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Comparison of auctions and alternative policy options for RES-E support

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Comparison of auctions and alternative policy options for RES-E support

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Executive Summary

This report concludes the work carried out in the course of Task 6.2 of the AURES project. It is its aim to compare auctions with alternative policy instruments and in particular, to examine under which circumstances auctions may be superior and inferior to achieve intended policy targets. For that purpose, we identify a number of potential drivers that might affect an instrument's effectiveness, its efficiency and further success criteria. Among this list of relevant drivers, the basis for our analysis is the factor risk, where our core focus is on risk for policy makers. Assuming a world of uncertainty, particularly policy makers or regulators are exposed to the risk of setting inefficient investment incentives by implementation of wrong policy. As such, the aspect of risk is deemed one of the most important challenges for the deployment of RES. We demonstrate that risk and uncertainty respectively constitute important factors understanding the decision-making of policy makers regarding which instrument to use. However, we also point out that independent of its importance, the factor risk constitutes only one of many factors, which may be relevant when selecting a policy instrument.

Our main analysis consists of two parts: First, we conduct a theoretical analysis, which summarises the insights gathered by Weitzman (1974). It illustrates that with uncertainty regarding the marginal costs and marginal benefits of RES, particularly the choice between price (e.g. a FIT) and quantity (e.g. an auction) instruments will be decisive, since incorrect price or quota signals may have different effects. In essence, while price schemes may reduce the risk of welfare losses given a relatively steep marginal cost and a comparably flat marginal benefit curve, a quantity scheme may be superior if the relation between the two curves is vice versa.

In the second part of our analysis, we employ modelled data by Held (2010) in order to build on the theoretical insights and compare the slopes of real marginal cost of RES in different European countries. Our main conclusions can be summarised as follows:

1. The incentives for the use of particular policy instruments to support the deployment of RES are both country and technology specific. In general, it appears that the incentive to employ a quantity-based mean such as an auction is larger when the natural resources of the technology that is to be supported are abundant and if that technology is rather well developed. Besides that, it requires a competitive market for an auction to be effective.

2. Since within a country the market and natural conditions of the different RES technologies and hence their supply costs may vary considerably, it seems possible that there exist incentives for both price and quantity support schemes. Our findings therefore provide an argument against a technology-neutral support.

3. Our analysis stresses the importance to consider temporal developments. Since both the potentials and the costs of the different RES technologies will change over time, so may the incentives for their support. It is therefore not only necessary to conduct a static assessment of RES potentials and their costs respectively but also to consider their dynamics

Our findings suggest that with uncertainty regarding the marginal costs and marginal benefits of RES, there may be valid reasons for policy makers not to employ auctions, since under particular circumstances it may be

desirable not to control quantities but the price. As such, they raise the question whether pure support cost minimisation should be the only goal when implementing regulatory policies. Our report develops useful insights, which may serve to argue for exceptional cases towards the European Commission. Moreover, it provides guidance to policy makers by indicating how to conduct similar yet case specific analyses.

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1 Introduction

This report concludes Task 6.2 of the AURES project, in which we sought to analyse how auctions perform relative to alternative control instruments. More precisely, the following analysis intends to answer the research question **when, i.e. under which circumstances, auctions may be superior or inferior to achieve intended policy targets** and the report thereby seeks to provide suggestions/recommendations for policy makers on when to draw on auctions for RES support.

We explore this research question by paying particular focus to the **market circumstances** and **policy objectives** that might make alternative support instruments more attractive. Thereby, we derive conclusions, among other things, with respect to the typical (sub-sets of) technologies for which auctions do not seem relevant and to the typical levels of maturity that technologies should have before auctions become favourable.

In their latest State aid guidelines the European Commission (2014) demands the gradual introduction of competitive bidding processes (auctions) for RES support in order to reduce market distortions and to enable a cost-effective support. Member States may, however, refrain from employing auctions under certain circumstances. The first mentioned alternative to auctions in the state aid guidelines are certificate trading schemes. They are considered sufficiently market-based and competitive and may thus be used as previously. For price-based schemes (such as administratively set feed-in tariffs or direct subsidies), several concrete exceptions are named in the guidelines, e.g. for small installation sizes and demonstration projects. See more detail on this in Section 5.3.

Further, Member States (MS) may be allowed to employ alternatives to auctions if they can convincingly argue for circumstances in which only a very limited number of sites or projects are available, or the implementation of auctions would lead to low project realisation rates or higher support levels (see more in Section 5.3). These last points are perfectly relate to the policy success criteria defined in WP2 of this project. **Table *1*** lists all seven criteria and indicators for measuring policy success.

If auctions lead to low project realisation rates, then they do not fulfil the success criterion of effectiveness. Higher support levels per technology fail to address the policy objective of low support costs. Note that this issue is not identical to reducing static efficiency, i.e. the reduction of generation costs. A consideration of socio-political feasibility is more ambiguous. It acknowledges that policy makers might pursue multiple targets with their energy policy, which are not only related to purely economic considerations of achieving the most cost-efficient deployment of renewables up to the socially desired volume. There can be more complex policy objectives that might be difficult to address with auctions, e.g. achieving a certain amount of technology diversification (e.g. because of security of supply concerns), avoiding regional concentration of deployment (e.g. because of system stability concerns), promoting local industry (although this explicit target has legal feasibility issues especially in a European context), protecting small actors, enhancing social acceptability, and more.

Which arguments are acceptable to the European Commission to justify exemptions from auctions remains to be seen, as only a very limited number of cases is available at this moment. Compliance with the European State aid guidelines is discussed further in Section 5.3.

Table 1: Policy success criteria and measurable indicators for assessing policy options as defined in the AURES project

Policy success criteria	Measurable indicators
Effectiveness	Realisation rate
Static efficiency	Total generation costs (Private) transaction costs Administrative costs
Dynamic efficiency	Private R&D investments Evolution of market shares and costs of technologies over time
Support costs	Average support level per technology (net of generation costs) Total support costs (net of generation costs)
Local impacts	Emissions, Reduction of fuel imports, promotion of local industry, regional concentration of deployment, additional jobs in the sector
Socio-political feasibility	Fit to decision makers' institutional capacity, number of small actors, social acceptability
Legal feasibility	Compliance with state aid rules, internal market principals, other rules and regulations

1.1 Focus, approach and aim of this report

The aim of this report is to explore when auctions may not be the favourable support instrument. We focus mostly on economic aspects, in order to evaluate the effectiveness and efficiency of auctions, but we also touch upon secondary policy objectives that may play a role. For answering the question of which support instrument is favourable, two important aspects have to be known: First, under which economic circumstances are auctions inferior to alternatives and second which alternative shall be used instead?

We approach these questions in several steps: First, we provide a context for the arguments that might be brought forward as justification for not employing auctions for renewable support and elaborate on interrelations between the success criteria and potential drivers behind. In doing so, we build on the insights from task 6.1 of this project that already listed pros and cons of different alternative instruments. Second, we review and set into perspective arguments for and against different support instruments that have been brought forward in the academic discourse on the issue. Here we focus on studies that compare auctions with alternative support instruments and analyse how each instrument performs under different economic circumstances. Third, we go into detail thereby particularly focusing on the aspect of risk and analyse the impact of market situations and policy objectives on the optimal choice of policy instrument. For this, we draw on the strong theoretical foundation of policy instrument analysis that has been developed throughout the last four decades. Finally, we exploit modelled data to show the practical relevance of the theoretical conclusions for the optimal choice of policy instrument for different RES technologies. This allows us to draw specific conclusions about which policy instrument (auction or alternative) may be favourable for different technologies and different country-specific circumstances.

In this report, we thus aim to develop a more comprehensive understanding for when auctions are economically favourable, and to provide assistance to policy makers for when alternatives should be considered.

2 Context for the decision about optimal support instrument

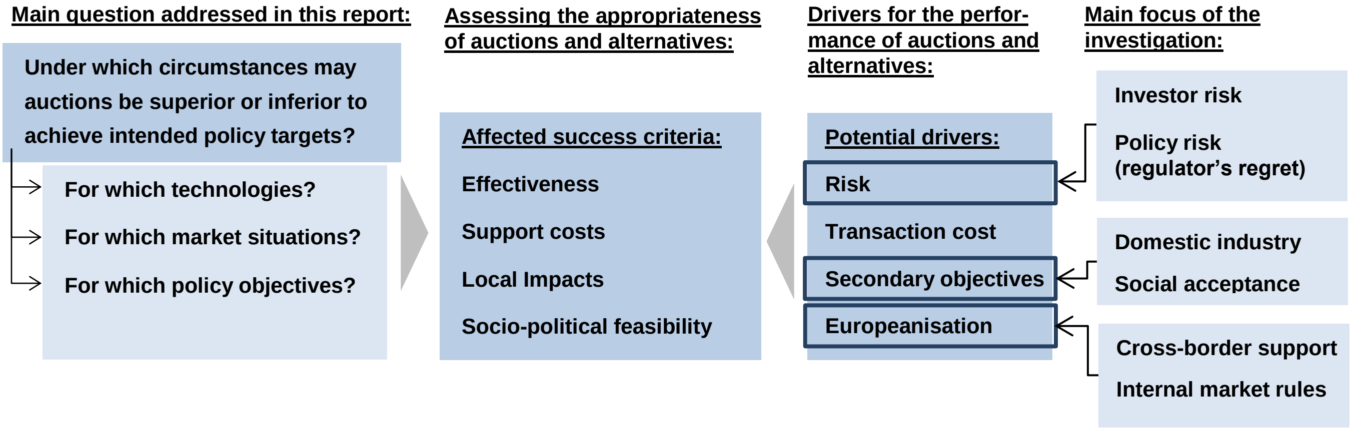

Figure 1: Overview over the main question and the focus and approach taken in this report

Figure 1 illustrates the research questions of the present report and how it approaches the challenges in the context described above. It is apparent that multiple drivers may affect the defined success criteria of auctions in similar ways. In this report we only briefly touch on the aspects of secondary objectives (through the impact on domestic industry and social acceptance) and on Europeanisation (through cross-border support aspects). Instead, our particular focus is on the factor risk, as risk for both investors and policy makers represents one of the most important challenges for the deployment of RES and one of the major factors for the success of competitive and market-based support instruments. It is thus an important goal to reduce risk elements by means of prudent choice and correct adjustments of policy instruments.

In general, risk can be seen from an investor's or a regulator's perspective, where it is important to distinguish between the two. For investors, risk constitutes an additional barrier exacerbating the participation in the respective RES market. It increases investors' costs of debt and their costs of equity respectively. For regulators, on the other hand, risk, which comes along with uncertainty, may result in suboptimal policy and thus may pose a jeopardy to societal welfare.

In the course of the following work, particularly the risks faced by policy makers shall be in the centre of attention. For that purpose, we will build on a theoretical framework developed by Martin Weitzman (1974) and employ modelled cost-potential data by Anne Held (2010) in order to perform our own analysis. This shall help to provide answers to the research questions raised above. However, to account for the fact that risk only constitutes part of the bigger picture, we also seek to set it into perspective through the additional sections on secondary objectives and Europeanisation and discuss their potential impacts on the relevance of our study for real life application.

3 Academic discourse of support instrument choice

Practically since their commercial emergence, it has been possible to observe a discussion about how to efficiently support the deployment of RES. Until today, questions regarding the suitability of support instruments are highly prominent and determine the agenda of environmental and energy policy respectively. In this, scholars derive very different conclusions about which policy instrument should be employed when – the discourse is highly controversial. In this light, this report cannot show any final conclusions, but it can highlight some of the arguments brought forward and set them into perspective in regards to the questions addressed here.

Broadly speaking, the literature comparing RES support instruments can be distinguished in two strands. The first strand, usually building on empirical methods and case study analyses, is primarily concerned with conducting direct comparisons of the different support instruments in place. Often, studies from this domain consist of country specific analyses where the performance of a policy instrument is investigated in relation to a different instrument in another country. The second strand, in contrast, is mostly of theoretic nature and more general. It is less concerned with particular instruments as such but rather dedicated to develop an understanding for the differences between price and quantity regulations – the two general criteria to categorise all instruments. Research within this strand goes back until 1974, when Martin Weitzman published his seminal article *“Prices vs. Quantities”*, which is highly relevant until today. The following review is intended to provide an overview of the core literature of these two strands.

3.1 Direct Comparison of Policy Instruments

To date, the feed-in tariff (FIT) with an administratively set support level has been the most frequently employed instrument to support the deployment of RES. Therefore, it often serves as the benchmark instrument, when conducting comparative studies with concrete examples. This review, too, will focus on administratively set FIT and the comparison of their impacts with those of auctions.

In our previous AURES report on the “*Identification of alternative policy options to auctions for RES-E support*”, Del Río, Fitch-Roy, & Woodman (2016) have pointed out that administratively set FIT are often considered as inappropriate to provide incentives for a cost efficient deployment of RES since they would not be able to generate price competition among project developers (e.g. Borenstein, 2012). In comparison with auctions, this would be a substantial disadvantage, as the very nature of the FIT system would allow investors to generate large profit margins that could become very costly for the state budget. In a slightly older, yet still popular study, Menanteau et al (2003) argue similarly. Comparing deployment and price data from Denmark, France, Germany, Spain and the UK in the 1990s, they claim that administratively set FIT might have been suitable to ensure large amounts of capacity installations, however, competitive auctions would have been more effective in driving down the costs of RES. Indeed, **Table *2*** and **Table *3*** provide support for this argument.

Table 2: Impact of incentive schemes on the installed onshore wind power capacity

Incentives	Country	Installed capacity in MW (end 2000)	Additional capacity MW (in 2000)
Administratively set feed-in tariffs	Germany	6113	1668
	Spain	2402	872
	Denmark	2297	555
	Total	10812	3095
Bidding systems	UK	409	53
	France	79	56
	Total	488	109

Source: Menanteau et al. (2003)

Table 3: Comparison of onshore wind power prices in Europe in 1998 (in euros/kWh)

Administratively set feed-in tariffs			Average bidding price	
Germany	Denmark	Spain	UK	France
0.086	0.079	0.068	0.041	0.048

Source: Menanteau et al. (2003)

While total installations of onshore wind power capacity in countries under the feed-in tariff significantly exceeded those of countries that employed auctions, it can be seen that wind power prices were considerably lower when auctions were used. However, Butler & Neuhoff (2008) note that the support of auctions in the UK as it is suggested by Menanteau et al. (2003) may not reflect the real level of support, because some of the planned projects were never realised. As the winners' curse suggest, it seems likely that particularly those projects that received low support could not be financed after all. This would imply that the average support level among the realised projects was likely to be higher and the difference in support levels to be lower as indicated in **Table *3***.

Further contrasting arguments are provided by Sawin & Flavin (2006). Focusing on cost efficiency – the main comparison criterion – they assess the performance of FIT decidedly more positively than their fellow researchers above. In particular, they claim that a simple comparison of nominal support levels between countries as it is done e.g. by Menanteau et al. (2003) is insufficient to allow for inferences on the instruments' ability to drive down costs because country specific differences in wind resources are not taken into account. For example, average wind speeds on sites used in Germany in the 1990s were considerably lower than the speeds reached in the UK in the same period. This, in turn, allowed British developers to generate electricity at lower costs and thus, constituted a relative cost advantage. In fact, the authors argue that once it is controlled for these differences in wind resources, the support payments paid under the FIT in Germany may have been lower than those under the competitive bidding schemes in the UK.

Support for this argument is provided by Butler & Neuhoff (2008), who conducted an analysis to identify in more detail the reasons for the price differences that arose in the 1990s between Germany and the UK. By means of expert interviews, they found that bidding schemes in the UK primarily triggered competition among developers during the bidding phase whereas developers in Germany competed mainly for suitable wind sites. As mentioned above, wind speeds in Germany are on average lower than in the UK because the variance between the different sites is large. Logically, the differences in the wind resource are reflected in the land lease. That is, while developers in the UK might have had to bear seemingly lower support but were able to keep large parts of the revenue streams to build their own profit margins, support payments in Germany were often passed on by the developers and reaped by land owners. As such, one factor to explain the difference in the support levels was that developers in Germany had to pay higher charges for their land use than developers in the UK.

Another important factor was the signalling effect of a slightly higher FIT. Compared to the British tenders, which were often run in intermittent intervals and thus caused instable investment conditions (Del Río & Linares, 2014), the German FIT entailed a more secure and encouraging investment climate (Lauber, 2004; Mitchell, Bauknecht, & Connor, 2006). Since support payments were paid for all realised projects and throughout their whole lifetime, the FIT inherently reduced possible risks as well as uncertainties and therefore entailed relatively low capital costs (Ofgem, 2007). In turn, the security of the FIT stimulated the development of the domestic production industry and generated competition in this sector. This development is considered decisive and is regarded as the foundation for additional cost decreases, both domestically and across borders. To date, the European market for wind production is mainly dominated by companies operating in Germany, Denmark and Spain. All these countries implemented a FIT to support their wind industry.

As Kitzing & Mitchell (2014) emphasise, reducing risk exposure for private investors is particularly important during the early stages of a transition period. Allowing investors to lower their costs of debt and their cost of equity respectively, a reduction of risks ensures a fast deployment of RES and facilitates the growth of niches where different technologies are protected to develop until they reach the stage to be integrated in the existing energy system. It is commonly agreed that administratively set FIT, compared to auctions, entail lower market risks. As such, they are often considered better suited to ensure the development and deployment of technologies that are immature and not yet ready to compete on the markets (Batlle, Pérez-Arriaga, & Zambrano-Barragán, 2012; Del Río & Linares, 2014). Moreover, while technology-specific FIT usually allow different technologies to develop in parallel, only few (usually the cheapest technologies at the respective point in time) manage to prevail under technology-neutral tendering schemes (Del Río & Linares, 2014; Lipp, 2007).

Finally, although usually disregarded in economic analyses, transaction costs often constitute a considerable part of the costs of a support instrument. As such, they should play an important role when analysing an instrument’s cost-effectiveness (Del Río & Linares, 2014). There is broad consensus that due to their bureaucratic procedures and their complexity, the transaction costs of auctions are higher than those of administratively set support (see e.g. Agnolucci, 2007; Finon & Menanteau, 2004). Particularly during the auctions in France and the UK, they were an important factor for the low installation rates (Menanteau et al., 2003). As emphasised by Del Río & Linares (2014), the high transaction costs of auctions may easily outweigh some of their possible advantages, especially for small investors. While this might reduce market competition and hamper the efficiency of auctions, it might as well lead to issues of social acceptance (Edge, 2006). Eventually, transaction costs may raise entry barriers and thereby impede the market access for innovative yet undeveloped technologies.

3.2 Prices vs. Quantities

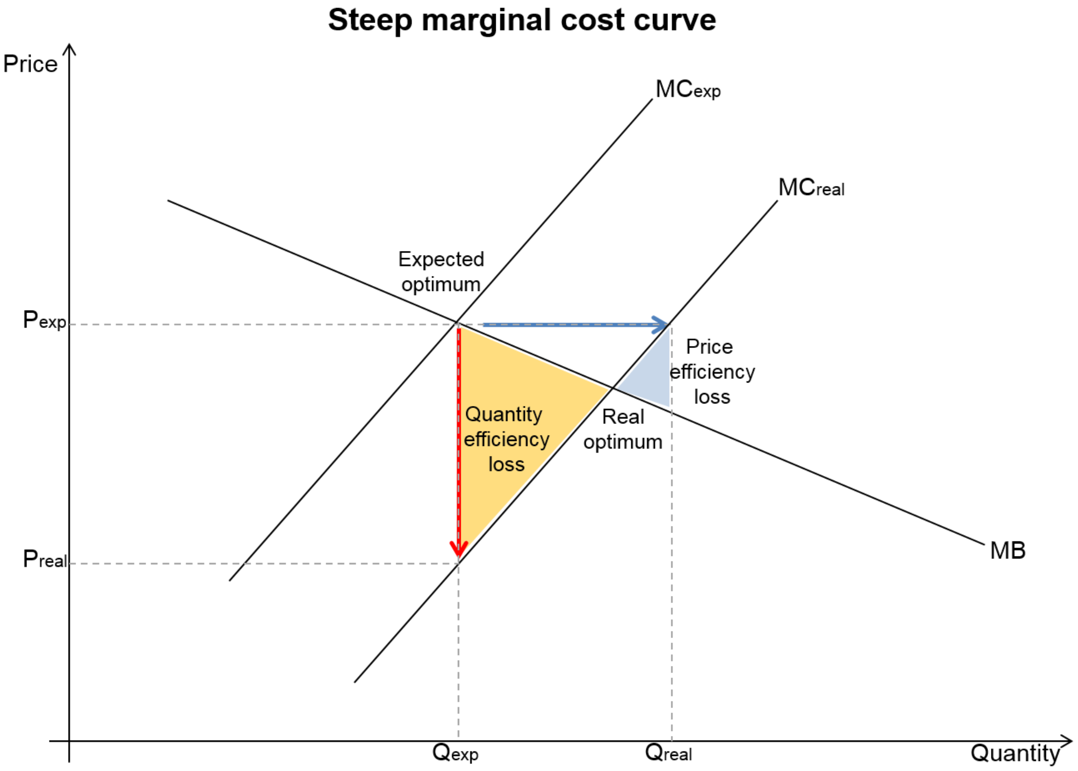

Figure 2: Prices vs quantities with a steep marginal cost curve
Source: Own illustration

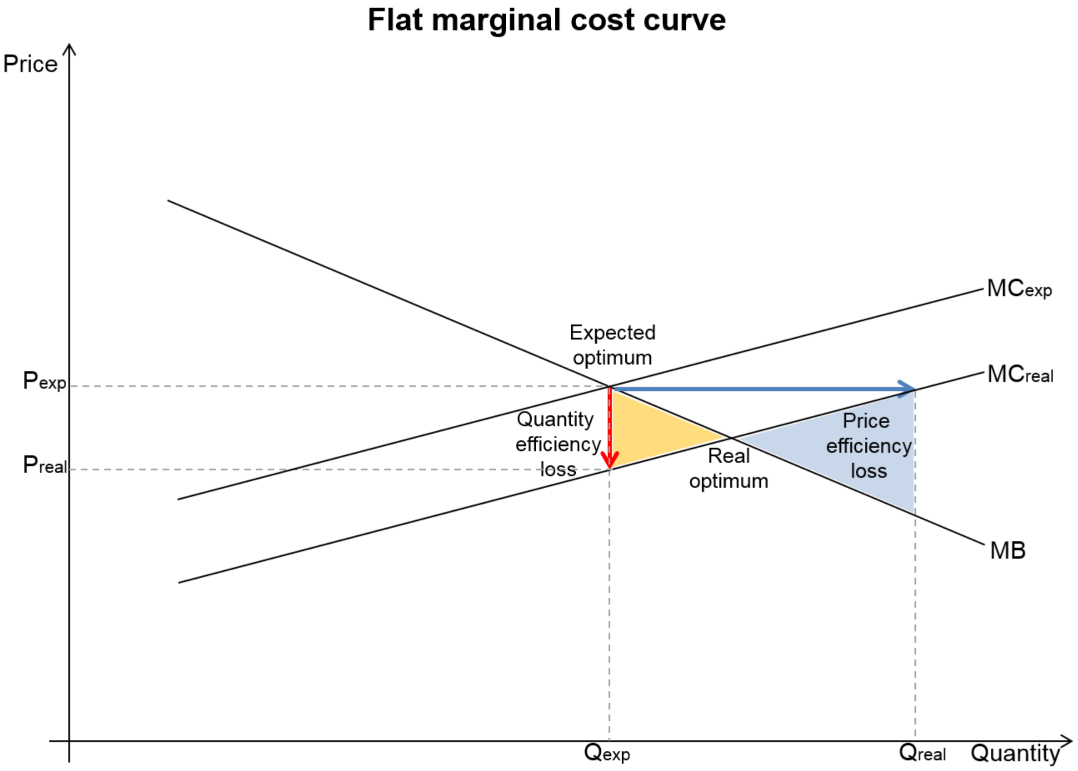

Figure 3: Prices vs quantities with a flat marginal cost curve
Source: Own illustration

In the remainder of this section, the focus of analysis shall be on the literature that is more theoretical. This literature takes a rather general perspective and defines policy instruments somewhat more broadly. That is, it does not in particular focus on comparing FIT and auctions based on their specific features and characteristics but rather aims at understanding the core differences that come along with their nature. In principal, all RES support instruments may be defined either as price or as quantity instruments depending on which of the two variables is exogenously given by the instrument. Thus, FIT with a predetermined support price can be considered a price instrument whereas auctions and tendering schemes may be understood as quantity instruments.[1] This part of the review intends to examine the above touched risk aspect in more detail, where risk shall be regarded from the perspective of a regulator. It will summarise the theoretical arguments for and against the two instruments and thereby lay out the foundation for the analysis that is to follow in section 4.

It is an essential lesson from resource allocation theory that prices and quantities – the two means of control – are strongly connected in that a particular outcome can always be achieved on two ways; either by setting a price or by setting the corresponding quantity. In fact, in a well-functioning market (i.e. under perfect competition) and one of perfect knowledge (i.e. under perfect information and certainty) there will be no difference between the two means such that a preference for one or the other should not exist (see e.g. Cropper et al., 1992; Weitzman, 1974). This symmetry between the two modes will blur, however, once the strong assumption of certainty proves not to hold, and regulators are exposed to the risk of setting inefficient incentives. In that case, both price and quantity instruments may entail fundamentally different results.

The disparity of price and quantity regulation was first demonstrated by Martin Weitzman (1974) in his much cited paper *“Prices vs Quantities”*. The paper investigates a situation of uncertainty regarding the marginal cost and the marginal benefit function, which implies an additional risk for the regulator to set inefficient prices and quantities. More precisely, the uncertainty induces a change of the regulator’s optimisation problem; while under certainty, the regulator had to determine the market clearing price or the corresponding quantity to maximise social welfare, the regulator will, under uncertainty, aim at maximising the *expected* social welfare and at the same time try to minimise the exposure to unexpected negative outcomes. As Weitzman’s (1974) postulated theorem suggests, the latter can be achieved by a prudent choice between price and quantity instruments.

The intuition of Weitzman’s (1974) proposition is illustrated in figure 2 and figure 3. If either marginal costs or marginal benefits are predicted incorrectly, both price and quantity regulation will entail suboptimal results implying a loss in societal welfare. Such welfare losses may have two different causes: First, if the actually produced quantity is lower than in the real optimum, the marginal benefit of an increase in production would outweigh its corresponding marginal costs. Thus, the welfare loss describes the lost surplus (quantity efficiency loss). This is indicated by the yellow triangle. Secondly, if the actually produced quantity is larger than the real optimum, the marginal costs of the additional production exceed the corresponding marginal benefits. As such, this additional production is not desirable from a societal perspective (price efficiency loss). This is indicated by the blue triangle.

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[1] In general, auctions do not per se need to be quantity instruments. In fact, this is only the case if a certain capacity to be auctioned is predetermined and bids are selected on a price basis. However, it might as well be possible to determine a budget first and subsequently award the bidder who is able to ensure the largest capacity deployment with the given financial means. We disregard the latter case in this analysis since it is (so far) not of relevance in RES policy-making.

Both Figure 2 and Figure 3 provide examples where the actual marginal costs are lower than those anticipated by the regulator. In that particular case, a quantity instrument may yield a price, which is lower than expected, whereas a price instrument may lead to an undesirably large production (the two arrows illustrate the discrepancies: red = price deviation under quantity instruments; blue= quantity deviation under price instrument). However, the two figures also demonstrate that the extent of the undesired result ("the regulator's regret") may differ depending on which instrument is employed. In the presence of uncertainty, it is the slopes (elasticity) of the marginal cost and the marginal benefit curve that suggest which of the two instruments to choose from. As can be seen in Figure 2, the expected social welfare under a quantity instrument falls short of that under a price instrument, given the marginal cost curve is steeper than the marginal benefit curve: The welfare loss under the quantity instrument (the yellow triangle) is larger than that of the price instrument (blue triangle). However, if the slope of the marginal cost curve is gentle relative to that of the marginal benefit curve, the quantity instrument will be superior (see Figure 3). In that particular case, a price instrument such as a FIT would entail a larger loss to societal welfare (area of the blue triangle is larger than that of the yellow triangle). This causal relation holds true independent of whether it is the marginal costs or the marginal benefits that are mispredicted and whether those factors are over- or underestimated.

Not surprisingly, several scholars used the theoretical framework of Weitzman (1974)in the years following his work. Particularly among environmental economists, some devoted themselves to the question of how potential cost and benefit curves for emission abatement technologies might look like in order to allow for inferences regarding the respective policy instrument. To date however, scientific insights in that respect are fairly controversial. While both Del Río & Linares (2014) and Finon & Perez (2007) assume that marginal cost curves of renewable energies are rather flat – providing an argument in favour of quantity instruments[2] – Kitzing & Mitchell (2014) advocate for a more differentiated view, namely, to distinguish between the different technologies. In fact, they claim that the slope of marginal cost curves depends on the maturity of the respective technology and will only be small if the technology is mature. By contrast, the marginal cost curves of immature technologies would be relatively steep since the niches in which they develop are often small. Usually, there exist only few equipment manufacturers for such technologies and only few sites may be exploited so that cost differences between available projects are likely to be large. Given relatively constant marginal benefits of emission reduction, the arguments laid out by Kitzing & Mitchell (2014) suggest, therefore, to draw on price instruments when regulating the deployment of immature technologies.

Another interesting argument is presented by Stern (2007), who implies that cost and benefit curves may have different shapes depending on whether the regulator adopts a short- or a long term perspective. Considering the short term (e.g., a perspective of one year), Stern (2007) argues that it becomes progressively more expensive to install additional renewable technologies unless it was possible to exploit further cost potentials by R&D or adjust the available technology (both is assumed to be impossible under short time horizons). Consequently, he assumes the short-term marginal cost curve to be relatively steep. On the other hand, the short-term marginal benefit curve of RES is assumed to be rather flat. This reflects the fact that deployment within a short time period will not have a considerable impact on the ultimate climate goals and it is, thus,

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[2] Although Del Río & Linares (2014) claim that flat curves of renewable energies provide a theoretical advantage for quantity instruments, they do not advocate for quantity regulation per se. In fact, they build their analysis on multiple cost factors among others e.g. transaction costs, which do not influence the shape of the curve.

justifiable if short-term deployment rates deviate (positively or negatively) from the respective short-term targets. By contrast, adopting a long-term perspective, the slopes of the two curves might change. As Stern (2007) suggests, it is the marginal benefit curve that will be steep (steeply decreasing) and the marginal cost curve that will be rather flat (gently increasing) in the long term. While the steep decrease of the marginal benefit curve expresses that it will be more important to employ renewable technologies as cumulative emissions increase, the flat nature of the marginal cost curve reflects that the regulator will be able to adjust the choice of technology and make use of technological developments in the long term.

Building on Weitzman (1974) theoretical suggestions, the notion of Stern (2007) implies that a price instrument may be a useful tool for regulation, when policy makers adopt a short term view (e.g. when they consider policies up to 1 – 3 years), whereas quantity instruments may be better suited for the long term (e.g. for policies of 20 years or more). However, since in reality the transition from short to long term will be continuous, the slope change of the two curves will be steady but slow. Therefore, the employment of both regulation types in tandem might be advisable for the medium term, when large welfare losses for either instrument can be ruled out. This recommendation is supported by Weitzman (1978) and will be further discussed in section 6.3.

Preliminary Conclusions

The analysis above has demonstrated that risk aspects constitute an important factor understanding the decision-making of policy makers regarding which instrument to use. Under uncertainty, particularly the choice between price and quantity regulation can be decisive as Weitzman (1974) theoretical elaborations have shown. While price instruments such as FIT may minimise the risk of welfare losses given the marginal cost curve is relatively steeper than the marginal benefit curve, quantity means (e.g. auctions) may be superior otherwise. Based on this theoretical foundation, it may now be interesting to understand which factors influence the shape of the two curves and how they might look like in reality. We will address this issue in the following section.

4 Marginal cost curves of RES technologies: Steep or flat?

Although there is broad agreement on the theoretical implications that follow from Weitzman’s (1974) theorem, insights from the theoretical discourse have found little application in real life policy-making. An important reason for that might be that there is considerable uncertainty about the actual slope of the marginal cost and benefit curves. As sketched in the review above, Del Río & Linares (2014) and Menanteau et al. (2003) argue, for example, that cost curves for renewable technologies are relatively flat whereas Kitzing & Mitchell (2014) claim the opposite – at least for immature technologies. Also, empirical research that has focused on this issue is to date rather scarce as it is very difficult to gather the data that is necessary to construct the cost curves. Particularly for real data, the enormous amount and the confidentiality makes it nearly impossible to obtain them.

In order to overcome this issue, the analysis following in this section draws on the modelling outcome by Held (2010), namely the cost-potential curves for onshore wind, solar and biomass for the year 2009, which have already been used in the course of the RE-Shaping project (Hoefenagels et al. 2011). These curves are well suited for the purpose of this analysis as they reflect the generation costs of different technologies depending on realisable potentials until 2050. Nonetheless, the curves are subject to some simplifying assumptions, which have been made during the modelling process. The following analysis shall not be understood as a basis of decision-making but rather as a tool of decision aid. As the focus of analysis will only be on cost curves, we do not intend to reflect the entire decision field of a policy maker but instead focus on one relevant aspect that may be important when deciding which instrument to use. In particular, we seek to understand under which circumstances those curves may be flat or steep.

4.1 Cost-potential curves for selected technologies

4.1.1 Onshore Wind

As explained above, the cost-potential curves developed by Held (2010) stem from 2009 and account for potentials realisable until the year 2050. This implies that certain restrictions (both technological and social), which prevent an immediate deployment, can be overcome until then. In principal, two factors are important in order to determine the potentials for wind energy; that is first the wind regime affecting the amount of energy that can be harvested and second the available land, which restrains the capacity potential. Both the data to determine the wind conditions and the data on the available land were taken from public databases (New et al. 2002 and EEA 2002). However, to calculate the corresponding full-load hours, based on the given wind conditions, it was necessary to define a reference turbine. For this purpose, Held (2010) selected a 2 MW Vestas (V80) turbine. This determination of a reference turbine was important in order to make turbines at different sites and under different wind regimes comparable. Nonetheless, it constitutes an important simplification as in general, investors would adjust the turbine parameters (generator size, hub height and rotor diameter) depending on the wind conditions. The power output and the corresponding full-load hours respectively may therefore be underestimated at sites with relatively low wind speeds.

The second necessary component for the cost-potential curves are the electricity generation costs. In principle, the factors determining the economic performance differ from technology to technology. For wind, it is primarily the regional wind conditions as well as turbine parameters, which make up its quality and determine the costs. The more wind can be harvested at a given site, the more profitable becomes the wind power plant and the lower its levelised energy generation costs. However, since only one turbine type was assumed for all different sites, investment as well as O&M costs are assumed to be the same. Differences in costs can therefore only arise due to different wind conditions at the available sites. The cost-potential curves for onshore wind in different countries developed by Held (2010) are illustrated in Figure 4.

Figure 4 depicts the cost-potential curves estimated by Held (2010) for 15 EU member states in 2009. It can be seen that the generation costs of onshore wind range from 4 €Cent/kWh to 12 €Cent/kWh. Note that, per assumption, values outside this spectrum are not possible because only sites with an average wind speed of min 5 m/s and max 9 m/s were considered in the model. Furthermore, the figure demonstrates that there are considerable differences in the annual onshore wind potentials and the corresponding generation costs among the countries. While in Denmark, for example, relatively much of the existing annual potential can be reaped at low costs, Austria or the Netherlands face much less potential and a steeply increasing cost curve. However, since the land areas of the EU countries as well as their population sizes differ to a large extent, comparing the slope of their cost-potential curves may be misleading and has to be done with caution. It is

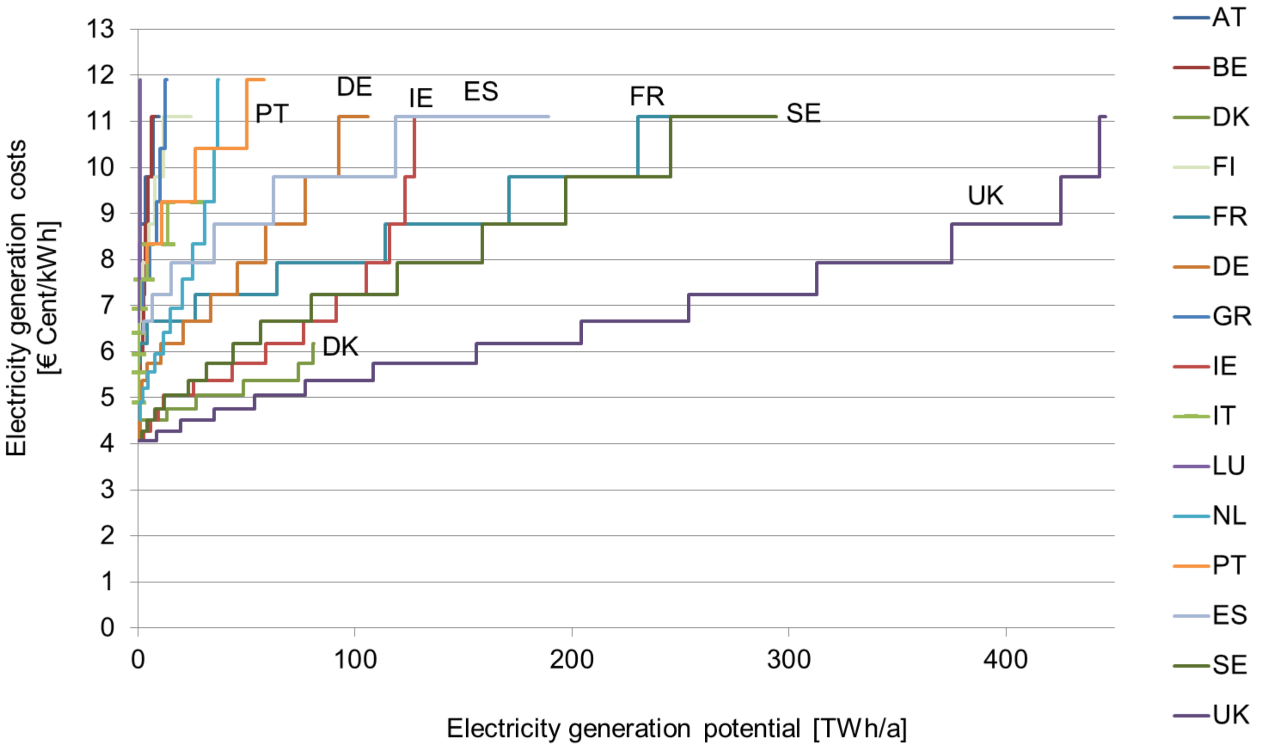

Figure 4 - Cost-resource curves for onshore wind energy in 15 EU countries for 2009
Source: Held (2010)

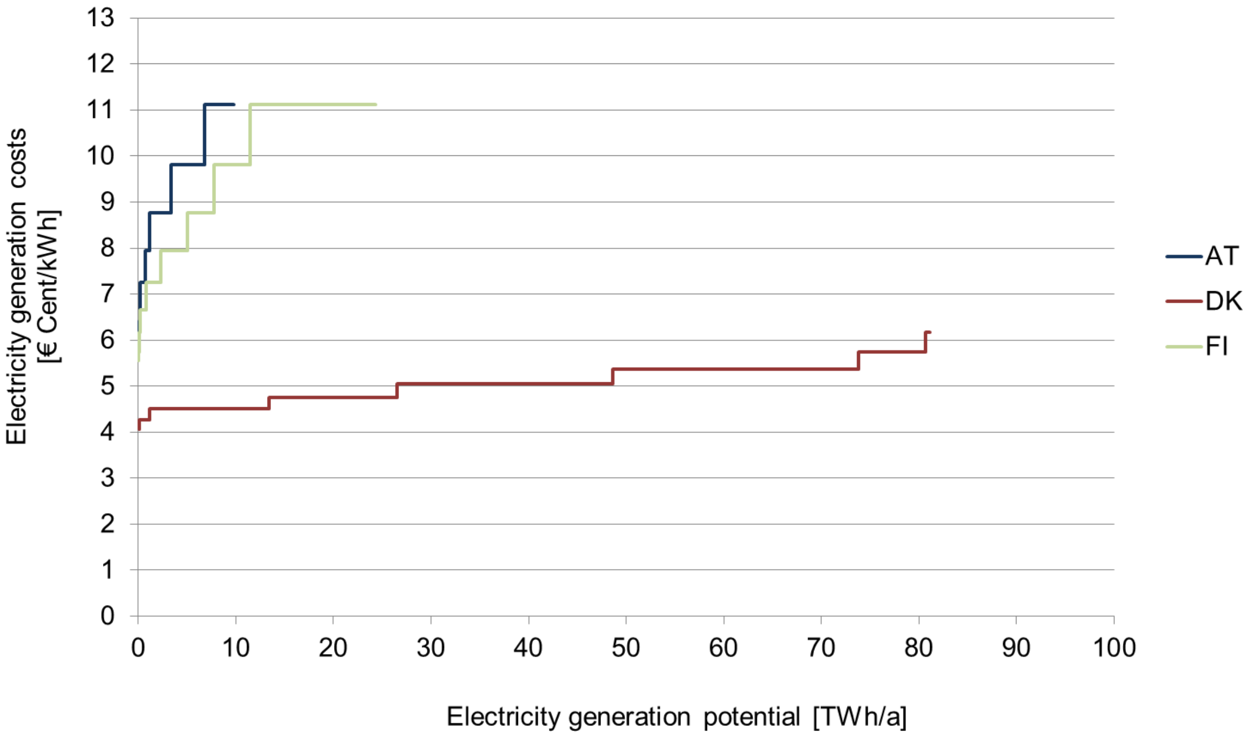

Figure 5 - Cost-resource curves for onshore wind energy in Austria, Denmark and Finland for 2009
Source: Held (2010)

obvious that a country large in size may have higher potential than a smaller country. Yet, it seems also likely that the larger country has to supply a larger demand, if its population is large. Therefore, comparing e.g. the cost curves of Luxemburg and the UK does not provide much information. To be able to interpret the cost curves' slope with respect to the framework developed by Weitzman (1974), they have to be seen in relation to the countries' demand curves (or marginal benefit curves).

An interesting comparison can be made for similar countries, e.g. between Denmark, Finland and Austria as in Figure 5. Since the three countries have similar population sizes, it seems reasonable to assume that they also have a similar demand for electricity. In Denmark, however, not only the amount of the available wind potential but in particular the amount of high quality potential (i.e. low-cost) is considerably larger than in Finland and Austria, which is reflected in the slope of the countries' cost curves. While Denmark faces a relatively flat cost-potential curve, the curves of Finland and Austria are comparably steep. Following Weitzman (1974) theoretical argument, the incentive to employ a price instrument for regulation seems therefore larger in Finland and Austria than in Denmark. More generally, the finding suggests that the incentive to employ an auction is larger in countries with abundant wind resources. Yet, since we only considered the countries' cost curves relative to each other but did not compare them to each country's actual benefit curve, this insight cannot not be understood as a concluding recommendation regarding the countries' regulation policy.

4.1.2 Solar PV

Unlike for onshore wind, where cost potential curves were analysed for single countries within the EU, Held (2010) considers cost potential curves for solar PV aggregated on the EU level. However, she distinguishes between three different PV types, that is, installations on free fields, roof-integrated and façade integrated PV plants. The generation potential of these three technologies depends on two factors; first the available land area suitable for the installation of solar plants and second, the solar radiation. While the former determines the capacity potential, solar radiation defines the quality of the sites. Similar to the wind speed, the radiation of solar energy may fluctuate from location to location, which makes certain regions more attractive than others. Particularly in northern Europe, the solar radiation intensity is considerably lower than in the South. In 2009, when Held's (2010) study was conducted, all three PV types were characterised by high investment costs, although façade-integrated PV plants were still more than twice as expensive as plants on free fields, both in the investment and in O&M. For that reason, the economic performance and the technologies' cost-effectiveness respectively were largely dependent on their energy generation, which again, was determined by solar radiation. In order to estimate the electricity generation costs, Held (2010) employed solar radiation data from the PVGIS database by the Institute for Environment and Sustainability (IES). Information regarding the available area was drawn from a study by IEA (2002).

Figure 6 shows the cost-potential curves for the three different solar plant types aggregated on the EU level in 2009. With a yearly potential of more than 1,100 TWh, free field power plants constitute the technology with the largest capacity potential. In addition, they have the lowest electricity generation costs (186 €/MWh – 411 €/MWh) among all three types, which correspond to an amount of 700 full-load hours in the north and 1,500 full-load hours in the south respectively. While the capacity potential of roof-integrated power plants amounts to ca. 450 TWh per year, their generation costs (214 €/MWh – 474 €/MWh) are only slightly below those of free-field plants. Façade-integrated plants have by far the lowest capacity of only 111 TWh, which

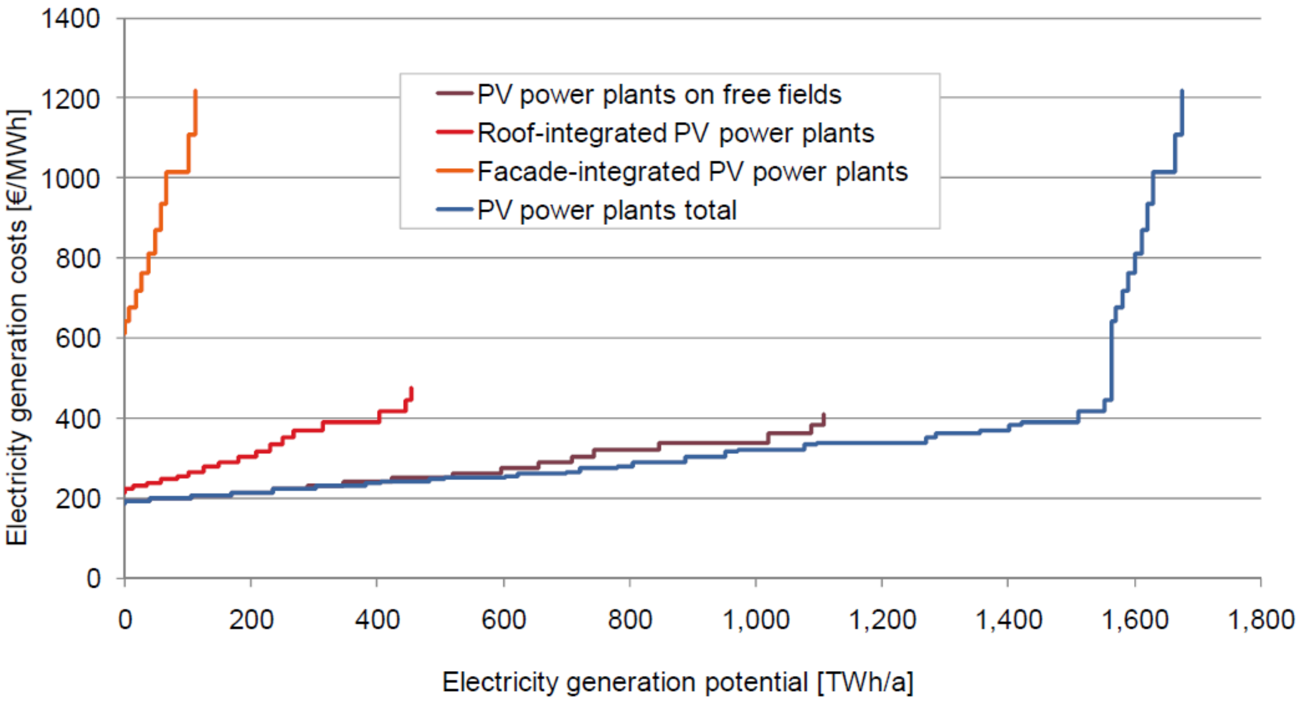

Figure 6 - Cost-resource curves for solar PV technologies in the EU27 in 2009
Source: Held (2010)

corresponds to ca. 7% of the total PV potential in the EU. Also, their generation costs (609 €/MWh – 1,218 €/MWh) are considerably larger than those of the two other plant types.

In order to interpret the slopes of the three curves, we make the important assumption that all three technologies are substitutes. This implies that all power plant types face the same aggregated demand. However, since we are unaware of the actual slope of this demand curve, assertions regarding the three technologies can only be of comparative nature. Considering the slopes of the three cost-potential curves, it becomes obvious from Figure 6 that the curve corresponding to the cost-potential of façade-integrated power plants is considerably steeper than the curves for free-field or roof-integrated plants. Thus, the incentive to employ a FIT (or an alternative price-based instrument) is comparably larger in the case of façade-integrated plants than it is for roof-integrated or free-field plants assuming that it is possible to tailor support policies for each individual technology type. It appears that the rather undeveloped, small-scale technology type faces the steeper cost-potential curve, which may imply that the incentive to use an auction is larger when dealing with rather mature technologies. However, as the cost-potential curves displayed in Figure 6 illustrate the generation costs and the capacity potentials on the EU-level, they do not allow for particular inferences on the incentives for each individual country. In fact, it seems likely that the curves on a country level might be of different shape since costs and potentials may differ substantially for each individual country.

4.1.3 Biomass

Eventually, Held (2010) estimates the cost-potentials for biomass in all EU countries. She exploits existing data by EEA (2006) on the available biomass potentials in the EU, similar to the case of PV solar. Data regarding the efficiencies of the electricity generation technologies and their costs is obtained by Ragwitz et al. (2006). It is important to note that, unlike for wind turbines and solar modules, where costs where assumed

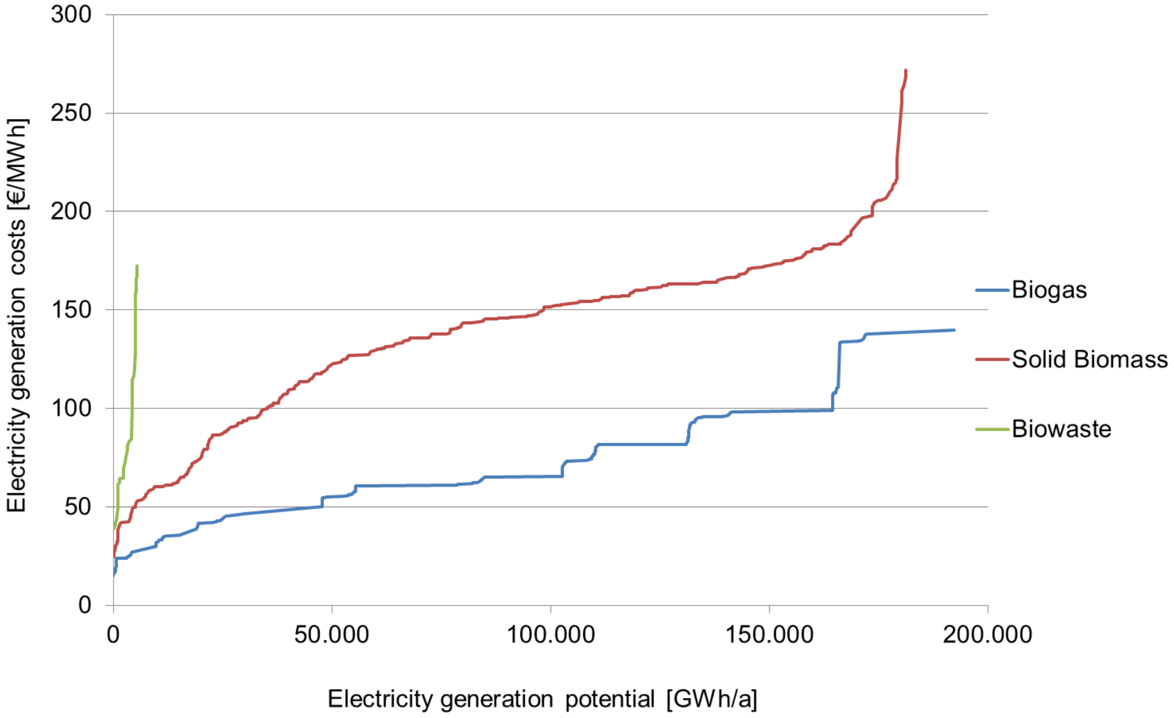

Figure 7 – Cost-potential curves of Biogas, Solid Biomass and Biowaste in the EU 27 in 2009
Source: Held (2010)

to be consistent for a given plant, both the investment and the O&M costs for biomass plant types vary considerably depending on the specific biomass technology and their corresponding characteristics (e.g. plant size or fuel costs). As illustrated in Figure 7, Held (2010) distinguishes between three different biomass types, namely solid biomass, biowaste and biogas.

Figure 7 shows the cost potential curves of the three biomass forms aggregated on an EU-level. It illustrates that the electricity generation costs of all three technologies have a wide range from 30 €/MWh up to 270 €/MWh in the case of solid biomass. However, the generation potentials of the biomass types differ considerably. While biowaste only reaches an annual resource potential of ca. 5,500 GWh, and thus faces a comparably steep cost-potential curve, the annual potentials of both biogas and solid biomass exceed 180,000 GWh. Since in relation to biowaste, the cost-potential curves of biogas and solid biomass are relatively flat, the incentive to support these technologies by means of a quantity-based instrument is larger. Similar to the case of solar PV, the data for the three biomass types suggest that the cost-potential curve of small-scale technologies are rather steep, while they are comparably flat when the technology is more mature. As such, they reinforce the impression that auctions are better suited to support the deployment of more developed technologies. However, as the estimated curves represent the costs and the potentials aggregated for 27 EU states (as for solar PV), this implication rests on the assumption that such a policy could be implemented on an EU-level. Moreover, it implies that the three biomass types constitute substitutes and therefore face the same demand function.

For the present report, another comparison has been made in order to contrast the cost-potentials for biomass on a country level, where only the cost-potential curves of Austria, Denmark, Finland, Ireland and Slovakia are considered (see Figure 8). Since these five countries are similar in terms of population size and presumably

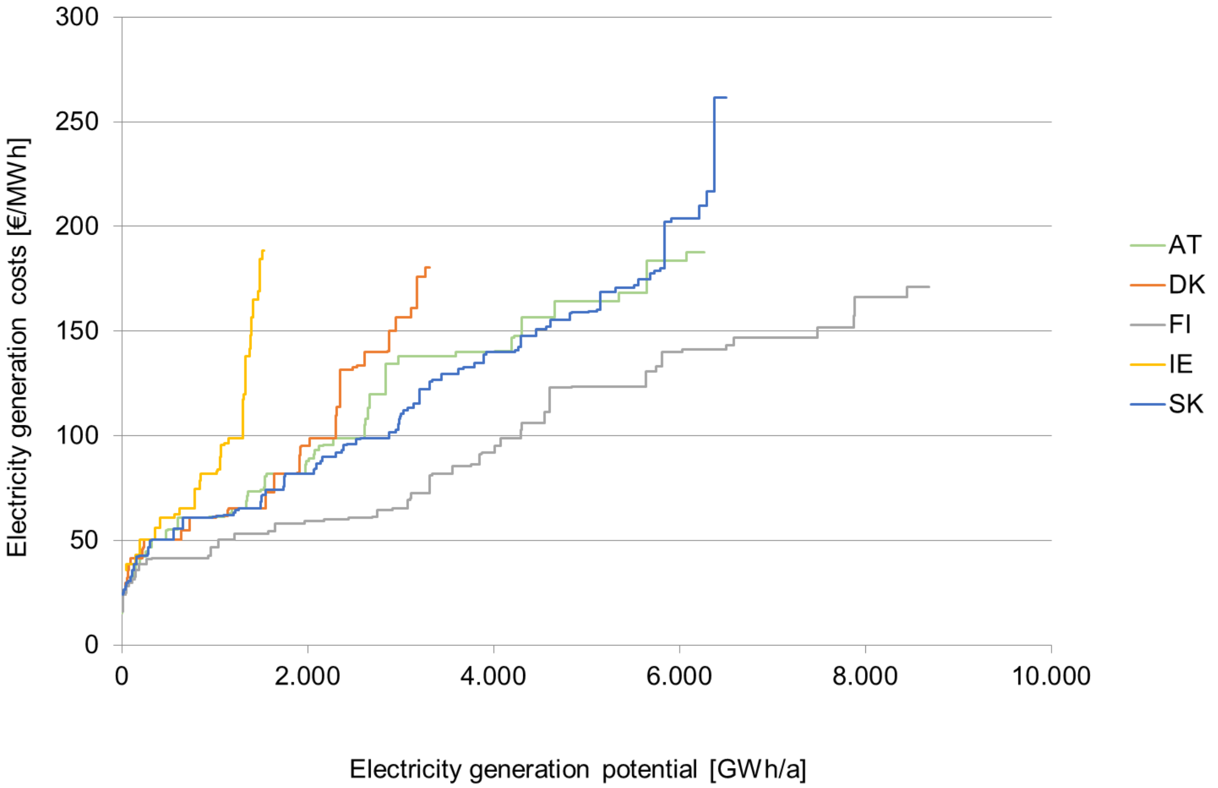

Figure 8 - Cost-resource curves for biomass in five EU counties
Source: Held (2010)

face a similar demand for electricity, we assume their cost-potential curves to be comparable. Note that for this comparison we no longer distinguish between the three biomass forms. Instead, the potentials and costs of the three types are aggregated and treated as a single technology.

As illustrated in Figure 8, the slopes of the five cost-potential curves vary considerably. While Ireland faces a poor supply of biomass potential (1,500 GWh/a) and a cost range from 30 €/MWh to 190 €/MWh, costs in Finland have a similar range but spread over a potential of 8,700 GWh/a. Thus, many of the biomass resources in Finland can be reaped at comparably lower costs than in Ireland. Yearly biomass potentials of Austria (6,300 GWh/a), Denmark (3,300 GWh/a) and Slovakia (6,500 GWh/a) are in between. Due to the large spread of costs but the low biomass potential, the corresponding cost-potential curve of Ireland is substantially steeper than the cost-potential curves of the other countries. Building on Weitzman's (1974) argument, this implies that the incentive to support biomass by means of a price instrument should be largest in Ireland. However, the biomass considered by Held (2010) comprises three different forms. Since the estimated cost-potential curves represent the aggregated potentials for all three biomass types, the slopes of the depicted curves are lower compared to each technology's individual cost-potential curve.

4.1.4 Comparison of Technologies

So far, this analysis has considered different RES technologies independently and has only focused on comparisons between countries, which implied that the conditions within the respective countries are similar. Particularly the countries' demand functions were assumed consistent in order to allow for comparative

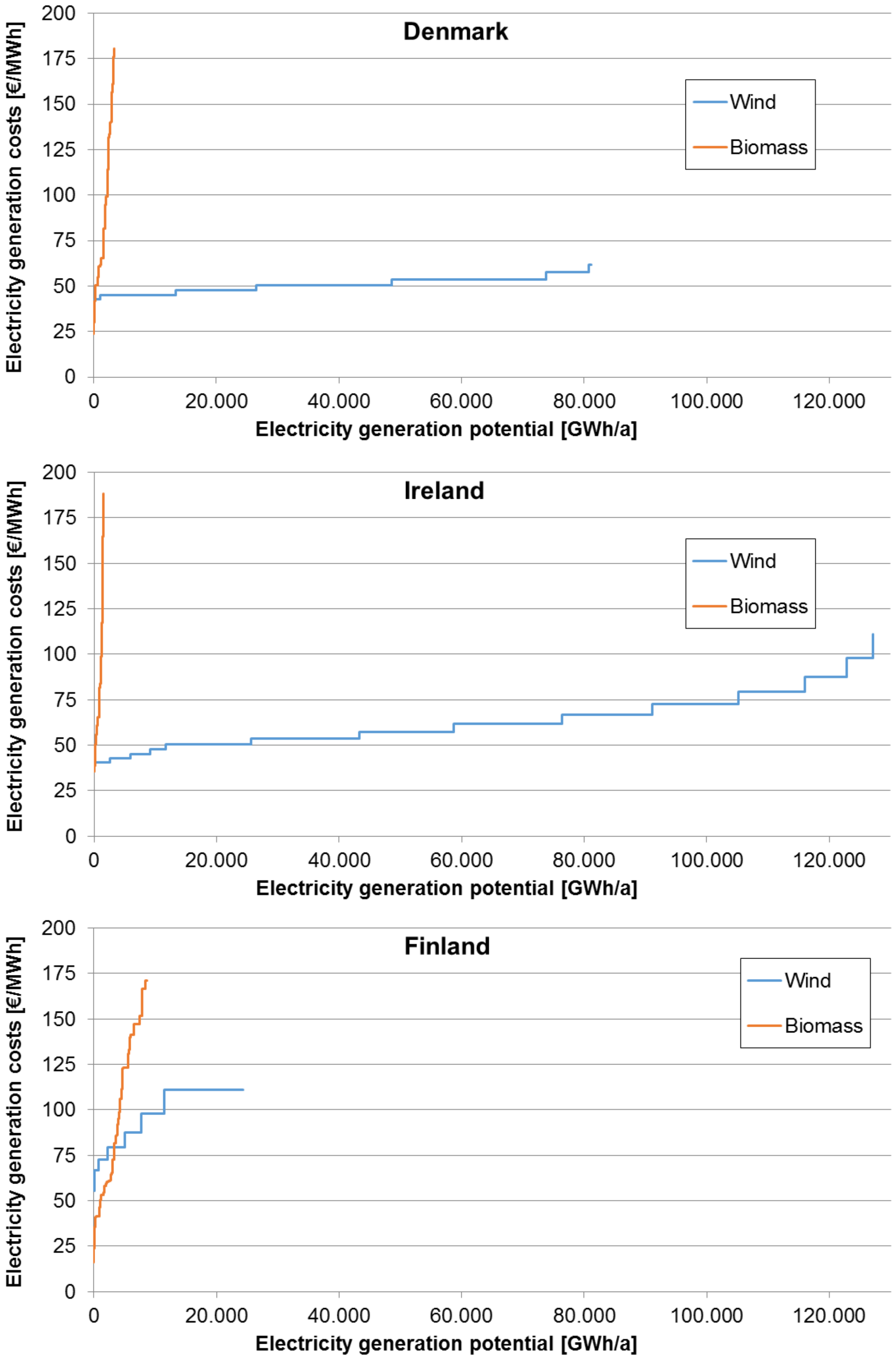

Figure 9 - Cost-potential curves for onshore wind and biomass in 2009
Source: Held (2010)

statements. Nonetheless, it is also possible to compare the technologies among each other to understand whether different technologies require different means of support and to evaluate the suitability of a technology neutral support. Focusing on specific country cases, such a "within-country" analysis allows dropping the vague assumption on similar country demand functions. It implies, however, that all RES technologies are substitutes and face the same demand.

Figure 9 depicts the cost-potential curves of biomass and onshore wind for the countries Denmark, Ireland and Finland in 2009. Comparing the different technologies among each other stresses the point that an analysis of a technology's costs-potential curves with respect to the theoretical results by Weitzman (1974) may only yield meaningful insights if it is set in relation to other technologies. It is obvious that in all three cases the pattern of the two curves is the same: While the cost-potential curve of onshore wind is rather flat, the cost-potential curve corresponding to biomass is comparably steep. The difference in the slopes is more striking in the cases of Ireland and Denmark but even in Finland where the biomass potential is relatively abundant and wind conditions are rather poor, the slopes of the two curves differ considerably. It is, therefore, a possible implication of Figure 9 that onshore wind could be supported by different support means than biomass even though this implication has to be treated with caution. This analysis has considered "biomass" as one single technology and has left out that, in fact, it comprises three different biomass types (biogas, solid biomass and biowaste). As seen before, all three biomass technologies may as well differ in terms of costs and potentials.

The differences in the slopes of the cost-potential curves illustrated in Figure 9 provide a tangible argument against a technology neutral support, which implies to treat all RES technologies equally. While for some technologies, like onshore wind, the incentive to employ a quantity-based instrument may be high, other technologies such as biomass and, in particular, immature technologies may be more efficiently supported by means of a price regulation. In fact, a technology specific support that allows adjusting an instrument to the individual needs of the technology could reduce the risk exposure for regulators by mitigating welfare losses in case of suboptimal, ex ante regulation.

4.2 Development of cost-curves over time

Considering the aspect of time when analysing the cost-potentials of RES is important, as it allows existing technologies to develop both in terms of efficiency improvements and cost reductions. Moreover, time may affect the existing potentials for RES, since some of them will be exploited whereas new potentials may arise. Not accounting for such dynamic considerations, the analysis conducted in section 4.1 did therefore only provide a static perspective. This section intends to provide insights about the temporal development of the technologies' cost-potential curves.

Unfortunately, the cost-potential curves developed by Held (2010) constitute the most recent figures regarding cost-potentials of RES and other cost-curves are not available. For that reason, an extensive analysis considering the development of all RES technologies is not possible. The focus in this section will be on an example case for solar PV in Germany, where the generation potentials modelled by Held (2010) have been updated for the year 2014 according to data from the German Federal Ministry for Economic Affairs and Energy (BMWi, 2015) and Agentur fuer Erneuerbare Energien (2016). Assumptions regarding cost developments of solar modules are based on price data by PV-Xchange (2016). It is important to note that the

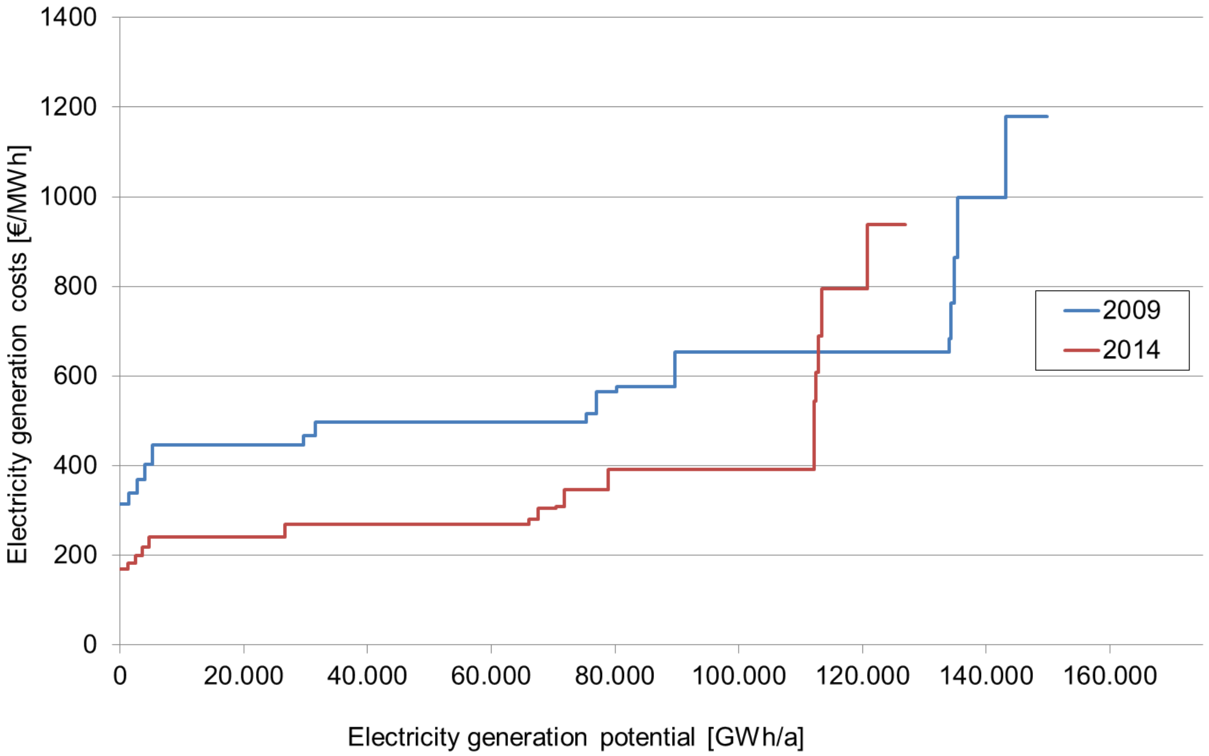

Figure 10 - Development of cost-potential curves for Solar PV in Germany

following example of the development of solar PV in Germany shall not be representative for the development of other RES technologies. It shall rather serve to stress the importance of dynamic aspects when deciding on the use of policy instruments.

Figure *10* illustrates the cost-potential curves of solar PV in Germany both for the year 2009 and 2014, where each curve comprises aggregated information for free-field installations, roof and façade-integrated power plants. It is obvious that the general shape of the curve is similar in both years, even though the curve has shifted further down and to the left due to general price drops and reduced capacity potentials. However, a closer look at the two curves reveals that there are in fact small differences in the shapes, which arise because the assumed cost and potential reductions are not equal for each individual PV technology type. For example, while potentials of roof-integrated PV plants have decreased by almost 25%, those of façade-integrated PV have only decreased by 6%. Similarly, cost reductions for façade-integrated plants were rather moderate (-20%) compared to those of free-field (-46%) and roof-integrated plants (-42%). Due to a lack of more detailed information, it was assumed that capacity reductions are similar for each technology band, which obviously constitutes a simplifying assumption. In fact, it seems likely that particularly low-cost potentials have decreased with a larger rate than cost-intensive generation potentials, unlike it is suggested by **Figure *10***.

As the two curves depicted in **Figure *10*** demonstrate, a temporal development usually entails two important effects. On the one hand, R&D causes a technology to develop which may be manifested in terms of efficiency improvements or reduced investment costs. On the other hand, the deployment of a renewable resource such as solar PV implies a continuous decrease of available sites suitable for that resource. Particularly those sites that prove favourable will usually be exploited early and thus will be unavailable later on. Importantly, both factors – the decreasing investment costs and the decreasing availability of sites – stand in contrast to each other. While a decrease in investment costs for solar PV causes its electricity generation costs to drop (and thus a flattening of the cost curve), a reduced availability of suitable sites pressures the generation costs to increase (making it steeper). Eventually, the remaining question is; which of the two effects looms larger?

Providing a general answer to that question is nearly impossible as it depends decisively on the initial overall potential of a technology as well as on its maturity level. Considering solar PV, a technology with large amounts of high quality potentials in many European countries, it is likely that efficiency improvements are dominant, which implies a continuously flattening cost-potential curve. Biomass, by contrast, constitutes a technology whose resources are rather limited so that the cheapest fractions of the potential are readily exploited. Since in this case electricity generation costs are likely to increase over time, the cost-potential curve may become steeper.

4.3 Preliminary Conclusions and Discussion

Drawing on modelled cost and RES potential data by Held (2010), the previous analysis sought to extend Weitzman’s (1974) solely theoretical discussion on the optimal use of price and quantity instruments and provide an application to policy-making.

Our analysis has shown that implications based on the cost-potential curves of the three selected RES technologies are both country- and technology-specific. It became obvious that the incentive to support e.g. onshore wind by means of quantity regulation is considerably larger in countries with abundant wind resources (e.g. Denmark or Ireland) than in countries where wind conditions are rather poor (e.g. Austria or Finland). Moreover, we found that rather small-scale technology types such as façade-integrated PV plants or biowaste provide a larger incentive for price-based instruments than their related pendants, that is, roof-integrated or free field plants and biogas or solid biomass respectively. A possible explanation for this finding could be the maturity level of the technology types, which might be responsible for the large cost differences and the rigidity to adapt to less suitable sites.

However, since the focus of the analysis was only on cost-potential curves of selected RES technologies (onshore wind, solar PV and biomass) and not on the technologies’ demand side, the analysis does not claim to be complete and shall not be understood as a foundation for decision-making. Instead, it was its primary goal to reflect on one important aspect when considering which instrument to employ and to point out avenues on how analyse it.

Our analysis has further provided an argument in favour of a technology-specific support. Assuming that there is no individual demand for onshore wind or biomass energy but only an aggregated demand for all RES, the modelled cost-potential curves of the two technologies suggested that the incentive to support onshore wind by means of quantity regulation is generally larger than in the case of biomass. This finding proved robust independent of the different conditions for the two technologies among the EU countries. Furthermore, this finding implies that in particular immature technologies, whose cost-potential curves are highly uncertain yet presumably steep, may face a considerable disadvantage and may expose policy-makers to unnecessary risks if they are pooled with rather mature technologies.

Eventually, we have shown the importance of temporal developments when deciding which of different support instruments to employ and have pointed out two contrasting dynamic effects. While temporal technological improvements may lead to efficiency gains or cost reductions, a shrinking availability of suitable sites might pressure generation costs to increase. Therefore, it is, a priori, difficult to say whether a RES cost-potential curve becomes steeper or flatter over time and thus whether the incentive to employ a quantity-based mean such as an auction increases or decreases. Following the argumentation of Resch et al. (2004), the answer to that question depends on the technologies' penetration levels and their realisable potentials in the different countries. Technologies with abundant potentials and promising prospects for decreasing generation costs are likely to face flattening cost-potential curves (implying an increasing incentive for auctions) whereas other resources with more limited potentials – e.g. biomass – might experience the opposite. In either case, it is important to consider these dynamic aspects since the choice regarding the optimal support scheme may change – e.g. during the maturation of a technology.

Since this analysis builds on the theoretical insights by Weitzman (1974), our findings and interpretations have to be seen in the light of the assumptions that underlie his study. It shall therefore (once more) be emphasised that our analysis, aiming at identifying practical incentives for different modes of control, rests on the assumption that the given information regarding costs and generation potentials are either inadequate or uncertain. This assumption is important as in an environment of complete knowledge and perfect certainty both a quantity and a price-based instrument would be formally identical (compare elaborations in section 3.2). However, it is also realistic, since even for global regulators or social value-oriented planners, it is hardly possible to obtain all necessary information, which would be needed for an accurate estimation.

Further, it is important to note, that our analysis does not employ real cost and real potential data but the modelling outcome by Held (2010). This data, too, has been generated based on assumptions. One decisive assumption that has been made in order to estimate the generation costs for each technology was that only the location (more specifically its characteristics regarding resource availability) would determine the energy output, yet it was disregarded that a technology adjustment could as well affect the generation. Held (2010) assumed only one representative power plant per technology (one wind turbine, one PV panel etc.) to be in place, which obviously constitutes a simplification. In fact, an adjustment of technology specific parameters (e.g. the rotor length or the generator size of a wind turbine) may allow increasing the energy production without changing the site where the technology is set up. It is possible that particularly the estimated costs of sites with poor resource conditions have been overestimated. Accounting for this misprediction, the actual RES cost-potential curve might be flatter than assumed in this analysis.

Following Weitzman's (1974) argumentation, the optimal choice of support instrument under uncertainty depends on the relation of elasticities of both marginal costs and marginal benefits. Nonetheless, as raised in the beginning of this section, our analysis has only focused on the cost-potential curves of RES technologies and thereby considered the technologies' supply side. Their demand side, however, remained unconsidered. To receive a better understanding in regards to our findings, it may be interesting to speculate about the demand curve's possible slope. It is then the decisive question whether each RES technology faces its own demand or whether all RES are considered substitutes implying an aggregated demand function for all technologies. In the former case, all RES would have to be treated individually and a comparison between the technologies, as it is done in section 4.1.4, would be obsolete. Depending on the individual slope of each technology's demand function, it might then be possible that even technologies, with relatively steep cost-potential curves (e.g. façade-integrated PV plants), should be supported by quantity-based instruments, while RES with relatively flat cost curves (e.g. onshore wind), might as well attract price-based means. In the latter case, however, if all RES were considered substitutes, this would be fundamentally different. Since in this case all technologies would face the same, aggregated demand function, which would be comparably flat[3], only (if at all) the technologies with relatively flat cost-potential curves would qualify for the support of quantity-based instruments. Unlike before, assuming an aggregated demand allows comparing the different technologies' cost-potential curves.

Although our analysis has not touched on all relevant points that would be necessary for a final recommendation regarding the choice between price and quantity schemes, it has pointed out important aspects that should be included in an assessment of policy instruments. It has illustrated the importance to conduct similar analyses prior to an implementation of policy instruments in order to gain insights about the market of RES technologies and to avoid unnecessary risks.

In regards to auctions for renewable support, one can conclude that the exemption rules set out by the European Commission regarding immature technologies seem reasonable, as they typically show steeper cost curves, which makes it more likely that a price-based instrument (such as an administratively set FIT) would lead to higher welfare gains than a quantity-based instruments (such as auctions). To assess the overall suitability of auctions in relation to other support schemes, it is, however, also necessary to quantify the impact of additional factors – e.g. transaction costs – and to analyse their repercussions on resulting competition levels. As emphasised by Del Rio & Linares (2014), these factors may in some instances outweigh the theoretical benefits of a policy instrument and jeopardise its efficiency.

5 Impact of secondary policy objectives and socio-political feasibility on instrument choice

5.1 National objectives: local impacts

As shown in Table 1, there exists a diverse set of policy success criteria. Amongst others, policy makers may be concerned with the impact of renewable development on the domestic industry.

Kitzing (2016) has argued that especially for immature technologies, the revenue certainty provided in price instruments can help spur technological progress, encourage investments into research and development, and help building up a domestic supply chain for equipment manufacturing. This is, because with long-term and foreseeable price developments, future surplus from cost reductions becomes predictable. This is crucial for developers to undertake the often significant upfront research and development (R&D) investments required for technological innovations (Menanteau et al., 2003). In quantity-based schemes, future prices are unknown and this lack of market anticipation decreases R&D incentives – it seems strategically better to focus on 'organisational' improvements and to procure new technologies externally (Finon & Menanteau, 2004; see Menanteau et al., 2003). Johnstone et al. (2010) have shown with an empirical patent analysis that innovation in quantity-based schemes occurs mostly for technologies close to market-competitiveness, whereas price-based schemes spur innovation for more immature technologies. However, Söderholm & Klaassen (2007) show that the positive innovation effect is highly dependent on finding the appropriate support levels. If they

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[3] By definition, an aggregated demand curve is never steeper than the flattest individual demand curve.

are set too high, then fewer incentives for cost reductions are provided. In European countries with price-based feed-in tariff schemes, strong domestic technology industries have developed (e.g. Denmark, Germany, Spain), whereas in countries with quantity-based tradable green certificate schemes, equipment is often procured from abroad (e.g. UK), as shown by Söderholm & Klaassen (2007) for wind energy.

5.2 European objectives: contribution to internal market (Cross-border cooperation potential)

An obvious reason for enlarging the scope of renewable support schemes to reach across borders is that cost savings can be achieved, i.e. a specified output of electricity can be generated at lower overall costs when countries reap the broader potentials from several countries. This means that renewable targets can be reached more efficiently than if each country provided the output individually from their own territories.

An opening of support implies that countries offer to support installations that are placed in locations that do not belong to their national territory. The country that ‘hosts’ the installation has to accept this placement. Typically, the governments of the respective countries would enter a dedicated cooperation agreement, regulating all specific conditions for the hosting (e.g. in regards to construction regulations and grid impacts) and the transferring of the RES benefits.

It is the outspoken aim of the European Commission to encourage cross-border cooperation on renewable support. Already in the first Renewable Energy Directive (RED) from 2009 (European Commission, 2009), cooperation mechanisms were introduced to facilitate such cross-border cooperation for the achievement of national renewable targets. The State Aid Guidelines from 2014 (European Commission, 2014) state that “*Operating aid schemes should in principle be open to other EEA countries and Contracting Parties of the Energy Community to limit the overall distortive effects. It minimises costs for Member States whose sole aim is to achieve the national renewables target laid down in Union legislation. […] The Commission will consider positively schemes that are open to other EEA or Energy Community countries*.”

In the first draft of the second Renewable Energy Directive (REDII)[4] from November 2016, a demand for cross-border cooperation is formulated: “*Member States shall ensure that support for at least 10% of the newly-supported capacity in each year between 2021 and 2025 and at least 15% of the newly-supported capacity in each year between 2026 and 2030 is open to installations located in other Member States.*” A lesson from the debate on cooperation mechanisms is that most EU member states are reluctant to pay support for RES installations in other countries, despite potential efficiency gains (Klessmann et al., 2014). A major reason for this reluctance is the (anticipated or actual) low public acceptance of such cross-border support. Hence, in practice a partial opening of support is expected to be most relevant – one that just fulfills the requirements of the REDII.

The opening of support can in principle be undertaken using any type of support instrument. The draft REDII states that “*Support schemes may be opened to cross-border participation through, inter alia, opened tenders, joint tenders, opened certificate schemes or joint support schemes.*” However, different instruments have different potential and characteristics in regards to the opening of support.

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[4] http://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v7_1.pdf

Certificate schemes can typically only reasonably be opened through a complete joining of support schemes, as done in the Sweden-Norway case. In this case, a partial opening (such as max. 15% of new installations abroad) cannot be implemented reasonably. Any market fragmentation in form of quota or similar would distort the price formation of the whole certificates market, which might be problematic for existing plants. On the other hand, certificate schemes are suitable for full opening and cross-border operation, as they benefit from larger markets and so increased competition.

There are no practical examples for opened FIT or FIP schemes. Since they typically do not feature any volume control, a partial opening could in practice be rather problematic – because an allocation mechanism of the 'extra-territorial' volumes would be missing without an auction or a similar allocation mechanism.

In contrast, auctions can rather easily be opened partially. This is due to two characteristics: 1) The focus of each auction on new installations only; 2) the strict volume control within each auction. Hence, auctions seem to be a suitable instrument for limited cross-border cooperation. Furthermore, the opening of auctions might lead to better performance, as cross-border auctions might benefit from increased competition and reduction of implicit collusion, which can again lead to efficiency gains.

It should be noted that general investment conditions significantly differ across countries. This applies for natural conditions such as resource availability etc., but also for general economic and policy-based conditions such as tax rates, fees, regulatory requirements and procedures, access to financing, and much more. It is practically impossible to create a complete level playing field across countries for the purpose of open renewable support. Such distorting differences in investment conditions need to be addressed outside the support scheme itself. If there are massive differences in regulatory and economic conditions, this may lead to distortions of the placement decision and thus create lower efficiency gains as well as acceptance problems. Also, there might be a risk that countries start to 'design the opened support scheme to increase the competitive position of their 'own' projects. This might start some inefficient competition between countries, which counteracts the idea of the support scheme opening and should be closely monitored.

5.3 State Aid compliance

As set out in the introduction to this report, the European Commission's (2014) Guidelines on State aid for environmental protection and energy 2014-2020 (EEAG) requires member states wishing to offer support to renewable energy electricity generators from the 1st January 2017 to use "*instruments, such as auctioning or competitive bidding process[es]*" (109) to ensure that the cost of support is minimised. The use of such instruments is presumed by the Commission to deliver RES support in way that "*is proportionate and does not distort competition to an extent contrary to the internal market*".

However, the EEAG (126) also allows for exemptions. In cases where member states can demonstrate that a) "*only one or a very limited number of projects or sites could be eligible*", b) "*competitive bidding process would lead to higher support levels (for example to avoid strategic bidding)*" or c) "*competitive bidding process would result in low project realisation rates (avoid underbidding)*" an application may be made to the Commission for approval to use alternative support instruments. Member states may also provide support on a non-competitive basis for installations less than 1MW capacity or for (non-wind) technology demonstration projects up to 6MW or with up to six generation units (127). For an exemption to be granted, the member state must demonstrate that the support does not over-compensate the producer – i.e. the support is no more than the levelised cost of energy (LCOE) (including a return on capital and adjusted to reflect any investment aid) and the realisable market price for the energy produced.

Since the publication of the EEAG in 2014, several member states have presented arguments to the Commission for exemptions from the auctioning requirement and this short section reviews the arguments made by member states and the outcomes of the Commission's decision in each case. Three state aid exemption cases are reviewed here from three member states: Bulgaria, Finland and Luxembourg.

Bulgaria's Renewable Sources Act (ZEVI)

> *Source: State Aid SA.44840 (2016/NN) – Bulgaria Support for renewable energy generation in Bulgaria - C(2016) 5205 final*

The European Commission received a number of complaints about, *inter alia,* the potential non-compliance of Bulgaria's renewable energy feed-in tariff (ZEVI) with EU state-aid requirements. Primarily a concern about over-compensation, the case also presented a potential conflict between Bulgaria's ZEVI and the EEAG rules on competitive allocation. Following the receipt of supporting evidence and clarification from Bulgaria, which confirmed the level of support to be in line with point 131 of the EEAG and that non-competitive support was offered only to projects with a capacity of 30kW or less, in line with point 127, the support system was approved on the 4th August 2016.

Luxembourg's renewable energy support modifications

> *Source: State Aid SA. 43128 (2015/N) – Luxembourg Modification du soutien aux SER au Luxembourg - C(2016) 5433 final*

In response to the upcoming EEAG deadline, the government of Luxembourg notified the European Commission on the 21st of September 2015 of changes to its support system for renewable electricity. The main change notified was the replacement of a feed-in tariff with a market premium system in which generators would be responsible for selling their own output as well as other market obligations such as balancing, as required by point 124 of the EEAG. For several reasons, however, Luxembourg's renewable electricity market was deemed eligible for exemptions from the requirement to allocate support through competitive bidding processes. The Commission's decisions were based on evidence that:

- Luxembourg does not have any planned solar PV installations larger than the 1MW threshold set out in EEAG point 127;
- There is currently only one wind installation progressing through development in Luxembourg and that nearly all development is carried out by one firm, fulfilling the exception criteria under 126(a) that "only one or a very limited number of projects or sites could be eligible";
- Hydropower installations are typically less than 1MW, as exempted by point 127 of the EEAG and only one project is anticipated to come forward during the lifetime of the EEAG, deemed adequate grounds for exemption under point 126(a).

The European Commission found the Luxembourg plans compliant with EEAG on 26th of August, 2016.

Finland's support for forest chip-fired CHP plants

Source: State Aid SA.42218 (2015/N) – Finland Operating aid for forest chips fired power plants - C(2016) 976 final

The government of Finland notified the European Commission on the 15th of January 2015 of a plan to increase the supplement payable to certain combined heat and power (CHP) installations for fuel switching to forest woodchips[5]. The payment is based on the difference of fuel costs between the current fossil stock (peat) and woodchips, per unit of energy produced. As such, the support is only attractive to co-firing plants that are able to rely on an adequate heat demand. Also, since the eligible plants are likely to be existing generators that can simply revert to the (cheaper) fossil fuel source, a bidding process is unlikely to bring forward competition. The European Commission approved the plans on the 15th of February 2016.

Table 4: Summary of state aid exceptions

	Date of decision	Installation size	Technology	Reason for exemption
Bulgaria	4.8.2016	<30kW	Wind Solar PV Biogas Biomass Hydropower	Exempted based on sub 1MW capacity as per EEAG (127)
Luxembourg	26.8.2016	<1MW	Solar PV Wind Biogas and wood waste Sewage gas	Exempted based on sub 1MW capacity as per EEAG 127 and likely lack of competition 126(a)
Finland	15.2.2016	N/A	Co-firing small-scale CHP	Exempted based on nature of support being unsuitable for auctions and likely lack of competition 126(a)

6 Overall discussion and conclusions

6.1 Relevance of the study for real life application

Our analysis has shown that there may in fact be valid reasons for policy makers not to employ auctions as regulatory means under certain circumstances. Moreover, the three cases of Bulgaria, Finland and Luxemburg show that a request for exceptions to elude competitive bidding processes may be deemed necessary for particular countries. However, the exceptions granted by the Commission so far were all based on EEAG point 126(a) and 127 respectively, which represent the rather well defined exception regulations. There exists to date no particular example where Member States were granted exceptions according to EEAG point 126 (b) or (c), which define the conditions for exceptions that are relevant for the arguments of this

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[5] The plan also includes a reduction to the supplement payable in the case that the woodchips are 'industrial roundwood' sourced from felling sites of large trees

report. Nevertheless, the insights of our analysis may still be useful for real life policy application as they provide a solid foundation to argue for exceptions.

It was demonstrated that under uncertainty neither quantity-based auctions nor price-based instruments such as FIT or premiums will necessarily ensure welfare optimal results. In addition, both regulation modes require extensive analyses a priori to their implementation in order to work efficiently. For that reason, it seems difficult to argue in favour of any specific instrument particularly since both regulation modes should – theoretically – be able to reach identical results. Nonetheless, the findings by Weitzman (1974) suggest that, independent of the target to minimise the RES support price, the two regulation modes may entail different total welfare effects. It was illustrated in Figure 2 that despite considerably lower support prices, the efficiency loss of a quantity scheme outweighed the loss of the price scheme, which raises the question whether pure support cost minimisation should be the ultimate goal. Against this background, our analysis develops useful arguments. Moreover, it provides guidance to policy makers by indicating how to conduct similar yet case specific analyses.

6.2 Limitations of the study

It is important to note that the present study contains several limitations with respect to both the analysis and the employed modelling data. Therefore, the following section intends to raise and discuss some of the issues that occurred in the course of this work.

1. *Neglect of marginal benefits*

As Weitzman (1974) has laid out in detail, the optimal choice of regulation under uncertainty depends on the curvature of both the marginal cost and marginal benefit function. In fact, it is the relation of the two curves around the optimal output level, which determines the theoretical suitability of price-based and quantity-based modes. This study, however, has only focused on the marginal costs of RES and has neglected their benefit function. As such, it has not been able to determine an equilibrium point. Focusing solely on the slope of the marginal cost curve, our analysis only allows for comparative statements regarding incentives of different policy instruments but not for explicit recommendations regarding their use. Nonetheless, this work does not claim to be complete. It may only be seen as a useful approach covering an important part of the risk analysis, which is necessary to determine the quality of an instrument.

2. *Modelling assumptions*

Since the employed data for the present analysis constitutes a modelling outcome, it is important to recall the assumptions that underlie the corresponding model. As already noted by Held (2010) both her simulations for onshore wind, solar PV and biomass rest on some simplifying assumptions. For example, in the case of onshore wind, it has been assumed that atmospheric stability conditions would be neutral, implying that wind speed variabilities would be the same in all EU member states. Certainly, this assumption is not entirely accurate. Furthermore, Held (2010) simplified the estimations of her model by selecting only one reference wind turbine for all available sites. However, since the energy production could be increased by adjusting (at least) specific turbine parameters, some of the modelled power outputs might be underestimated and thus corresponding generation costs might be too high.

Similarly, for solar power plants to be integrated at buildings, Held (2010) made the assumption that the available area for those technologies could be estimated based on the number of inhabitants. This assumptions, too, appears somewhat inaccurate, since the living-space per inhabitant might differ considerably from country to country. For example, in the Netherlands where more than 90% of the population lives in urban areas it may be considerably lower than in Poland where the share of the urban population is only around 60%. Moreover, it was assumed that all PV plants would be optimally inclined, so that efficiency losses would not occur. Since in reality this assumption is unlikely to hold true, the modelled energy production from solar PV might be overestimated. Finally, it seems probable that particularly in well-suited PV areas such as the southern parts of a country, a larger share of land area is dedicated for PV power plants than assumed by Held (2010). This would imply an underestimation of the energy output and hence an overestimation of the generation costs.

3. *Role of additional impact factors (drivers)*

Eventually, it should be recalled that in order to discuss rationales for the use of different policy instruments, the core focus of the present report was on the factor risk. Other potentially relevant impact factors (e.g. Europeanisation, local impacts or transaction costs), which might as well influence a policy maker's instrument choice, were only touched briefly but not analysed in detail. Our analysis may therefore only provide limited insights. As mentioned before, it is not able to cover the entire decision field of a policy maker.

We have argued in section 5.1 that the various policy instruments may provide different incentives to help building up a country's domestic supply chain. Therefore, policy makers intending to support their local industry may as well allow for such considerations when deciding on their regulation policy. Further, an opening of boarders for the support of renewables can be an important argument for the instrument choice. Such Europeanisation might allow extending the scope of RES support and reaping additional efficiency gains. Eventually, as stressed by Del Río and Linares (2014), transaction costs – not considered in our analysis – may outweigh some of the theoretical benefits of an instrument. In particular in markets with rather small actors, transaction costs may hamper participation and result in undesireably low competition levels.

6.3 Outlook: Are hybrid schemes the perfect compromise?

Our analysis has demonstrated that support conditions for the various RES technologies may largely differ among the EU countries. Even within a country, the specific technology types may face different potentials as well as natural conditions, which, in turn, may be subject to temporal variations. A generic instrument of a "one-size-fits-all" character therefore rarely seems to be an optimal solution. Instead, it may be advisable for regulators to pursue a policy that is, to some extent, flexible for adjustments and, accounting for a technology's temporal maturation, open for mixtures of both price and quantity modes. In particular for medium-term RES policies, such a hybrid scheme may be beneficial in order to ensure a smooth transition from one regulation mode to the other (Stern, 2007).

Moreover, as concluded by Weitzman (1978), a mixed price-quantity scheme may in fact be the optimal regulation system under uncertainty as it allows price and quantity instruments to safeguard each other. By means of a theoretical model, it is shown that single price and single quantity schemes respectively may only be superior under specific, extreme, conditions whereas a system including both price incentives and quantity targets will be beneficial most of the time. Nonetheless, it is important to note that a random implementation of a hybrid scheme – combining price and quantity modes at discretion – does not solve the regulator's problem of mitigating risk exposure. Instead, selecting a hybrid scheme requires the regulator to make similar analyses in order to determine the optimal price-quantity mix.

6.4 Concluding remarks

Conducting a comparison between auctions and other regulatory policy instruments, the present study aimed at investigating under which circumstances an auction may not be a favourable mean of support. For that purpose, it has identified a number of potential drivers that might affect an instrument's effectiveness, its efficiency and further success criteria. Among this list of relevant drivers, the basis for our analysis was the factor risk, where our core focus was on risk for policy makers – the regulator's regret. Assuming a world of uncertainty, particularly policy makers or regulators are exposed to the risk of setting inefficient investment incentives by implementation of wrong policy. As such, the aspect of risk was deemed one of the most important challenges for the deployment of RES. We have demonstrated that risk and uncertainty respectively constitute important factors understanding the decision-making of policy makers regarding which instrument to use. However, we have also pointed out that independent of its importance, the factor risk constitutes only one of many factors, which may be relevant when selecting a policy instrument.

Our main analysis consisted of two parts: First, we have reviewed the findings of several scholars providing a direct comparison between particular policy instruments. We have further built on the theoretical elaborations by Weitzman (1974) and illustrated that with uncertainty regarding the marginal costs and marginal benefits of RES, particularly the choice between price (e.g. a FIT) and quantity (e.g. an auction) instruments will be decisive, since incorrect price or quota signals may have different effects. In essence, while price schemes may reduce the risk of welfare losses given a relatively steep marginal cost and a comparably flat marginal benefit curve, a quantity scheme may be superior if the relation between the two curves is vice versa.

In the second part of our analysis, we have employed modelled data by Held (2010) in order to build on these theoretical insights and compare the slopes of real marginal cost of RES in different European countries. Three insights prove to be important: First, the incentives for the use of particular policy instruments to support the deployment of RES are both country and technology specific. In general, it appears that the incentive to employ a quantity-based mean such as an auction is larger when the natural resources of the technology that is to be supported are abundant and if that technology is rather well developed. Besides that, it requires a competitive market for an auction to be effective. Second, since within a country the market and natural conditions of the different RES technologies and hence their supply costs may vary considerably, it seems possible that there exist incentives for both price and quantity support schemes. Our findings therefore provide an argument against a technology-neutral support. Finally, the analysis has stressed the importance to consider temporal developments. Since both the potentials and the costs of the different RES technologies will change over time, so may the incentives for their support. It is therefore not only necessary to conduct a static assessment of RES potentials and their costs respectively but also to consider their dynamics.

The findings of this study suggest that with uncertainty regarding the marginal costs and marginal benefits of RES, there may in fact be valid reasons for policy makers not to employ auctions, as it may be desirable not to control the volume. Thus, the important question is not necessarily how to optimise the design of an auction but possibly how to substitute it. This may e.g. be the case if the regulator's risk to set sub-optimal incentives can be minimised by controlling the price. It is obvious that the allocation mechanism of an auction ensures the minimisation of support prices. However, it was shown that under certain conditions (e.g. for particular technologies or given the specific natural conditions in a country), it may not be worthwhile to reduce this price to its minimum as it may lead to evitable efficiency losses and thus to an increased loss of societal welfare.

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

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

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