risks. Green certificate schemes yield top-ups to electricity prices whose

[13] De Jager and Rathman (2008, p. 43) for example argue that investment subsidies in the Netherlands in the 1980s have led investors to optimize their wind installations according to capacity and not production.

level depends on the demand and supply conditions in the certificates market. They therefore expose investors to price movements in both the wholesale electricity market and the certificates market (in addition to production risks). De Jager and Rathmann (2008) and Newberry (2011) discuss the pros and cons of some of these schemes.

The length during which these subsidies are paid is another relevant dimension of contracting as far as risk sharing is concerned. In the context of highway franchising, Engel et al. (1997) argue that adjusting the franchise length to realized demand reduces unnecessary risk for investors (who have little control over demand) and thereby reduces costs. In the context of production support for renewables, this is equivalent to adjusting the time during which production subsidies are paid, as a function of realized production.

3.2.3. Quantity versus price

A classic distinction when discussing policy instruments concerns whether they primarily act on price or on quantity. The basic difference is that a price instrument will influence prices faced by investors and let them adjust their investment or production accordingly. A quantity instrument will set investment or production targets and let prices be determined endogenously to meet the target. In the context of support for renewables, price-based instruments include investment and price subsidies such as feed-in tariffs. Quantity-based instruments include auctions and tradable certificates (combined with a renewables obligation placed on distributors or generators) whose price adjusts to balance demand and supply.

In the absence of uncertainty about supply and demand conditions, setting a quantity is equivalent to setting a price and these different instruments can be shown to be equivalent. This is no longer the case in the presence of uncertainty. Neither pure price nor pure quantity-based will in general be able to implement the efficient outcome (Weitzman, 1974). For example, if technology costs are uncertain and subsidies are too generous, we are likely to invest too much in renewables and overpay for electricity. The reverse will hold, if subsidies are too low. Setting quantities ensures that we reach the target but can lead to volatile prices, as experienced in certificates markets. Hybrid instruments, such as combining price floors and price caps to a certificates scheme, adding a quantity cap or a budget cap to a price subsidy scheme, or allowing auctioned quantities to vary with bid prices, can improve on pure price or quantity instruments.

A subtle point, in the context of support for renewables, is that the choice between price and quantity instruments also influences incentives and the risks borne by investors and therefore their costs of capital (see section 3.2.1.). So the uncertainty about supply and demand conditions is not entirely exogenous, but can itself be driven by the choice of policy instrument. A policy that reduces investor risks will reduce investment costs (but will often imply more risks for public finances or consumers).

4. Auction design for renewables

In section 3.1., we argued, through an example, that auctions can contribute to both identifying which technology to support and how much to subsidize it. An implicit assumption in that example was that bidders submitted bids that closely reflected their funding gap. In practice, bids will be close to costs only if there is enough competition. Otherwise, if a bidder is sure to win even if he submits an uncompetitive bid, he will do so.

Whether competition is sufficient to warrant competitive bids depends on exogenous factors (number of potential bidders) but also, crucially, on the design of the auction. Klemperer (2002, 2004) and Milgrom (2004) provide comprehensive, yet accessible, analyses of key considerations in auction design on the basis on their extensive research and consulting experience on this topic. These can be summarized in three general determinants of auction success: (1) encourage entry and participation, (2) foster competition and price discovery, (3) ensure that the winner is someone who will pay or deliver as promised.

In this section, we first review the key elements of auction design, emphasizing those considerations that are particularly relevant in the context of support for renewables. Specificities of the auction environment for renewables include:[14]

1. The fact that the capacity or the production for which support is auctioned may be split between multiple winners, with each winner possibly getting different capacity or production commitments. In technical terms, such auctions are **multi-units auctions.**

2. The fact that there exist **several technologies** to produce electricity from renewable sources. These technologies differ in maturity, costs, operational and development risks, life duration of the investment, predictability and dispatchability of the electricity produced, among others. This technological heterogeneity means that these technologies are only **imperfect substitutes from the perspective of the electricity system** and, thus, the agency that organizes the auction. On the bidder side, technologies may also interact in a number of ways. Potential bidders may be specialized in a technology or at least have a competitive advantage in one of them. Or they may view these technologies as independent opportunities worth investing in depending on the level of subsidies. Less likely (in the context of auctions for support for renewables), bidders may view these technologies as complements.[15]

3. **Electricity production and future electricity prices are uncertain at the time of investment**. Depending on the way the subsidies on which bidders bid are designed, there may be common elements of uncertainty across bidders, such as future electricity prices or weather conditions.

4. The fourth and final specificity of auctions for renewables support is that it is just **one part of a broader policy mix** intended to meet the renewables target of Member States. Moreover, RES are just one way to produce electricity and so policies that affect these other (mostly fossil-based) sources of energy are also bound to affect incentives for investment in renewables (cf. the discussion about the impact of subsidies for conventional sources of electricity in section 2). As a result, efficiency or cost effectiveness considerations will imply

[14] To make the exposition as concrete as possible we will again focus on electricity generation but the arguments can be made for other applications, mutatis mutandis.
[15] Complementarities on the bidder side significantly complicate matters in auction design. Given that it is unlikely to apply in the context of support for renewables, this case is not covered in this report.

that support decisions for RES cannot be entirely independent of the costs of alternative policy options.

Next, we will discuss how these key elements of design contribute to meeting the goals of encouraging entry and participation, fostering competition and price discovery, and ensuring delivery. Several illustrative case studies are presented in section 5.

4.1. Dimensions of auction design

4.1.1. What to auction?

The decision about what to auction is a critical step towards ensuring participation and competition. Should the auction be technology-specific or allow different technologies to compete? Should bidders come up with investment projects and sites or should the agency preselect sites and tender production from these sites? Should one auction off investment subsidies or production subsidies? How much capacity should be auctioned off in the same auction and, relatedly, at what frequency should these auctions be held? We discuss some of these questions in this section.

Single versus multi-technology auctions

Let us first consider the first question: Should the auction be technology-specific or allow different technologies to compete? Technology-specific auctions have the advantage of simplicity (one compares bids on homogenous goods so that price can be the driving criterion). However, they limit the ability of tendering authorities to have different substitute technologies compete for support (potentially leading to lower subsidies) and they limit their ability to coordinate support policies across different technologies (by, for example, limiting support to expensive technologies and increasing support to cost-effective technologies).[16]

There are two ways to bring different technologies to compete for subsidies. The first one is the use of all-encompassing auctions (sometimes referred to as "technology-neutral") where all technologies compete on an equal footing and the cheapest bids (and technologies) are selected. Brazil (see section 5) uses this type of auction for new capacity. In the absence of a price correction, and providing that there is enough competition, this auction implements the cost-effective solution from a public finance point of view.[17]

All-encompassing auctions are simple but imply that the tendering authority loses control over the resulting technology mix: 100% of the capacity or production could be allocated to a single technology. All-encompassing auctions may also lead to an increase in the overall subsidy level if costs are very heterogeneous and some technologies are capacity constrained.[18]

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[16] This is related to the appropriateness criterion of state aid.

[17] All-encompassing auctions can be combined with a scoring rule that converts bids from different bidders or different technologies into a score. Such scoring rule can for example consist of technology-specific bid premia and/or bid penalties that correct for differences in externalities to implement the efficient outcome (as in the example of section 3.1). See also section 4.1.4. below.

[18] For example, suppose that the tendering authority auctions support for 200 MW. They are two technologies 1 and 2. Technology 1 has a funding gap around 10 EUR/MWh; technology 2 has a funding gap around 40 EUR/MWh. Suppose the tendering authority goes for a technology-specific auction with 100 MW tendered from technology 1 and 100 MW tendered from technology 2. Assuming there is enough competition in these

The second way to bring different technologies to compete is to use simultaneous technology-specific auctions where quantities allocated to each technology are set endogenously as a function of the observed prices and the preferences of the tenderer over the energy mix. The exact way in which quantities are allocated across technologies as a function of submitted bids can be announced ex-ante, as in the EDF virtual power plant auctions discussed in section 5, or can be decided ex-post on the basis of the submitted bids as in the UK NFFO auctions and the product-mix auction proposed by Klemperer (2010).

Relative to the all-encompassing auction, such auctions can accommodate rich preferences over the different technologies. The agency can set a floor or a cap on the capacity procured from each technology or, more generally, have preferences over the resulting technology mix.

Table 3: Auction formats in the presence of substitute technologies

	Pros	Cons
Technology-specific auctions	Simple Control over quantities of each technology	Leverages competition only within technology Does not help to choose among technologies
All-encompassing auctions	Simple Leverages competition Can be combined with a scoring rule to correct for external costs/benefits and non-price attributes	No control over resulting technology mix Can result in lower competition and higher prices if technologies have too different costs
Simultaneous technology-specific auctions with endogenous quantities	Maintains control over technology mix while at the same time leveraging competition Flexible	More complex to run: valuable only if there is flexibility re the technology mix and technologies sufficiently comparable

Simultaneous technology-specific auctions provide a flexible solution to the dual concern of ensuring competition and maintaining control over the technology mix. In particular, they are more robust to the risk of lower competition induced by technological cost heterogeneity: the auction can maintain competitive pressure on bidders by ensuring that the quantities auctioned to a technology remain sufficiently small relative to supply. If technologies are perfect substitutes from the point of view of the tendering agency (which, in particular, means that the agency has no preference over the resulting technology mix), there is no difference between such simultaneous technology-specific auctions with endogenous quantities and all-encompassing auctions.

technology-specific auctions, the price will be around 10 EUR/MWh in the first auction and 40 EUR/MWh in the second auction for an average price of 25 EUR/MWh. Consider now the all-encompassing auction and suppose technology 1 bidders are capacity-constrained and cannot build 200 MW of new capacity with technology 1. Then they are guaranteed to win support subsidies as soon as they bid just below 40 EUR/MWh. The average subsidy in the all-encompassing auction can then be arbitrarily close to 40 EUR/MWh.

Example 1 illustrates the differences across these auction formats. In example 1, the agency is seeking to auction off support for 100 MW of new capacity. The table below describes the price and quantity (capacity) bids received for technology 1 and technology 2 respectively. Suppose first that the agency uses two independent technology-specific auctions, of 50 MW each (bidders receive their bids). In that case, the agency selects the cheapest bids in each technology up to the desired quantity of 50 MW. The cutoff winning bid for technology 1 is 11 and the cutoff winning bid for technology 2 is 9. This implies an average winning bid of 10.2 EUR/MWh for technology 1 ((9 x 10 + 10 x 15 + 10.5 x 10 + 11 x 15) / 50) and of 8 EUR/MWh for technology 2. The overall average cost of support is 9.1 EUR/MWh.

If the agency brings both technologies together in an all-encompassing auction, bids from both technologies are compared on an equal footing and a common cutoff bid (9.5) is set such that the total awarded quantity is equal to 100. The auction awards support to 10 MW of technology 1 and 90 MW of technology 2. The resulting average cost of support is 8.6 EUR/MWh. It is lower than the price under the technology-specific auction. This illustrates how bringing different technologies to compete can reduce the level of subsidies.[19]

Example 1: Comparison of auction formats – submitted bids

Technology 1			Technology 2		
Price	Qty	Cum. Qty	Price	Qty	Cum. Qty
9	10	10	7	15	15
10	15	25	8	10	25
10.5	10	35	8.5	20	45
11	20	55	9	25	70
12	30	85	9.5	20	90
			12	40	130

The idea behind the simultaneous technology-specific auction is to allow the technology-specific cutoffs to be determined both on the basis of submitted bids and of the agency's preferences over the resulting technology mix, unlike in the technology-specific auctions (where quantities are pre-allocated across technologies) and the all-encompassing auction (where the cutoff depends only on bids). For example, the agency could decide to allow for a maximum cutoff difference of 1 EUR between the two technologies. For this particular example, this implies a cutoff of 10 for technology 1 (and quantities between 10 and 25 MW) and a cutoff of 9.5 for technology 2 (and quantities between 75 and 90 MW). Section 4.1.4 below discusses other decision rules for the simultaneous technology-specific auction.

Table 3 summarizes the pros and cons of these three different types of auctions. The choice among them will depend on the competitive environment and the preferences of the agency over the technological mix.

Single versus multi-dimensional bids

[19] In this example we assume that bids do not change across auction formats. In practice, bidders will adjust their bids to the perceived level of competition, increasing the price difference between the all-encompassing and the technology-specific auction. Of course, if the agency knew enough about costs it could implement the cost-effective outcome through a technology-specific auction, with a 10-90 ex-ante split of capacity.

The potential benefit of all-encompassing auctions and simultaneous technology-specific auctions with endogenous quantities resides in their ability to bring different technologies to compete. A related design problem concerns the definition of the product to bid on. Should the contracts that bidders bid on be fixed and, in particular, set the financial terms and other non price attributes? Or should bidders be allowed to bid on other dimensions than the price and the capacity they are willing to install?

Standardization (fixing all parameters and letting bidders bid only on prices) is simple and straightforward to implement. It is commonly used in auctions but also in other markets (e.g. standardized contracts for derivatives traded on exchanges) to ensure thick-enough markets.

Standardization facilitates bid comparison but is not problem-free. First, standardization may lead to an unequal level-playing field among heterogenous competitors, favoring those bidders whose competitive advantage is most closely aligned with the tender specification. This is likely to be a concern when the auction allows multiple technologies to compete. We have for example seen in section 3.2.2., that the optimal level of risk-sharing is likely to be technology-specific. Allowing bidders to bid both on an investment component and a production subsidy component may be valuable in this context. Second, it reduces the dimensions on which bidders can compete and may miss win-win opportunities where a bidder offers a product configuration that equally meets the needs of the agency at a lower cost.

Multi-attribute auctions (also known as scoring or multi-dimensional auctions) provide a solution: bidders submit bids on several dimensions including price, bids are converted into a score, and the bidder with the highest score wins. When the scoring rule is designed to represent the agency's preferences over the different offers, multi-attribute auctions truly allow for a real level-playing field among bidders. They also help bidders identify win-win opportunities (see Asker and Cantillon, 2008, for a comparison between scoring auctions and other solutions in the presence of non-price attributes). On the negative side, defining the scoring rule can be difficult and can expose the agency to adverse selection (if, for example, the agency evaluates a production support bid on the basis of a wrong estimate of future production).

Auction size versus frequency

The auction size and the frequency at which auctions are held are another way to influence the degree of competition. Larger and infrequent auctions are more likely to attract more bidders. There are tradeoffs however. Infrequent auctions imply discontinuous, bulky additions to capacity, which themselves may lead to harder to predict future electricity prices and an increase in uncertainty about future cash flows from the investment.

4.1.2. Eligibility rules

Eligibility rules are conditions on participation in the auction. These can be technical conditions (expertise, proven track record), economic conditions (existing planning and environmental permits), or financial conditions (bond payment, proven solvability or proven financing arrangement). Their main role is to ensure that the bidders who participate are likely to deliver.

The tradeoff between the restrictions on participation that eligibility rules imply and ex-post competition in the auction is complex. While common intuition suggests that restricting participation reduces competition in the auction, the auction literature has identified a number of settings in which this simple intuition does not hold and where, instead, some kind of restriction on entry may be desirable. Entry fees, for example, can serve to screen cost-competitive bidders and therefore increase ex-post competition (Menezes and Monteiro, 2000). Restricting entry can reduce the winner's curse in the presence of common values elements in bidders' payoffs and therefore induce more aggressive bidding (Levin and Smith, 1994).[20] When the project on which bidders bid is complex and requires extensive due diligence and bid preparation, restricting entry can increase incentives for carrying out such due diligence and incurring these costs (Ye, 2007). To the extent that the eligibility rules correlate with those conditions, then eligibility rules may contribute both to delivery and competition.

4.1.3. Bidding rules

Bidding rules describe what bidders bid on (just on the level of support requested or also on additional contractual terms such as capacities made available, structure of support, and so on), and how bidding converts into final offers. One usually distinguishes between open and sealed bid formats. In sealed bid auction formats, bidders submit bids independently and these bids result, after comparison, in a final binding decision. In such auctions, it can be useful to allow bidders to submit multiple bid-quantity pairs (or supply schedule) rather than a single price quantity pair.

In open formats, on the other hand, bidders can react to bidding by others. This can be done literally, when bidders compete by trying to outbid one another (as in the classic English auction used for art). Or this can be done using a clock that progressively decreases and bidders submit capacities they are willing to build at the current clock (price) level. The auction ends when the bid quantities equal the quantities the agency is seeking to fund.

The main advantage of open formats is their ability to aggregate dispersed information and to reduce the cost of information acquisition for bidders. Their progressive format allows bidders to decide "on-the-go" whether they want to stay in and/or invest in further information depending on what they see. This contrasts with sealed bid formats where bidders have only one chance to submit their best bids. On the other hand, open formats can make collusion easier. For this reason, recent auction designs have combined a first stage open auction format with a second stage sealed bid format. The first stage helps aggregate information, which is valuable in the presence of significant cost and revenue uncertainties that may share common elements across bidders. The second stage uses a sealed bid format to foster competition among the remaining bidders. The Brazilian auctions for new capacity use this format.

4.1.4. Winner determination

Winner determination describes the rule used to select winners on the basis of submitted bids. In the simplest case, when the agency is interested in cost effectiveness and bidders bid on identical goods or services, the winners are the bidders who submitted the lowest bids, up to the auctioned quantity.

[20] Common values in auctions refer to the fact that bidders' expected future cash flows are uncertain and share common elements (for example: the future wholesale price of electricity). The winner's curse refers to the idea that winning is informative in such auction and usually means that the other bidders may have had less optimistic beliefs about future cash flows. Bidders' bidding in auctions with common values should take this into account by conditioning their bid on the information revealed from winning. There is ample experimental and empirical evidence that this is hard to do, even for experienced bidders.

If, instead, efficiency is the goal pursued, bids should be corrected for the differences in external costs and benefits among alternatives before selecting winners. The score of a bid is equal to the value of the external benefits of the bid, minus the value of the external costs and the bid.[21] The winners are the bidders who submitted the bids that generated the highest scores, up to the auctioned quantity.

For example, consider again example 1 in section 4.1.1. and suppose that technology 1 generates a positive externality in the form of learning-by-doing evaluated at 1 EUR/MWh. If the agency is interested in correcting this potential source of market failure, it can subtract 1 EUR from each technology 1 bid. In that case, the cut-off bid in the all-encompassing auction with bid correction is 9.5. The average resulting price with uniform rationing is 8.7 EUR/MWh.[22] It is higher than it was without price correction since we are no longer minimizing out-of-pocket costs but maximizing efficiency.

When bidding is multi-dimensional and, more generally, when different technologies and/or offers compete in the same auction but are not perfect substitutes, a rule is needed to compare the submitted bids and determine the winner(s).

When offers differ in non-price dimensions but the agency is otherwise indifferent about the final technology mix, a scoring rule in an all-encompassing auction can be used to convert multi-dimensional bids into a single dimensional score. Bids generating the highest scores win, up to the auctioned quantity. For example, imagine bids differ in their system integration costs. A scoring rule that accounts for both the requested subsidy and the resulting system costs can restore a level-playing field (alternatively, this externality may be internalized through appropriate pricing of connection charges). As a second example, imagine that the auction allows bidders to bid on both the investment subsidy they need, I, and a production subsidy, P. Bids can then be compared on the basis of *expected* total subsidy, I + P x q, where q is the expected production.

When the agency is not indifferent about the final mix, a scoring rule is not sufficient to represent its preferences. One way to incorporate preferences over technology mix is to add constraints on the final allocation in a simultaneous technology-specific auction (for example, a floor or a cap on capacities in a given technology). The agency will then choose winners whose offers minimize the requested total support, given the target capacity and the constraints on the allocation of this capacity across technologies. To illustrate, let's return to example 1 and suppose that the agency does not want to procure more than 70 MW from each technology. In that case, the cutoff bid for technology 2 is 9 and the cutoff for technology 1 is 10.5. The resulting average price is 8.72. It is higher than the average price in the all-encompassing auction since we have placed an additional constraint on the final allocation, but it remains lower than the average price in the technology-specific auction.

Another way to introduce technology mix considerations in the simultaneous technology-specific auction is to generalize the intuition behind the scoring rule and evaluate bids both on the basis of

[21] As in the example of section 3.1.2, one only needs to account for those external costs and benefits that differ across the alternatives.
[22] This corresponds to (9 x 10 + 10 x 15 + 10.5 x 10/6 + 7 x 15 + 8 x 10 + 8.5 x 20 + 9 x 25 + 9.5 x 20/6) /100). Recall that corrected bids are used to decide which bids win but original bids are used to set the financial compensation.

their characteristics but also on the basis of the technology mix they imply if they win. For example, the agency might want to consider bids from both technologies as equivalent except if they imply that more than 45% of capacity is awarded to technology 2. In that case, it may still want to award additional capacity to technology 2 only if the price for technology 2 is significantly lower than that for technology 1.[23] The next table describes such a penalty scheme. Bids that bring the share procured from technology 2 between 45 and 55% of the tendered capacity are penalized by a factor of 1.1, bids that bring the share procured from technology 2 between 55 and 65% are penalized by a factor of 1.2, and so on. The right hand-side table of example 1 (cont'd) shows the corrected technology 2 bids that account for this penalty. Using these corrected bids together with the original technology 1 bids to determine the final allocation, we see that 65% of capacity is now allocated to technology 2 (at the marginal price of 9) and 35% of capacity is allocated to technology 1 (at the marginal price of 10.5). The resulting average price is 8.8.[24]

Example 1 (cont'd): Implementing decreasing marginal rate of substitution between technologies in a simultaneous technology-specific auction

Technology 2 (original bids)

Price	Qty	Cum. Qty
7	15	15
8	10	25
8.5	20	45
9	25	70
9.5	20	90
12	40	130

Penalty imposed to T2 bids as a fn of capacity procured from T2

T2 ≤ 45%	1
45% < T2 ≤ 55%	1.1
55% < T2 ≤ 65%	1.2
65% < T2 ≤ 75%	1.3
75% < T2 ≤ 85%	1.4
85% < T2	1.5

Technology 2 (penalty-corrected bids)

Price	Qty	Cum. Qty
7	15	15
8	10	25
8.5	20	45
9.9 (= 9x1.1)	10	55
10.8 (= 9x1.2)	10	65
11.7 (= 9x1.3)	5	70
12.35 (=9.5x1.3)	5	75
13.3 (=9.5x1.4)	10	85
…	…	…

4.1.5. Payments rules

Payment rules describe the financial consequences of the auction for bidders. A first set of payment rules defines how the aid ultimately received by winners is determined on the basis of their bids. In uniform price auctions, the clearing price, i.e. the price at which offered capacity is equal to the tendered capacity, determines the aid received by the winners, independently of their bids. In pay-as-bid auctions, in contrast, winners are paid the amounts they bid for, which can result in different winners getting very different support levels for their investment or production. Uniform price auctions and pay-as-bid auctions create very different incentives for bidders but neither has been found to systematically dominate the other from a cost perspective. In high stake auctions, uniform price auctions are often seen as politically less risky by bidders because there is no risk of underbidding (winners receive the same amount) and the auction does not require them to reveal too much private information about their private costs.

[23] This is analogous to diminishing marginal rate of substitution in demand theory.

[24] (7x15 + 8x10 + 8.5x20 + 9x20 + 9x10 + 10x15 + 10.5x10)/100. As usual, corrected bids are used to pin down the allocation but original bids are used to set the financial compensation.

Payments may be contingent on actual production, as in auctions for production support, where bidders bid on a monetary support per MWh, or in auctions where bidders bid on an investment subsidy component (EUR/MW) and a production subsidy component (EUR/MWh) and bids are compared on the basis of total expected costs. We saw in section 3.2.2. that contingent payments help balance risk sharing and moral hazard considerations and are likely to be desirable features in the context of support for renewables. Bidding for contingent payments introduces new effects on top of the risk sharing and incentives considerations discussed so far, however. Hansen (1985) was the first to investigate the impact of bidding on contingent payments on expected revenue in auctions. His model, which ignores moral hazard and risk, can be easily adapted to a setting where bidders bid for production or investment support to show that bidding for investment subsidies will lead to lower subsidies per MWh produced than bidding for production subsidies. Intuitively, in both auctions, bidders who expect to produce more electricity for the same investment (for example because their windmills are located in a favorable location) will require a lower subsidy. But in the auction for investment subsidies, this subsidy will be even lower, once converted to EUR/MWh. This result depends finely on the way cost heterogeneity is modelled, however, and the addition of risk aversion and moral hazard may change these recommendations (see Samuelson, 1987 or Skrzypacz, 2013, for a review of recent developments).

A second set of payment rules are exogenous to the bidding process itself. These are participation fees, if any (they play a similar role to eligibility rules), and penalties for non-delivery.

4.1.6. Reserve prices and other ways to make auctioned quantities responsive to prices

In the context of procurement auctions where bidders bid for support and the lowest bids win, reserve prices are caps on bids. They protect the tendering agency against too high prices if competition is weak. Price caps are, however, a stark way to achieve this and may sometimes lead to the reverse of the intended result by having bidders coordinate on this reserve price (this happened in several of the 3G auctions in Europe in the early 2000s for example). Determining the right level for the reserve price is also informationally demanding.

An alternative is to make the auctioned quantities respond to the submitted bids (higher quantities if bids are low, i.e. an elastic "demand curve"). This can be done ex-post at the agency's discretion or through the announcement ex-ante of a demand schedule. Budget caps are an example of pre-announced demand schedule (of constant unit elasticity). Simultaneous technology-specific auctions with endogenous quantities also imply an elastic demand since auctioned quantities for one technology depend on its relative price.

Responsive quantities have been found to be a robust way to both ensure a minimum level of competition (like reserve prices) and induce more aggressive bidding (Hansen, 1988, Back and Zender, 2001, Milgrom, 2004, Li Calzi and Pavan, 2005). The intuition is simple. When auctioned quantities are fixed, bidders trade off an increased chance of winning for a higher profit conditional on winning. When auctioned quantities respond to prices, a lower bid also increases the quantities that a bidder can get. This increases the bidder's incentives to bid low.

Responsive quantities offer two additional advantages. First, in the presence of uncertainty about the costs of RES, efficiency requires increasing quantities when costs are low and decreasing them when costs are high. This is exactly what responsive quantities do.[25] Second, responsive quantities can serve as a tool for policy coordination by making quantities auctioned in one technology responsive to its relative costs.

4.1.7. Information

When setting up an auction for support, an agency needs to decide how much information about the economic environment to provide to potential bidders prior to the auction, and how much information to release during the course of the auction. Pre-auction information reduces the risk of winner's curse and can facilitate entry by new, less experienced, participants. It can also decrease procurement costs (through what the scientific literature has termed the linkage principle). Information release during the auction, of the kind generated by open auction formats, is helpful for price discovery and convergence to the equilibrium.

On the other hand, information can also help bidders to collude by identifying competitors and providing ways to signal interest and areas for mutually-beneficial tacit agreement. Cramton and Schwartz (2000) describe collusive bidding practices allowed by the open format used in the US spectrum auctions in the 1990s and discuss solutions that can maintain the benefits of information generation while making collusion harder.

4.2. Contribution of auction design to auction performance

In this subsection we bring together the insights from section 4.1 to highlight how the different design dimensions of an auction contribute, collectively or individually, to auction success, and in particular to the ability of the auction to encourage entry and participation, foster competition and price discovery, and ensure delivery. As we do this, it is important to recall that there is not one optimal auction design that fits all situations but that auction design needs to be tailored to the particular situation at hand. When possible, we highlight design choices that are likely to be good practices for most auctions for the support to renewables.

Market participants must learn how bid in auctions. Some auction formats make it easier for bidders to identify optimal strategies. When this is not the case, bidders are likely to learn over time and, as a result, the performance of one auction may not repeat itself in another auction, *even if the auction format remains the same* (for evidence about bidder learning in the context of the UK frequency response market, see Doraszekski et al. 2014).

4.2.1. Entry and participation

Bidders will participate in an auction if they feel they have a chance to win the auction profitably and the costs of participation are not too high. The definition of the product to be auctioned is a key determinant of participation. Flexible product definitions that avoid restrictions on technologies or on minimum investment levels, and limit financial risks for investors (payment rules are important here) will generally be more conducive to entry. Likewise, designs where winners' responsibility is limited to the actual generation capacity investment, and do not include connection to the grid and other non-generation issues, can facilitate entry by non-energy firms. Eligibility rules put conditions

[25] This relates to the discussion in section 3.2.3. on the choice between quantity and price instruments. A bare-bone auction where quantity is fixed and exogenous is a pure quantity-instrument. The quantity is set, prices are determined as a result of competitive forces. Auctions with responsive (or endogenous) quantities are hybrid instruments.

on participants and should be scrutinized for any unnecessary restrictions that raise barriers to participation without delivering any advantage.

The tendering agency can also foster entry by publicizing the auction widely, and by sharing technical and economic information with potential participants with the view to reduce the perceived financial risks of the investment and the risks of the winner's curse.

Finally, how winners are selected on the basis of bids can make entry by new market participants profitable or not (but may or may not decrease procurement costs). Examples seen in practice include favorable treatment for small and medium enterprises or minority-held firms, caps on the capacity share won by a single participant, scoring rules that value characteristics more common in entrants than in incumbents.[26] Table 4 summarizes how design contributes to foster entry and participation.

4.2.2. Price discovery and competition

All the dimensions of auction design that we have reviewed in section 4.1. have the potential to contribute to price discovery and/or competition. However, many of the design features that contribute to price discovery and/or competition also come with costs, either strategic (for example: open formats help aggregate information effectively when there is a lot of uncertainty about the economic environment but can also facilitate collusion) or administrative (for example, multi-attribute auctions increase the scope for competition but are more complex to run). Whether the benefits of these design features outweigh their costs depends on the likely heterogeneity among bidders, the agency's degree of uncertainty about their costs, and the extent to which bidders face common elements of uncertainty about their future payoffs. Different elements in the design also interact. For example, there is no benefit to having very flexible product definitions if the eligibility rules are such that only a very specific (and homogenous) pool of bidders can participate.

Three design choices are likely to be desirable, irrespective of the specificities of the market environment where the auction is implemented. First, and at least as long as technologies are sufficiently comparable, it will usually be profitable to bring multiple technologies to compete, either through an all-encompassing auction or through simultaneous technology-specific auctions. Bringing technologies together will not only bring the cost of support down but will also generate the necessary information to determine the optimal technology mix based both on the preferences of the agency and the information about the cost of support revealed by the auction process. When the agency is indifferent about the resulting technology mix, an all-encompassing auction is enough. It can be combined with a technology-specific bid correction of the type described in section 4.1.4. if efficiency or broader notions of cost effectiveness than cost effectiveness from the perspective of public finances are used as the policy criterion.[27] If the agency has preferences over the resulting mix, the simultaneous technology-specific auction is more appropriate.

[26] Some of these rules may be discriminatory and therefore ruled out by the EEAG.

[27] It may appear that some technologies are not competitive enough to compete in an all-encompassing auction, even after the bid correction intended to internalize externalities. This may be a signal that R&D support rather than deployment support is the appropriate policy instrument for this particular technology. Alternatively, it may simply mean that this is an inferior technology that does not belong to the optimal mix and is not worth support.

Second, it will usually be good practice to allow auctioned quantities to respond to prices. This automatically follows from the use of a budget cap in the auction or the use of simultaneous technology-specific auctions but needs to be built in the design otherwise.

Third, extensive pre-auction information about the technological and economic environment and a stable regulatory environment will reduce barriers to entry and perceived risk and help foster a healthy competitive environment.

4.2.3. Delivery

When a bidder wins an auction, there is still no guarantee that he will effectively deliver. This concern is often raised to argue against auctions. In fact, non delivery may have little to do with the actual use of competition *per se* to select aid recipients. There are three main reasons for non-delivery:

1. **Unexpected events happen**: A planning permission is not granted, the technology turns out to be inadequate, input prices happen to be higher than expected, and so on. As a result, the winning bidder is no longer in the conditions to deliver. This first reason for non-delivery is a consequence of the fact that the selection of aid recipients in auctions is made at the very beginning of the development and production cycle.
2. **Winner's curse and broke winners**: The winning bidder failed to take the winner's curse into account and did not bid prudently enough. Upon winning he realizes that the project is not profitable.
3. **Strategic underbidding**: Bidders bid too low in the auction on purpose to win and thereby preempt competitors to get in or expand capacity (this was a concern in the UK non-fossil fuel obligations auctions described in section 5).

Table 4: Contribution of design choices to auction success

		Determinants of auction success		
		Encourage entry and participation	Foster competition and price discovery	Ensure delivery
Design dimensions	What's being auctioned?	X	X	
	Eligibility	X	X	X
	Bidding rules		X	
	Winner determination	X	X	
	Payment rules	X	X	X
	Reserve price / elastic demand		X	
	Information to bidders	X	X	X

Auction design can help reduce these risks of non-delivery. **Strict eligibility conditions** for participation can address the first source of non-delivery by preselecting experienced bidders or requiring that bidders have already secured the relevant planning permissions (as in the Brazilian auctions described in section 5). **Improving bidders' information** can help reduce the winner's curse. Well-functioning futures markets, adequate forecasts about future demand and supply, the sharing of engineering estimates about the different technologies, or benchmarking, are all services and information that the tendering agency can provide to potential bidders to reduce the winners' curse.

Finally, **penalties for non- (or late) delivery and deposits** remove incentives for strategic underbidding. They also increase incentives for due diligence to reduce bad surprises that can cause winners to abandon their projects.

As discussed in section 4.1., some of these measures can reduce competition. Strict eligibility conditions may restrict competition. Penalties may increase the perceived risk of the project and therefore its cost. They should therefore be defined with a view to balance their costs and benefits. Improving bidders' information is generally a good idea.

5. Case studies

According to IRENA (2013), 44 countries in the world used auctions for renewable energy in 2013 and auctions are used in several other sectors to deal with problems that are also encountered in the energy sector. In this section, we describe several of these auction applications with a focus on how they deal with three issues that are particularly salient in the context of auctions for renewables, namely (1) the fact that the agency or the auctioneer does not consider the different technologies or, more generally, competing services, as perfect substitutes, (2) the presence of significant payoff uncertainty for bidders, and (3) concerns about project completion and delivery. These examples serve to illustrate the diversity of possible auction designs and their pros and cons, rather than good practices valid across the board. The range of possible designs is much larger. Table 5 summarizes the key features of these auctions and their relevance in the context of auctions for renewables. Maurer and Barroso (2011) and IRENA (2013) provide additional case studies.

5.1. The UK non-fossil fuel obligation (NFFO) experience

Between 1990 and 1998, the UK organized auctions for production support for non-fossil sources of electricity. Five auctions were held between 1990 and 1998 (Mitchell, 2000 and Mitchell and Connor, 2004, describe how the format evolved across auctions). The interesting feature of these auctions is that many different electricity generation technologies were allowed to bid, including wind, hydro, municipal and industrial waste, and biomass. Bids were first compared within technologies and then technology-specific cutoffs were chosen, as a function of submitted bids, to determine winners within each technology category. Winners received the production support for which they had bid (pay-as-bid format) for a number of years.

Several features of the NFFO auctions fostered entry and competition. First, the NFFO auctions are an example of simultaneous technology-specific auctions. Many different technologies were allowed to compete. This fosters competition, as wind technologies know that they also compete with other technologies and that the eventual quantities for each technology will be determined by their relative competitiveness (thus making auctioned quantities endogenous from the perspective of bidders).[28] Second, OFGEM did not commit to an amount of subsidy (although this subsidy was

[28] The actual rule that OFGEM used to decide between technologies was not public (see e.g. OFGEM, 1998, for an analysis of the bids in the 1998 auction). When bidders have control over the characteristics of their offer that influence the decision, Asker and Cantillon (2008) have shown that announcing the scoring rule before the auction yields better prices and quality. Given OFGEM's selection rule, this does not seem to have been an issue in this particular case but, in general, transparent rules can help foster legitimacy and increase participation.

capped) or capacity to be eventually auctioned and this further encouraged competitive bids (elastic demand). Third, the reserve price (price ceiling) in any auction was set to the average price observed in the previous auction, fostering early participation.

An important weakness of the NFFO auctions, however, was the lack of penalty for non-delivery. This encouraged aggressive bidding in the hope that development costs would go down before winning bidders had to deliver. If cost decreases did not materialize, winners could simply decide not carry out the project. The lack of penalty also introduced a strategic incentive to bid low (and not deliver) because winning in the auction meant that competitors would not be able to increase capacity.

In addition to these perverse strategic incentives to bid low, delays or rejections of planning permissions have affected completion rates under the NFFO. The UK NFFO scheme was replaced by a certificates scheme in 2002, among others, because of low completion rates and concerns that the UK NFFO scheme "picked winners" given the ex-post (unannounced) rule to determine technology-specific cutoffs (Mitchell and Connor, 2004).

5.2. Virtual power plant auctions

Virtual power plant (VPP) auctions are sales of electricity capacity that are virtual, rather than physical divestures. The generating firm keeps the control and management of the plant but auctions off withdrawal rights on its capacity. The main motivation for virtual power plant auctions is to promote entry into the electricity market and, concurrently, promote the development of a wholesale market. Variants of virtual power plant auctions are or have been used in France (EDF), Belgium (Electrabel), Denmark (Elsam), Germany (E.ON and RWE), the Netherlands (Nuon), Portugal (REN and EDP) and Spain (Endesa, Iberdola). Ausubel and Cramton (2010) discuss variations in the designs and their properties.

The relevance of virtual power plant auctions in the context of support for renewables arises from the fact that, within product categories (peak load and base load capacity), bidders can bid on contracts of different lengths. This flexibility can be valuable for new entrants who are facing uncertainty about future demand or about their own production. Bids on different contract maturities confront the auctioneer with the challenge of comparing them. To have the flexibility to allocate capacity across the different contract lengths, the EDF variant of VPP auctions uses a scoring rule that maps prices on different contract lengths into a single reference price and makes EDF indifferent between selling a 3-month contract at price X or a 6-month contract at price Y. The market clears at the reference price such that demand (summed across all contract lengths) is equal to supply. The exact allocation across contract lengths depends on the underlying demand and competition. This simultaneous maturity-specific auction format implies that bidders bidding on different contract lengths effectively compete with one another.[29]

5.3. Capacity auctions in Brazil

Brazil has been using auctions for existing and new capacity since 2005 to promote price discovery and cost effectiveness. Auctions for new capacity in renewable energy were introduced in 2007 to

[29] Most VPP auctions have a multi-round ascending format that is particularly valuable when bidders view contracts of different lengths as substitutes but are less relevant for auctions for RES support if bidders are specialized across technologies (some specialize in wind, others in biomass, etc.).

meet growth in demand and serve as a complement to Brazil's large hydro capacity base. Until recently, these auctions were technology-specific.

Prices are determined in two phases. In the first phase, a descending clock auction is run until quantities offered equal the production target plus a reserve margin whose size is unknown to bidders. The equilibrium price of this first stage serves as a reserve price cap for the second stage pay-as-bid auction. Bidders commit to a production level and bid a requested support (R$/MWh). The fact that total supply in this stage is larger than the production target provides incentives for competitive bidding. Production support is provided for 20 or 30 years depending on the technology. Bidders for new capacity must also secure demand-side commitment in a capacity obligation market (Firm Energy Certificates). Winning bidders in new capacity auctions have 3 to 5 years to deliver.

Table 5: Examples of auctions used in the energy sector, with lessons for the support of renewables

Purpose	Appl'n	Relevance for RES	Key features	Results / lessons
Auction for new investment in RES. Bidders bid for production support (£/KWh)	UK non-fossil fuel obligations (1990-1998)	Simultaneous technology-specific auctions for new RES capacity	Quantities contracted in each technology endogenous depending on technology and bids (exact decision rule not announced to bidders) Reserve price is equal to average price in previous auction	Auctions attracted many bidders Auction format allowed different technologies to compete and reserve price rule provided incentives to participate early Lack of penalties for non-delivery resulted in strategically low bids to deter competition and low delivery rates
Virtual power plant auctions (options to withdraw) Bidders bid a price per MW per month to have the right to acquire power. Several contract lengths.	EDF (since 2001)	Need to compare bids on different products (here: different maturities; in RES different technologies) Uncertainty about structure of demand (which type of contracts will attract bids)	To allow comparison of bids across maturities, price relationship across maturities fixed (scoring): single reference price discovered through ascending price auction and quantities of each maturity set endogenously	Auctions fostered new entry into electricity markets and contributed to the development of wholesale power markets Flexible quantities across maturities foster competition and price discovery when the auctioneer does not know ex-ante where demand lies
Auctions for new RES capacity and for reserve (R$/MWh)	Brazil (since 2007)	Technology-specific and all-encompassing auctions for RES	Hybrid format (open followed by sealed bid) Demanding technical and financial pre-qualification	Strong participation and competitive prices Declining prices in last auctions raising concerns about profitability and completion

Sources used for this table: (1) VPP auctions: Ausubel and Cramton (2010); (2) UK NFFO: Cozzi (2012), Mitchell (2000), Mitchell and Connor (2004), OFGEM (1998); (3) Brazil: IRENA (2013), World Bank (2011), Barroso (2012).

Brazil started using all-encompassing auctions in 2011. No bid correction is used. In the recent auctions, wind has proved to be very competitive, even outbidding natural gas. In contrast, small hydro and solar have not proved to be able to compete against wind, natural gas and biomass in these auctions (IRENA, 2013).

A special feature of the Brazilian auctions is their demanding pre-qualification requirements and strong incentives for delivery. Bidders must have secured an environmental license and grid access to participate. They must also deposit 1% of the estimated costs as a bid bond. Upon winning, project developers must deposit a project completion guarantee equal to 5% of the value of the investment. Penalties are applied in case of delays (including the possibility of termination) and under/over production relative to the commitment. Despite these demanding conditions, the auctions have attracted a high level of participation (IRENA, 2013). These auctions are generally considered a success but very low prices in the recent auctions have raised concerns about future lower completion rates.

6. Concluding comments

6.1. Make auctions work twice for you

Auctions are competitive mechanisms that can bring the cost of support down by having bidders compete and thereby reveal information about the minimum level of support that they need. This role, which is stressed in the EEAG, is directly related to the proportionality criterion of state aid.

But auctions are also selection mechanisms and, in the presence of multiple technologies, the information revealed during the auction can also help determine which technology or technologies should be supported. This is all the more feasible that the service provided by the different technologies is sufficiently comparable and the tendering agency is able to make explicit its preferences, if any, over the resulting technology mix. To fulfill this role, the auction must bring together all technologies, through an all-encompassing format or in a simultaneous technology-specific format.

6.2. Auction design matters

An auction will never be able to extract a competitive price if there is only one bidder. However, the way the auction is designed plays a critical role in determining participation and competition. Auction design is both an art and a science. It is a science because it relies on theoretical, empirical computational and experimental analyses to ground recommendations. It is an art because every application is special and will often warrant a tailored auction design that deals with its specificities. A number of good practices emerge nevertheless:

1. **Multi-technology**: When possible, bring all technologies that fulfill the purpose of the support scheme to compete in the auction;
2. **Flexible product definition**: When possible and relevant, given the set of potential market participants, be flexible about what's being auctioned and allow the contractual terms (nature of product, compensation scheme, etc.) to be defined inside the auction;
3. **Elastic demand**: make auctioned quantities responsive to demand;

4. **Bidder information**: advertise the auction widely and provide as much technical and economic information to bidders, including planned future capacity additions, target energy mix, electricity price forecasts and wind forecasts;
5. **Regulatory environment**: provide a stable regulatory environment to reduce uncertainty about future payoffs for bidders, and clear rules and timely decision making for zoning permits.
6. **Penalties**: provide incentives for winning bidders to complete their project on time.

6.3. When are auctions not desirable?

When the agency has very specific needs that can only be met by a single or a limited number of suppliers, bringing multiple technologies together in an auction and flexible product design are unlikely to be valuable as means to ensure a sufficient level of competition. In contrast, intense due diligence akin to the review process required in cost-plus type of regulation will be especially valuable in determining the right level for the reserve price. Competitive bidding per se is unlikely to add much relative to the reserve price in these circumstances. An administratively set tariff or premium can equally do the job at a lower administrative cost.

Auctions require that winning bidders commit to a project and an associated remuneration. In case of extreme uncertainty about future development and production costs, bidders may not be willing to commit to such an extent. They will therefore not participate. For such technologies, remuneration schemes based on ex-post costs and production level may be more appropriate.[30]

6.4. Technological neutrality and other notions of non-discrimination

A big challenge when bringing different technologies together or allowing flexible product definitions is to clarify how the agency will compare the different offers (bidder determination). We have argued that the concept of technological neutrality or, more generally, non-discrimination, depends on the agency's policy objective. If the objective of the agency is to restore efficiency in the presence of market failures and incorrect prices, technological neutrality may require treating different technologies differently. If the objective of the agency is to minimize the cost burden of support, then there is no reason to treat different technologies differently, unless the agency has preferences over the technology mix. Ensuring an equal level-playing field means treating all bids equally unless there are objective differences in the service provided or the agency is pursuing an efficiency objective and there are differences in external costs and benefits across these technologies.

[30] But see Engel et al., 2001, for an auction that protects bidders from such risk.

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