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Quantifying technology skewness in European multi-technology auctions and the effect of design elements and other driving factors

Preprint Version

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Abstract

Multi-technology auctions are a popular instrument to support renewable electricity in the European Union. While they increase competition, some technologies could dominate, which might be an issue for some countries' power system reliability. Using statistical methods, I analyse how balanced or skewed European multi-technology auctions are and investigate driving factors. I show that 80% of all multi-technology auction rounds from 2011 to 2020 were skewed, strongly or exclusively favouring one technology. None of the investigated design elements and general context factors can explain this. Instead, specific auction-external context factors may better explain the observed skewness. Furthermore, the aggregated outcome across all rounds, years, and countries is relatively balanced because the rounds are differently skewed. This could be coincidental and change in the future if outcomes remain strongly skewed. Policymakers may consider shifting to technology-specific auctions that target single technologies, particularly if they cannot manage the risks of skewed auction outcomes. Thereby, they promote a diverse and targeted deployment of renewables.

Keywords
Energy policy, Renewable electricity,

Renewable energy auction, Auction design, Technology diversity.

1 Introduction

Many countries employ support schemes for the expansion of renewable electricity technologies[1] to achieve their climate targets. In 2022, auctions have become the most popular policy instrument for determining and allocating this support: from 2010 to 2020, their adoption quadrupled (REN21, 2021). At the same time, a shift from feed-in tariffs to premiums and from administratively-set to auction-based allocation of support occurred, mainly with the intention of steering deployment and reducing costs (del Río and Linares, 2014; Haufe and Ehrhart, 2018). While in the beginning, most auctions were technology-specific, i.e. only eligible for one type of technology (like onshore wind), policymakers have been increasingly opting for technology open schemes, such as multi-technology auctions (del Río and Kiefer, 2021). Between 2011 and 2020, multi-technology auctions provided about 60% of all awarded capacity in the European Union (EU) (see Section 4.1). This means that research about multi-technology auctions is very relevant.

The European Commission's state aid guidelines (see Section 2.3) and their general provision for technology neutrality contributed to the shift towards more neutral schemes (EC, 2014a). These guidelines have been updated in 2022. While the previous version from 2014 already allowed exemptions from the general neutrality provision, the current ones more explicitly allow EU countries to rely on technology-specific auctions (EC, 2022). Now, policymakers need to know whether they should continue relying on multi-technology auctions or adopt technology-specific designs.

In general, hardly any policy is purely neutral (Azar and Sandén, 2011). Most auctions in the EU, including multi-technology ones, were discriminatory to some degree (Jerrentrup et al., 2019; Mora et al., 2017). Nevertheless, some have argued that technology open designs guarantee efficiency, i.e. achieving targets at the lowest possible cost, while others have stated that specific designs can be efficient, as well (overview see Section 2.4). Notably, if technology-specific auctions promote various technologies in parallel, technology diversity can increase and costs decrease in the long term (Sandén and Azar, 2005; Schmidt et al., 2016; Haelg et al., 2018; del Río, 2018).

Furthermore, the relevant literature suggests that a broad portfolio of technologies[2], i.e. high technology diversity, is a necessary factor for increasing security of supply (Stirling, 2010). From a power system reliability perspective[3]—which is part of supply security, and the focus of my paper—studies modelling a fully renewable power system propose a relatively diverse portfolio of renewables (Zappa et al., 2019). This does not mean, however, that countries must have a fifty-fifty split of wind and photovoltaic (PV) capacity. Varying resource potentials and political priorities promote various types of power plant portfolios. Zappa et al. illustrate this for Europe: high diversity, i.e. large variety and balance are general patterns, but a strong dominance of single technologies works well in some countries[4].

If multi-technology auctions lead to a strong and continuous dominance[5] of particular technologies, there may be the long-term risk of lowering diversity, power system reliability, and

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[1] In the remainder, referred to as "renewables".

[2] This includes different types of renewables like wind and PV. Compared to past years, agencies like the IEA have been treating renewables as more than one "block of renewables".

[3] Compared to a geopolitical perspective.

[4] Zappa et al. show that the power systems in Spain / Hungary are stable despite having dominant technologies.

[5] I define dominant as winning at least twice the capacity of all other technologies in a round (see also Method).

dynamic efficiency (see Section 2.2). Although some dominance can be expected when one technology is consistently cheaper and sufficient projects are in pipeline, and even if the main aim of multi-technology auctions is to minimise short-term support costs, technology outcomes and balance should be considered if policymakers need to reach several policy goals in parallel.

1.1 Research questions and overview

While previous research has investigated dominance and diversity issues, as well as technology bias (Diallo and Kitzing, 2020; Haelg, 2020), there is a lack of data-based empirical work about the effects of multi-technology auctions on technology outcomes, dominance and diversity. In this paper, I close this research gap for EU countries and ask two research questions: (1) *how skewed are multi-technology auctions in the EU, favouring dominant technologies, and (2) how do potential driving factors affect the skewness*? To answer these questions, I assess the skewness of multi-technology auction outcomes in the EU between 2011 and 2020 and analyse the significance of design elements and context factors.

Using descriptive statistics and a novel definition of skewness in auctions, I show that 80% of all multi-technology auction rounds in the EU are skewed and strongly favour one technology, meaning that the dominant technology gained at least two-thirds of the awarded capacity. However, the aggregated outcomes on yearly, national, and EU-wide levels are more balanced, even though this may just be a coincidence and could change in the future. Using (regression-type) analysis of variance, I show that design elements and general context factors cannot explain the skewness of the outcomes. Based on literature, I then discuss relevant auction-external factors for several of the countries in this paper and suggest potential endeavours for future research. I conclude that policymakers may consider introducing more technology-specific auctions if they need to adjust any imbalances and increase technology diversity. The updated state aid guidelines provide the means to do so.

2 Background and literature

My study draws on several literature sources and contributes empirical insights. It is based on literature about security of supply, power system reliability, technology diversity (Section 2.1) and the links to auction design (Section 2.2). The EU state aid guidelines (Section 2.3) are relevant in the context of the technology specificity debate (Section 2.4). A review of empirical studies also highlights the current gaps and my contribution (Section 2.5).

2.1 Technology diversity and its goals

Power system reliability is a central pillars of a robust European electricity system (Mitchell et al., 1996; EC, 2014b, 2022), and technology diversity is one of the principal means for increasing it (Chalvatzis and Ioannidis, 2017). Technology diversity has three dimensions: balance, variety, and disparity (Stirling, 2010). In the context of my study, balance and variety are relevant concepts. Balance denotes the shares of different technologies in the national portfolio, and variety denotes the number of technologies that are in the system. If both measures increase, overall diversity and power system reliability will probably increase as well, and therefore, many policymakers have an incentive for expanding several technologies, particularly renewables, in parallel.

Although diversity increases if countries expand renewables like wind, PV and biomass (Grubb et al., 2006; Chalvatzis and Ioannidis, 2017), their generation varies. Thus, relying on few technologies could be an issue. In addition to flexibility options (Alizadeh et al., 2016), countries should deploy a balanced mixture (i.e. high balance) of different generation technologies (i.e. high variety) to secure a reliable power supply (Gul and Stenzel, 2005; Grubb et al., 2006).

Technology diversity is also related to long-term system costs. Solely expanding the currently cheapest technology may lead to technological lock-in (Unruh, 2000; Kim and Tang, 2020). Such lock-ins affect global market developments, which may contribute to low dynamic efficiency, i.e. higher than necessary costs in the future (del Río González, 2008). Despite rationales like power system reliability and long-term costs, technology diversity tends to be overshadowed by the aim for short-term costs in policy (REN21, 2017), highlighting the need for a stronger focus on diversity.

In this paper, I introduce and investigate *the skewness* of auction outcomes towards the dominant technology (Section 3.2). This is relevant for the diversity literature because strongly skewed auction outcomes could increase the risk of low balance and variety in the overall country's technology mix. For instance, if large rounds favour one technology, its share in the national portfolio will increase in the long term and it could exacerbate existing imbalances or make the power mix dependent on this one technology.

2.2 Auction design and technology diversity

There is an increasing consensus in the literature that auctions are well suited to allocate support for renewables, especially in the EU context (Anatolitis et al., 2021), for mature technologies (Kitzing et al., 2020) and among larger investors (Braunholtz-Speight et al., 2020; Melliger and Lilliestam, 2021). Moreover, the deployment of renewables in the EU still depends on support schemes (Held et al., 2019; Melliger and Chappin, 2022).

Auctions differ in their design elements (del Río and Linares, 2014; IRENA, 2019), which can have both positive and negative effects on various outcomes. Scholars have investigated the effects of design elements and identified several potential links with general technology diversity (Haelg, 2020). One of the most important and ambivalent drivers of diversity is the *technology specificity* of an auction (see also Section 2.4). While technology-neutral designs may be cheaper, specific designs (including any design with specific elements like technology banding) better promote diversity in auctions (Polzin et al., 2019).

Furthermore, prequalification criteria could exclude certain bidders that have insufficient experience or no financial securities (del Río, 2017; Held et al., 2014), which may indirectly affect the bids and technologies in rounds. The *award criterion*, i.e. multi-criteria vs price-only auctions, could favour particular technologies by design (IRENA and CEM, 2015; Mora et al., 2017). The *ceiling price level* is relevant because it may be set in a technology-specific manner or exclude some technologies from participating (del Río, 2017; Mora et al., 2017; Diallo et al., 2019). The *lead time* matters because different technologies may require different deadlines (Winkler et al., 2018). Eventually, the *support duration* can affect the technology bias because of different lifetimes (Diallo and Kitzing, 2020).

Not only the auction design but also context factors could affect technology diversity. For instance, financing conditions differ between technologies (Steffen, 2020). Resource potentials, administrative procedures (Bayer, 2018; Winkler et al., 2018), and acceptance issues (Grashof et al., 2020) affect the general chances that technologies prevail. Economic factors may also matter, e.g. wealth, energy consumption (Matthäus, 2020), human resources (Bento et al., 2020), as well as economic cycles, learning curves or exchange rate variations (Lilliestam et al., 2020; Matthäus, 2020).

These findings are mostly based on case studies or qualitative considerations. An empirical data-based analysis of the effects of design elements and context factors on the technology outcome is mostly missing, particularly in the context of multi-technology auctions (see also Section 2.5). One reason for the lack of such analyses has been the difficulty to analyse the existing heterogenous data. However, with the advent of databases about outcomes, new approaches, such as the one presented in this paper, become feasible.

2.3 State aid guidelines for renewables in the EU

To implement auctions, EU countries need to follow the Commission's state aid guidelines. From 2014 to 2021, the Energy and Environmental State aid guidelines (EEAGs) were the relevant legislation (EC, 2014a). In general, the use of technology-neutral auctions was mandated, but exceptions contributed to the wide adoption of effectively technology-specific auctions (Jerrentrup et al., 2019). These exceptions included the support for immature technologies, and for upholding sufficient diversification and power system reliability.

In 2022, the updated guidelines on state aid for climate, environmental protection and energy (CEEAG) came into effect (EC, 2022). The CEEAG still mandate the use of technology-open auctions, in general, but the possibilities to implement technology-specific auctions have broadened and are more explicit. Policymakers can adopt multi-technology or technology-specific auctions for diversity and power system reliability reasons[6]. This applies if they expect "suboptimal results" (regarding outcomes such as reliability) or "significant deviations between bid levels", i.e. whenever bid levels differ by more than 10%. Overall, these changes were generally well-received by renewable technology interest groups[7]. Based on lessons learned from past literature (see next Section) and actual auction outcomes, I explore whether policymakers should consider shifting from multi-technology to specific designs.

2.4 Technology specificity in auctions

There are several views about whether auctions should be designed technology-neutral or -specific (Ericson, 2020; Kreiss et al., 2021; Lehmann and Söderholm, 2017; Schmidt et al., 2016). In economic theory (about auctions in general), non-discriminatory auctions are considered optimal (McAfee and McMillan, 1989; Myerson, 1981). Proponents of technology neutrality thus argue that policymakers inefficiently pick the winning technology in technology-specific auctions[8] (Jaffe et al., 2005; Nordhaus, 2010). Although technology diversity is essential, policymakers cannot know which technologies will prevail, so they should not pick the winners (van den Bergh et al., 2006). However, in markets with high innovation potential, picking winners can also be welfare increasing (Ericson, 2020).

In the context of suboptimal market environments, technology-specific support may be a viable second-best option to tackle market failures and path dependencies (Gawel et al., 2017; Lehmann and Söderholm, 2017). Transition scholars tend to favour technology-specific support for innovation reasons. Pushing immature and more expensive technologies out of their niches may increase dynamic efficiency and lower long-term costs (Sandén and Azar, 2005;

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[6] Point 96 and 104 of the CEEAG are particularly relevant in my paper's context.

[7] For instance: http://pr.euractiv.com/pr/new-state-aid-guidelines-allow-technology-specific-auctions-endorse-contracts-difference-deploy (last access 9.3.22)

[8] Related to specificity in auctions is the question of whether dedicated support is required at all, particularly in the presence of economy-wide policies like carbon prices. This topic is out of my scope and discussed elsewhere (Frontier Economics, 2014; Jägemann, 2014; Lehmann and Gawel, 2013; Lilliestam et al., 2021).

Jacobsson and Bergek, 2011; Santana, 2016; Markard, 2018). Also, in the context of local supply chain promotion, policymakers may want to introduce technology-specific support to promote a technology's industrial value chain and increase long-term investment and planning security (del Río, 2017; del Río and Kiefer, 2021).

Overall, the specificity of policies varies between countries (Schmidt and Sewerin, 2019), and there is no single best design (Maurer and Barroso, 2011). The optimal design and implementation depends on the policy (Azar and Sandén, 2011), the application (Schmidt et al., 2016), the degree of market failure (Lehmann and Söderholm, 2017) or the country's potential to benefit from learning rate effects (Sawulski and Witajewski-Baltvilks, 2020). My paper contributes to the technology-specificity literature by showing the outcomes and the skewness of past multi-technology auctions. With this, I close knowledge gaps about a little-explored outcome (next Section).

2.5 Empirical studies about auction outcomes

Most EU countries have introduced auctions for renewables in the mid-2010s; hence data is scarce and the body of empirical literature comparably small. Although some scholars are analysing existing datasets about auction outcomes, proper statistical analyses remain difficult (Winkler et al., 2018). This may explain that most studies about outcomes are either limited in scope or individual case studies. However, this is problematic because data-based studies are important for empirical decision making as they validate or generate theory.

Based on Table 1, I highlight three gaps in the scientific literature: missing evidence (1) about multi-technology auctions, (2) about their effects on technology diversity, outcomes, and dominance, and (3) from data-based analyses. Most studies investigate specific designs or do comparative analyses to neutral designs; selective studies on multi-technology designs are scarce. Most studies focus on efficiency (i.e. cost-effectiveness), effectiveness (i.e. realisation rates), or actor diversity. The focus on the effect of current auctions on technology diversity is either missing or only indirectly considered as dynamic efficiency. Furthermore, most diversity literature is qualitative rather than driven by empirical data analyses (overviews in Diallo and Kitzing (2020) and Haelg (2020)). The dominance of single technologies in auction outcomes is mainly addressed by Diallo and Kitzing (2020). They use a quantitative model to estimate technology-bias based on costs, bid prices and social value (provided by the technology to society) in various hypothetical scenarios, and analyse the effect of various design elements and support polices through scenario analysis.

The effects of multi-technology auctions on the awarded prices, and hence efficiency, has been addressed by a more recent study (Anatolitis et al., 2022). Anatolitis et al. do a regression analysis using the AURES II database and find that multi-technology auctions for small-scale projects (below 1 MW) increase the awarded prices compared to technology-specific ones. Vice versa, in auctions open to large-scale projects, multi-technology auctions tend to decrease the awarded prices.

Additionally, grey literature has focused on individual case studies in various countries. In particular, the AURES I/II projects published studies about auctions in the EU (Szabó et al., 2020), including Denmark (Garzón González and Kitzing, 2019), Germany (Sach et al., 2019), Greece (Anatolitis, 2020), Poland (Diallo et al., 2019), Portugal (del Río et al., 2019), Slovakia (Diallo et al., 2020), Spain (del Río, 2016; del Río and Menzies, 2021), the Netherlands (Jakob et al., 2019), as well as the UK (Woodman and Fitch-Roy, 2019). Most of them focus on the efficiency and effectiveness of the national auctions, however, some explore dynamic efficiency, technology diversity and explanatory factors (see also Section 5.4). For instance, they identified low diversity in auctions in the UK but more balanced results in Denmark.

In summary, studies and reports cover some of the three literature gaps, but only in specific contexts. This shows that my paper contributes to the current empirical literature, focusing on multi-technology auctions and technology diversity in the EU.

Table 1: Review of empirical and data-based studies about auction outcomes in the EU. Methods used: Quant=quantitative analysis; Qual=qualitative analysis; Lit=literature review; Desc=descriptive statistic; Int=interviews; Case=case studies; Mod=models. NA=not applicable or not reported.

Source	Specificity	State (ISO)	Years	Method	Outcomes
(Anatolitis et al., 2022)	Specific vs multi-technology	20 countries	2011-2020	Quant	Efficiency
(Bayer et al., 2018)	NA	BRA, FRA, ITA, ZAF	2009–2016	Desc, Lit, Int	Effectiveness, efficiency, market concentration
(Bento et al., 2020)	NA	20 countries	2004–2014	Quant	Effectiveness
(Cassetta et al., 2017)	Specific (wind)	ITA	2012–2016	Quant	Effectiveness, efficiency
(Gephart et al., 2017)	NA	EU	Pre–2017	Lit, Case	Effectiveness, Efficiency
(Grashof et al., 2020)	Specific (wind)	DEU	2017–2018	Lit, Desc	Efficiency, actor diversity
(Kreiss et al., 2021)	Specific vs Neutral	USA, MEX and EU	2010–2017	Case	Efficiency
(Kylili and Fokaides, 2015)	Specific (PV)	CYP	2013	Quant	Effectiveness, efficiency
(Liñeiro and Müsgens, 2021)	Specific (PV)	DEU	2015–2020	Quant	Effectiveness
(Lundberg, 2019)	Specific (wind)	DEU	2017–2018	Desc, Mod	Efficiency, effectiveness, actor diversity
(Matthäus, 2020)	Specific vs neutral	42 countries	1990–2017	Quant	Effectiveness, efficiency
(Mitchell, 2000)	Specific	GBR	1990–1998	Qual, Case	Effectiveness, efficiency
(del Río, 2017)	Specific and neutral	Global	until 2017	Lit, Case	Effectiveness, static & dynamic efficiency, local impacts, actor diversity, etc.
(Winkler et al., 2018)	Specific and neutral	BRA, FRA, ITA, NLD, ZAF	2004–2017	Desc	Effectiveness, efficiency

3 Method

My study's aim is to understand the skewness towards dominant technologies in multi-technology auction outcomes in the EU. For this, I use the AURES II database (Section 3.1) and quantify[9] the skewness of technology outcomes (Section 3.2). To estimate the effects of potential factors (Section 3.3), I use statistical tests (Section 3.4).

3.1 Data source, scope, and definitions

I base my analysis on auction data from the AURES II Auction Database[10]. From the available data, I consider national[11] multi-technology auctions which were held between 2011 and 2020 in EU countries[12]. While there is data for 2021, it was still incomplete at the time of writing, and hence, I exclude this year to avoid unrepresentable results.

I only consider multi-technology auctions but not technology-neutral ones because the database only contains the former type. Jerrentrup et al. (2019) define technology-neutral auctions as auctions with a "competitive bidding process, without any formal restrictions on the participation of available technologies, in which neither negative nor positive technology-specific discriminatory rules exist explicitly or implicitly". Thus, multi-technology auctions underlie such rules and restrictions. In fact, Jerrentrup et al. find that EU countries did not conduct any purely technology-neutral auctions (at least not prior to their data analysis).

My study is not comparative, and hence, I do not compare multi-technology to technology-specific auctions. Nevertheless, my results have implications for the adoption of these two types in light of policy goals (see Section 6). Furthermore, I differentiate between *auctions* and *rounds*. Auctions are distinct calls and can contain multiple rounds. Auction rounds are the basic unit of my statistical analysis, i.e. there is one skewness figure per round (see next Section). Different rounds can be eligible to different technologies, categories, or classes like mature and immature technologies. Also the number of technologies per round varies. For instance, the Netherlands has auctioned more categories per round (including a free category with different technologies that is here summarised as "other") than other countries like Poland.

I specifically focus on technologies with the largest overall shares, i.e. onshore and offshore wind, PV, and bioenergy. I summarise less-common technologies as "other" (e.g. hydropower or combined heat and power). Furthermore, most auctions award capacity, but some award an electricity amount or budget. I consider rounds for which the awarded capacity and electricity is reported[13]. To convert electricity to capacity, I use ten-year average[14] capacity factors based on generation and capacity data from IRENA for each country and technology[15] (IRENA, 2022a). This conversion adds five auction rounds, in which only one technology was awarded all electricity.

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[9] The analysis is written in R and available online. (DOI: 10.5281/zenodo.7622120).

[10] Results are based on v1.8 of the database: http://aures2project.eu/auction-database/

[11] While cross-border auctions could occur, none did in multi-technology auctions.

[12] Including the UK because the data ranges from 2011 to 2020.

[13] Budget-based auctions are all covered by their awarded capacity or electricity values.

[14] Averages compensate for weather variations.

[15] Only applies to rounds in which the type of technology is reported, i.e. no "other".

Finally, almost[16] all relevant factors from the literature (see Section 2.2) are reported in the comprehensive AURES design element database. Other general factors like GDP data stem from OECD (OECD, 2022), and LCOEs stem from IRENA (IRENA, 2022b).

3.2 The skewness

I define and use the term *skewness* as a measure of asymmetry to quantify how much a dominant technology in multi-technology auctions skews the technology outcome. It can be applied to the outcome of single rounds or the sum of outcomes on different aggregation levels, e.g. for each year or country. For this, I derive an *outcome-ratio R,* as a ratio of the capacity[17] share of each technology and all other capacity shares (only of awarded capacities). For example, an outcome-ratio of 2 means that technology X won twice the capacity of all other technologies. I then use the maximum score form all *outcome-ratios* of all awarded technologies as the *skewness* S of an outcome (or sum of outcomes); it is expressed as

$$R_x = \frac{C_{\mathrm{x}}}{1 - C_{\mathrm{x}}} \mid S = \max(R_x)$$

with a technology x's capacity share C_{x}. If the skewness is ≥ 2, I denote the outcome as skewed because there is a dominant technology gaining two-thirds of all capacity (or twice as much as all other capacities combined). If the skewness is < 2, I understand the outcome as relatively balanced, meaning no technology strongly dominates. I label the technology with the highest capacity gain as the *winning* technology; in skewed rounds, this is also the *dominant* technology.

The *skewness* is not the same as the technology diversity of the resulting national power mix, even though these are likely affected by the auction outcomes[18]. Furthermore, I treat very large values as outliers ($S > 99$) and recode them to 99. Some of these values had high leverage in the statistical assumption checks and could skew results, even though they always mean that one technology wins virtually all capacity.

3.3 Potential driving factors of skewness

Various driving factors could potentially affect the skewness. Therefore, I rely on literature about context factors, auction design elements, and technology diversity to select the relevant ones (Section 2.2). I summarise the final selection of factors, their units, categories, and names in Tables A-1 and A-2.

First, country-related context factors (financing conditions, resource potentials, administrative procedures, acceptance issues and economic factors) could skew the technology shares if they favour individual technologies. I do not represent each of these factors separately in the statistical analysis but consider the *general* country-related context with the *country context factor* (the country's name). I also represent yearly dynamics (economic cycles, learning curves and exchange rates) with the general *year context factor* (the year).

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[16] One relevant factor, the "unit of remuneration", was only relevant for auctions outside the EU scope.

[17] The skewness relates to capacity because this is the basic unit of the analysed auctions.

[18] To quantify the technology diversity on the national level, e.g. using the Herfindahl-Hirschman index, all technologies and their capacities should be considered.

Second, scholars suggest that certain design elements affect technology diversity. These include the *award criterion, ceiling price level*, *lead time*, and *support duration.* I consider them as potential driving factors (reasoning see Section 2.2). Furthermore, I include *financial prequalifications* to assess whether financial factors such as securities and liquidity levels indirectly affect technologies.

Finally, I include two outcomes to test for relevant correlations. An effect from the *winning technology* (the dominant one in skewed outcomes) indicates an inherent competitive advantage. Although the goal of auctions is to select the most competitive projects, a large and significant effect may indicate different levels of maturity, calling into question the decision to allow different technologies to compete. And the *subscription status* shows if undersubscribed auctions systematically affect the skewness.

3.4 Statistical analysis for the driving factors

To determine the relevance of the driving factors, I conduct *analysis of variance* (ANOVA) tests. An ANOVA is a linear regression method used to compare the means of different groups. A mean is the continuous dependent variable (DVs), and the groups are the categorical independent variables (IVs). I treat the driving factors as IVs of the DV skewness and do one-way (one IV) or two-way (two IVs) ANOVAs. In line with previous studies (Bento et al., 2020; Matthäus, 2020) and own methodical considerations, I consider the general context factors, country and winning technology, as a control variable in the two-way ANOVA. The relevant test statistic is based on the F-distribution, with two degrees of freedom, and a significance level of 0.05.

These statistical tests show if the average skewness numbers in the data, split by the different categories of the categorical IVs, differ significantly. Hence, they potentially explain the skewness. Significant F-values (considering the two degrees of freedom) in the ANOVAs indicate that the null hypothesis of equal means can be rejected. This indicates that at least one of the categories leads to a different skewness than the other(s). To determine which categories are different (if the results are significant), I do contrast analyses in the one-way ANOVAs and multiple pairwise comparisons in the two-way ANOVAs.

Because all ANOVAs require categorical data, I transform continuous variables into categorical variables by taking intervals (see Table A-1 for category overview). My choice for defining the skewness with a quotient, opposed to a share, is due to the statistical method: an ANOVA is in principle a linear regression and assumes a continuous scale rather than one of 0–1. The latter would require a more complex logistic regression analysis. Overall, my approach is different from similar work like Diallo and Kitzing (2020) by relying more on a statistical regression framework.

The three main ANOVA assumptions are roughly fulfilled for the presented results. Using plots, I visually checked[19] the assumptions of homogenous variances and normality. Outliers occur but are rarely influential. The assumption of independence was given because different rounds usually occur separately and independently from each other.

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[19] The criteria for accepting the assumptions were that residuals occurred on both sides of the mean line and that most points followed a normal distribution, except on the tails of the distribution, where the assumptions can usually be relaxed.

In an additional analysis, I analyse the effects of general auction-external factors, namely the gross domestic product (GDP), as well as the global[20] average lifetime costs of energy (LCOE). These factors could affect the dominance of single technologies: the economic context through (here unspecified) indirect effects on the economy and thus investment/bidding decisions, and technology costs through the direct effect on bid prices and hence auction results. The DV in these analyses are the outcome-ratios. I use the Pearson's correlation coefficient (PCC). The correlation analysis is useful as both DV and IV are continuous.

4 Results

My results indicate a general trend for skewed technology mixes in the auction outcomes (Section 4.1). However, single factors cannot easily explain this (Section 4.2). The trend is also reflected in individual countries (Section 4.3), but even in a technology- or country-specific context, design elements cannot clearly explain the trends (Section 4.4).

4.1 General trends in multi-technology auctions

Although there were only 86 multi-technology rounds from 2011 to 2020 (Table 2), compared to 241 technology-specific ones[21], the total volume of multi-technology rounds (60.5 GW) is considerably larger than that of the technology-specific rounds (40.6 GW). Although shares vary, having slightly less capacity from multi-technology auctions in 2020, these auctions were the most popular design choice between 2014 and 2019.

Table 2: Yearly count and capacity of multi-technology and technology-specific auction rounds in the EU from 2011 to 2020. Percentages are yearly shares (missing shares to 100% are project-specific rounds).

Year	Count of rounds and share		Awarded capacity (MW)		
	Multi-technology	Technology-specific	Multi-technology	Technology-specific	Multi-technology share
2011	1 (100%)	0 (0%)	189.76	-	100%
2012	0 (0%)	9 (100%)	-	690.41	0%
2013	0 (0%)	16 (100%)	-	1'113.39	0%
2014	1 (20%)	4 (80%)	1’362.42	455.21	75%
2015	3 (18%)	13 (76%)	3’520.21	992.86	78%
2016	4 (12%)	28 (82%)	4’322.72	3'821.61	53%
2017	13 (27%)	36 (73%)	18’633.15	9'096.04	67%
2018	12 (24%)	39 (76%)	8’657.61	7'611.43	53%
2019	21 (31%)	45 (67%)	16’984.42	8'821.76	66%
2020	31 (38%)	51 (62%)	6’874.66	8'021.65	46%
Total	**86**	**241**	**60’544.93**	**40'624.37**	**60%**

Table 3: Number (N) of multi-technology auction rounds in the EU between 2011 and 2020.

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[20] Global costs are a sufficient proxy for my purpose as the paper is only interested in effect correlations, not estimating a specific prediction model.

[21] Project-specific rounds contribute 4 rounds and 1.9 GW of capacity. 0 MW results are excluded.

Country	N
Italy	21
Slovenia	16
Netherlands	11
Poland	9
Germany	7
Greece	4
Hungary	4
United Kingdom	4
Denmark	2
Estonia	2
Spain	2
France	1
Finland	1
Ireland	1
Lithuania	1

These 84 rounds were conducted in 15 countries, mainly in Italy, Slovenia, the Netherlands, Poland, and Germany (Table 3). Of all awarded capacities in multi-technology auctions in the EU, PV had the highest share, followed by onshore & offshore wind (Figure 1). Bioenergy and other technologies (e.g. combined heat and power, hydropower, and others) only won minor shares. Nevertheless, no technology in the aggregated EU-wide outcome was strongly dominant, i.e. having twice the share of all others. Moreover, if the Netherlands are excluded—the country awarded significantly more capacity—the remaining outcomes of the other 14 countries are even less skewed.

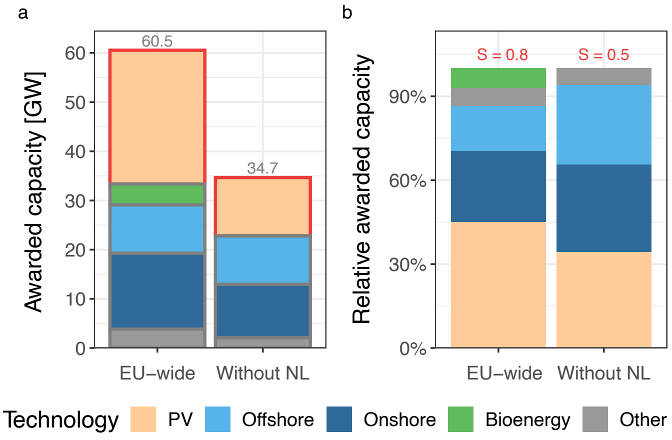

Figure 1: Aggregated awarded capacities in multi-technology auction rounds, EU-wide and without the Netherlands (a–b). The skewness (S) is shown above the columns in b. Technologies with the largest amount are framed (red).

Figure 2 depicts the auction outcomes on different aggregation levels, i.e. by project countries (a–b), years (c–d) and rounds (e). First, the figure underlines the high shares of PV and the large auction volume in the Netherlands. Figure 2a&b further show that (1) the awarded technology mix differs strongly between project countries, (2) that PV gained most capacity in about half of the countries and onshore wind in the other half, and (3) that less than half of the countries' outcomes are strongly skewed (having a skewness >2). More than half of all countries have thus a relatively balanced technology mix resulting from multi-technology auctions, which is similar to the finding for the aggregated EU-wide outcome.

Second, the distribution over the years shows no clear trends (Figure 2c&d), though most years, except 2018, are balanced, with no technology dominating. The dominance in 2018 is mainly driven by rounds in the Netherlands (due to the large auction volume) and thus not a general trend. In summary, neither the EU-wide, national nor temporal aggregation levels show clear and systematic developments towards one dominant technology in the EU.

Finally, on the level of single rounds (Figure 2e), 80% of all rounds are skewed. Only 17 rounds (20%) have a skewness <2, while 34 have a skewness ≥2 (40%), meaning that a dominant technology gained at least two-thirds of all awarded capacity. In 35 rounds, only a single technology was submitted and awarded (resulting in an infinite skewness). This section shows that most multi-technology auction rounds in the EU tend to favour one technology over others, even if the aggregated outcomes on higher levels are less skewed.

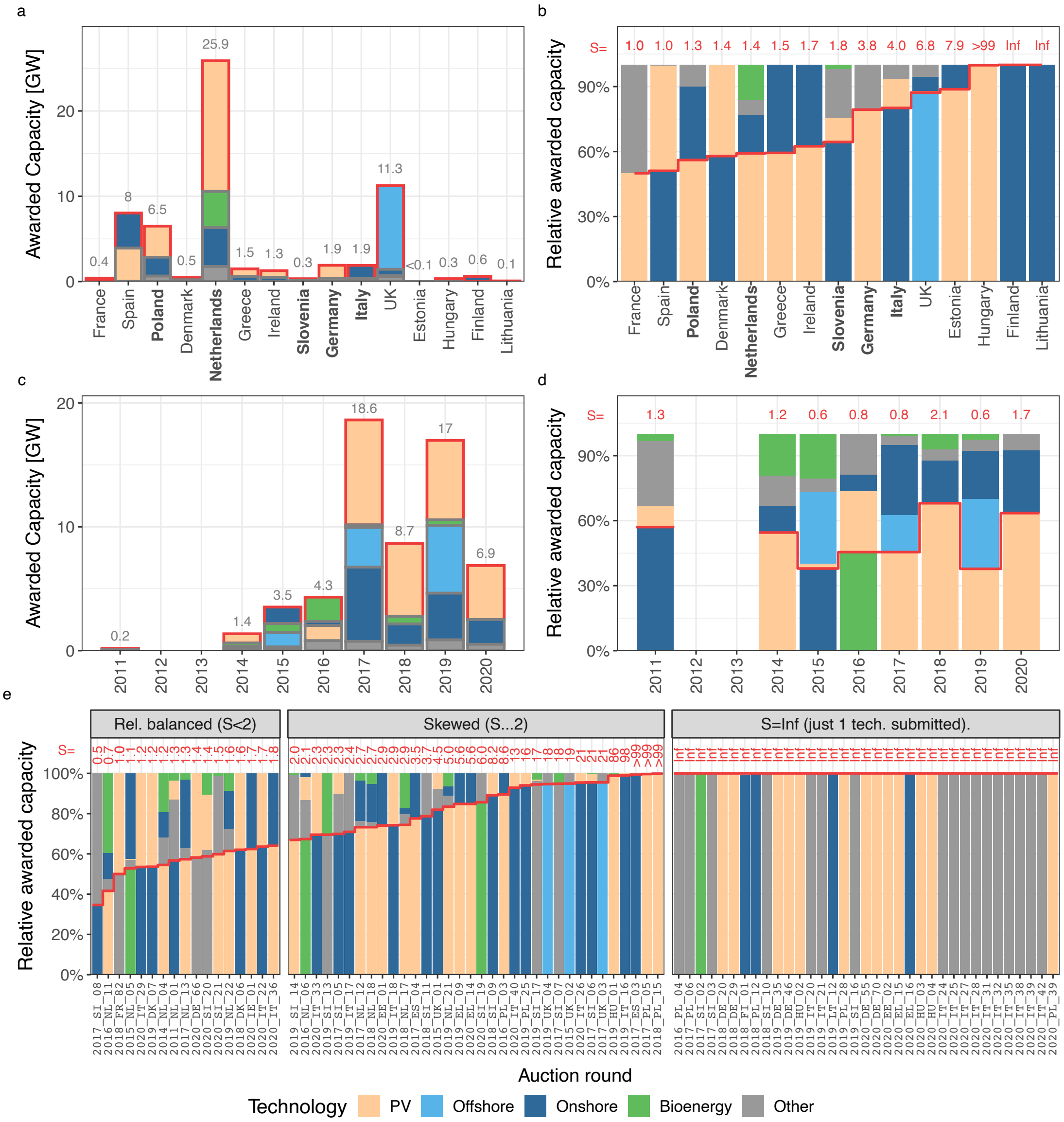

Figure 2: Awarded capacities in multi-technology auction rounds per (a, b) project country, (c, d) year and (e) round. The skewness (S) is shown above columns (b, d, e). Winning and dominant technologies are red framed (a, c) or below the red line (b, d, e). Labels (in e) are "[year]_[country]_[number]" which corresponds to the naming "[country]_[number]_MT" in the AURES II database. "just 1 tech. submitted" means that only projects of one technology submitted bids. Countries with bold labels are discussed in more detail in Section 4.3.

4.2 General driving factors of skewness

The previous section showed that rounds tend to be skewed towards one technology. To determine the driving factors, I conduct one-way ANOVAs for the 51 rounds in which at least two different technologies submitted bids and summarise results in Table 4.

First, at the significance level (p<.05), average skewness is neither affected by the *winning technology* nor by the *year*. This indicates that multi-technology auctions do not systematically favour wind, PV or biomass and that dynamic effects do not affect the skewness. The *subscription status* does not affect the skewness either. However, there is a significant effect for *country*, but the average skewness only differs significantly in Poland and Hungary (according to the contrast analysis, see Table D-1). As these two countries only represent 10 rounds, it is not possible to accept the country as a general driving factor. Hence, the general country context factor is a minor but not irrelevant determinant for the skewness of single rounds.

Second, results indicate that none of the investigated design elements significantly affect the skewness either, at least not in a univariate model. P-values are generally high and above the significance level for the award criterion, ceiling price level, lead time, support duration and financial prequalification. Hence, I cannot pinpoint a single auction design element or general context factor that sufficiently explains the skewness. Instead, combined effects of country-specific factors and design elements might affect the skewness, which I explore in the following sections.

Table 4: Summary of the one-way ANOVA results. Showing the number of categories, F-statistics, both degrees of freedoms (df) and the associated p-values. Full results, see 8Appendix B The * indicates significance at p<.05.

Factor	Categories	F-value	df1	df2	p-value
Winning technology	5	0.27	4	47	0.89
Year	8	0.71	7	44	0.66
Subscription status	2	0.32	1	41	0.58
Country	13	2.85	12	39	0.007*
Award criterion	2	0.88	1	50	0.35
Ceiling price level	5	0.47	4	34	0.76
Lead time	5	0.18	4	35	0.95
Support duration	4	1.58	3	48	0.21
Financial prequalification	2	0.80	1	50	0.38

Although the winning technology is not a determining factor for the skewness in a univariate analysis, it could be that design elements have different effects in different technology groups, and that certain design elements are always present if a specific technology dominates. Thus, in an additional two-way ANOVA, I control for the winning technology variable and summarise results in Table 5. However, the results show that design elements do not affect the skewness significantly if specific technologies are considered.

Table 5: Summary of the two-way ANOVA results, controlling for the technology context, but here only showing the main factor. Showing the number of categories, F-statistics, both degrees of freedoms (df) and the associated p-values. Full results, including control variables see Appendix C.

Factor	Categories	F-value	df1	df2	p-value
Award criterion	2	1.11	1	46	0.30
Ceiling price level	5	0.25	4	30	0.91
Lead time	5	0.30	4	31	0.87
Support duration	4	1.27	3	44	0.30
Financial prequalification	2	0.73	1	46	0.40

4.3 Trends within the country context

Figure 3 shows in more detail the trends of five countries that conducted at least six rounds. In line with the previous results, I find a trend towards skewed outcomes (i.e., skewness ≥ 2) in most rounds in all countries. However, the aggregated outcomes on the national level can be more balanced. In Germany and Italy, most rounds have a skewed outcome, like in the aggregate outcome on the country levels (skewness of 3.8 and 4). In contrast, the aggregated national outcomes in Slovenia, Poland and the Netherlands are relatively balanced (skewness of 1.8, 1.3 and 1.4), even if rounds are mostly skewed (at least half of them). These deviations occur because the winning or dominant technologies varied over time[22].

This section shows that the trend for skewed rounds is not only a general pattern in all rounds but also within countries. Nevertheless, single rounds and the sum on the country level need to be considered separately to draw meaningful conclusions about the effects of multi-technology auctions on technology balance. This means, even if most rounds are skewed, the aggregate national outcome can still be relatively balanced.

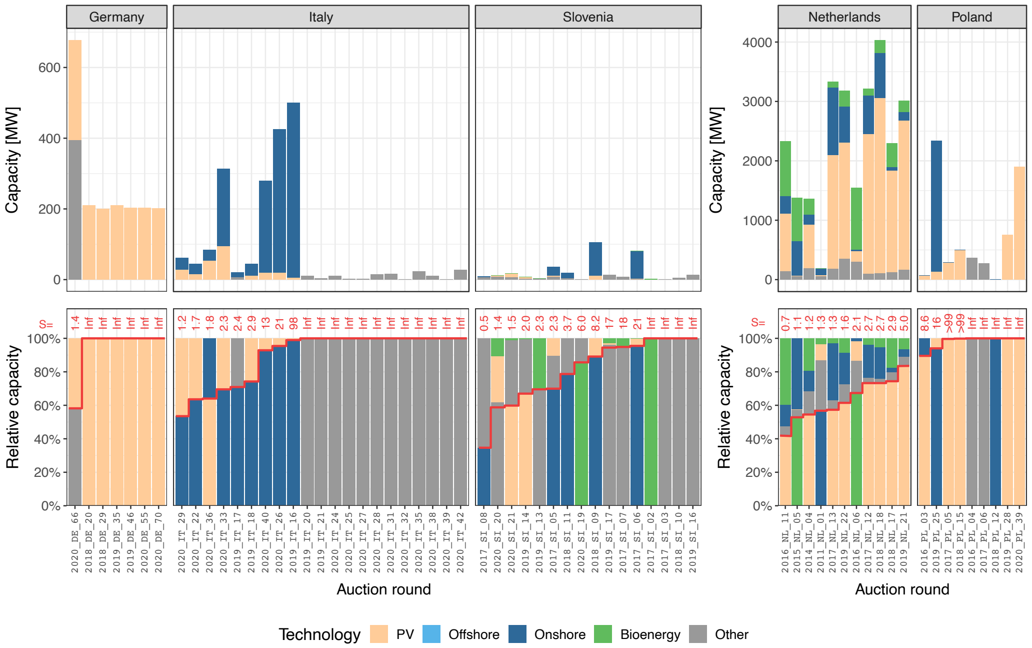

Figure 3: Awarded capacities (MW) in multi-technology auction rounds by country. Winning and dominant technologies are below the red line. The skewness (S) is shown in red above the relative capacity columns.

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[22] In the Netherlands, for example, it was mostly PV, but also twice bioenergy and once onshore wind.

4.4 Factors of skewness within the country context

To determine the driving factors in different country contexts, I conduct two-way ANOVAs for the subsample, control for the general country context, and summarise results in Table 6. Again, the results show that the average skewness is not significantly different across design elements, but in the country context p-values change and can be smaller. P-values are generally high for the ceiling price level, but comparably low for the lead time and the award criterion. The *award criterion* would even reach significance if the significance level was relaxed to 10%. However, I can only observe such an effect in Italy, which used both types of criteria[23]. Hence, there is only weak evidence that the choice between price-based and multi-criteria auctions is relevant for the skewness of the outcome. For the financial prequalification and support duration, two-way ANOVAs were not possible because of insufficient variation within the groups (e.g. always the same prequalification). Overall, this section shows that the country context affects the significance of design elements. However, I can still not confirm that design elements are relevant factors to explain the observed skewness in multi-technology rounds.

Table 6: Summary of the two-way ANOVA results, controlling for the country context, but here only showing the main factor. Showing the number of categories, F-statistics, both degrees of freedoms (df) and the associated p-values. Full results, including control variables, are in Appendix C.

Factor	**Categories**	**F-value**	**df1**	**df2**	**p-value**
Award criterion	2	3.03	1	31	0.09
Ceiling price level	5	0.20	3	19	0.89
Lead time	5	2.04	2	19	0.16

4.5 General auction-external factors

As design elements have no significant effect, general and country-specific auction-external factors might be more relevant. For instance, two of the more general (country- and technology-specific) factors are the economic context and costs of renewables. For this, I do an exploratory correlation analysis yielding the Pearson correlation coefficient (PCC).

Results indicate that no general correlations between the outcome-ratios and the GDP (PCC=0.04) and the LCOEs (PCC=0.02) exist. Thus, other specific auction-external factors are potentially causing the skewness. Such effects are discussed below in a qualitative manner based on existing case studies.

5 Discussion

Based on the results and the literature, I discuss four main insights: multi-technology auctions favour technologies (Section 5.1), which affects future power mixes (Section 5.2). As design elements and context factors do not determine the skewness (Section 5.3), auction-external factors may be more relevant (Section 5.4). I also discuss potential limitations and opportunities for upcoming research (Section 5.5).

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[23] For the award criterion, and under a relaxed significance level, pairwise comparison results are equal to the ANOVA results and thus not presented separately.

5.1 Multi-technology auctions tend to favour single technologies

My research finds that multi-technology auctions in the EU tend to favour single technologies. 80% of all outcomes in rounds from 2011 to 2020 were skewed towards the dominant technology, meaning that one technology gained at least two-thirds of all capacity. In this sense, many rounds are more technology-specific than -neutral, which is not only a counter-intuitive outcome but possibly an undesirable one if policymakers aim to expand different renewables in parallel.

The trend for skewed outcomes in single rounds does not mean that the resulting European technology mix will necessarily be unbalanced, too. While most rounds have skewed outcomes, they are skewed in different ways because their dominant technologies vary (see next Section). Therefore, the resulting mixes were relatively balanced in each country and year, which is currently beneficial for a solid and resilient electricity system (Gul and Stenzel, 2005). Furthermore, I did not find a clear trend towards one dominant technology at the European level; even the high (but not strongly dominant) shares of PV are mainly due to the influence of a single country, the Netherlands.

5.2 Skewed outcomes may affect future power mixes

The aggregated outcomes from multi-technology auctions are not the same as the national power mixes because capacity does not only originate from these auctions. But if countries use those auctions as their principal instrument to expand renewables, the aggregated outcomes will become similar to the power mix in the long run. Policymakers must therefore be aware of the outcomes.

Currently, the aggregated auction outcomes, on national and EU-wide levels, are relatively balanced. But this balance may just be a coincidence, hinging on the alternating dominance of renewables in different rounds, caused by possibly random but changing factors (changing because the dominance differs between rounds). Moreover, the fact that most rounds are skewed increases the risk for sudden changes, especially if upcoming large rounds strongly affect the overall technology mix, like in the Netherlands. My results thus imply that the national and European power mixes could become skewed in the future if multi-technology auctions are increasingly implemented. I expect that these power mixes could be more balanced and diverse in the long term if the outcomes of single rounds were less skewed towards single technologies.

Despite the benefits of a balanced system, such as increased power system reliability, the degree of balance in individual countries and the EU is still a decision that must be made by policymakers. After all, it may be fine for countries to have a technology mix that favours one technology, for instance due to local resource potentials, flexibility from cross-border connections, or other specific circumstances.

5.3 Design elements are not determinants of skewness

The design elements and general context factors analysed cannot explain the skewness in individual rounds in almost any country[24]. This applies to univariate effects and effects in which the effects of the winning technologies and countries are considered (see discussion of models below in Section 5.5). Particularly the latter is surprising and suggests that neither

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[24] I found significant skewness differences in contrasts with Poland and Hungary.

design elements nor the differences between countries and technologies are the main factors for skewness.

I only found weak evidence for an effect in one instance, the award criterion in Italy. However, this finding is not sufficient to draw a generalisable conclusion. The effects of the ceiling price level, lead time, support duration, financial prequalification and award criterion should therefore not be overestimated, even if literature suggests potential effects on diversity (see studies cited in Haelg (2020), and Diallo and Kitzing (2020)).

I see two potential explanations for a general lack of significance. First, the design elements could be set in a manner that does not favour single technologies, and thus, not result in a bias or dominance. For this outcome, however, policymakers need to have an excellent market knowledge to optimally[25] design the elements for each technology (Mora et al., 2017; Kitzing et al., 2019), which may not always be the case. Second, even if there were causal effects, they may be too small to detect empirically or may be obscured by factors external to the auction, which vary by context and country (see next Section).

Overall, my paper contributes to the understanding that there are no general rules or single-best auction designs (Maurer and Barroso, 2011), particularly not for avoiding technology dominance and bias in multi-technology auctions (Diallo and Kitzing, 2020). This also makes it difficult to transfer design concepts from one country to another (Gephart et al., 2017).

5.4 More attention towards specific context factors needed

While design elements and general (including auction-external) context factors cannot explain the skewness in auctions, more country-specific auction-external factors could be underlying causes. Several studies have indeed identified context-specific factors such as interest rates or market potentials that affect other auction outcomes like the deployment rates or support costs (Gephart et al., 2017; Bayer et al., 2018; Haufe and Ehrhart, 2018; Polzin et al., 2019; Bento et al., 2020).

Case studies, mainly from the AURES II project, have further illustrated the mechanisms of country-specific factors for the countries analysed in this paper, notably, the Netherlands, Italy, Germany, Poland, but also others. The findings in these studies confirm that specific auction-external factors rather than design elements are the probable driving factors of technology outcomes.

In the Netherlands, an early adopter of technology-neutral and multi-technology auctions, technology shares, e.g. of PV, were affected by factors such as the availability of cheap projects (Jakob et al., 2019). Once project pipelines of Dutch developers were depleted, partly due to legal and societal factors like permitting and opposition, other projects of different technologies have gained more shares.

In Italy, a case study identified auction-external reasons for the consistently high shares of wind power (Diallo et al., 2021). This is peculiar given the high potential for PV in this sunny country but can be explained by administrative hurdles and regulations that ban ground mounted PV from agricultural land. Thus, few PV projects are developed, showing that circumstances can be more important than any effects from design elements of general context factors regarding the skewness of auctions.

Furthermore, in Germany, permission and acceptance issues blocked the expansion of wind power (Grashof et al., 2020), in Poland, the government precluded any further expansion of wind plants (Diallo et al., 2019), and in Spain, all available wind projects in the developers'

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[25] For example, knowing the exact ceiling price levels to avoid any technology biases.

pipelines were awarded in the first round, leaving only PV projects to participate in subsequent rounds (del Río, 2018). Administrative delays also negatively affected auctions in Greece and outside of the EU (Anatolitis, 2020; Bayer, 2018). Finally, random, and unsystematic effects might be relevant factors in any outcome.

5.5 Limitations and outlook

My paper has some limitations that present opportunities for future research. First, the selection of design elements is not exhaustive. Some design elements are mentioned[26] in literature (Diallo and Kitzing, 2020; Haelg, 2020) but I do not consider them due to various reasons. First, due to the scope, *technology specificity* and *location specificity* do not vary in my study. Second, *grid integration costs* and *environmental harm compensation* are not represented in the database. Third, the *auctioned product* is studied in the literature (Haelg, 2020) and is available in the database, but the variables are defined differently in the two sources.

Second, I have focused on the effect of individual design elements and general context factors. However, auctions consist of a combination of several design elements, hence the *combination* of several elements could potentially better explain the technology outcome than each element in isolation. Future studies should provide theoretical and empirical reasoning for how such combinations affect technology diversity, build multivariate models, and explore relevant interactions. However, researchers should keep in mind that larger models may also require larger sample sizes.

Third, 29 rounds were undersubscribed (about 21% of all submitted capacity). They probably did not work as intended. In such cases, the competition is generally too low and prices are too high (Grashof et al., 2020; IRENA, 2019). Importantly, their outcome cannot be fully determined by design elements, since all accepted bids are awarded. Nevertheless, I could not find any significant influence of subscription status on skewness, suggesting that this factor can be neglected here.

Fourth, while my study has ruled out design elements and general factors as causes for varying skewness, empirical research should continue focusing on the effects of auction-external factors, and particularly how very specific context factors, like the ones outlined above, influence technology diversity in different contexts over time. Vice versa, the effect of multi-technology designs on local value chains can be of high interest. Qualitative research could systematically summarise, categorise, and evaluate[27] auction-external factors. In addition, more case studies about less researched countries such as Slovenia or a global scope are needed to provide a deeper understanding of these factors.

Finally, empirical studies like mine are useful to evaluate past policies and support future policy decisions but depend on the availability and quality of data. While the AURES II dataset currently provides a good and complete overview of recent auctions, it may be discontinued when funding ends. Hence, I suggest that the EU establishes an official database of auction results or provides sustainable funding to maintain this or similar databases.

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[26] I refrained from correlating random design elements unless literature suggests an effect. While some factors may remain unexplored, I reduce the chance of spurious correlations.

[27] E.g. using interviews, or the study and qualitative comparative analysis of reports.

6 Conclusion and Policy Implications

Multi-technology auctions have become a popular policy instrument to promote renewables in the EU, and therefore, national policymakers need to understand how they affect technology diversity. I show that multi-technology auction rounds tend to favour single technologies. However, these skewed outcomes are not necessarily reflected in the national and EU-wide outcomes, which are relatively balanced. The reason is that the dominant technologies of individual rounds vary, even in subsequent rounds in the same countries.

Differences in auction design elements cannot explain the skewed auction outcomes, nor can general context factors (such as country or year). If policymakers rely on multi-technology auctions, they may be limited in their ability to steer the resulting technology mix. This does not mean that design elements will not affect auction results—quotas, for instance, determine the maximum amounts that technologies are eligible to gain—but other, specific auction-external effects are generally more relevant regarding the skewness. In the long term, skewed auction outcomes may decrease the balance and variety of the national power mix and thus pose a risk for the power system reliability and cost-effectiveness. Unless countries are able to manage such risks, policymakers should consider balancing the outcomes of auctions. Relying more on technology-specific designs is one possibility to expand renewables more targeted, both to guide the deployment pathway and to "correct" any unwanted imbalances, should multi-technology auctions remain.

In conclusion, multi-technology auctions in the EU have often resulted in one dominant technology. While no technology was continuously dominant over a longer period of time, it is unclear if this balance remains in the future. The updated state-aid guidelines provide an opportunity to rely more on technology-specific auctions. My results suggest that EU countries should not shy back from taking this opportunity to better steer the technology deployment as the energy transition makes its largest strides so far during the 2020s.

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Appendix A : Design elements

Table A-1 shows the variable names in literature and their counterparts in the AURES II database.

Table A-1: Units, categories, and names in the database and literature for the analysed design elements. Literature sources: Diallo et al. (2020) and Haelg (2020).

Design element	**Unit**	**Categories**	**Name in AURES II DB**	**Name in literature**
Award criterion	-	Price, multi-criteria.	Award procedure	Award criteria
Ceiling price level	[€-cent/kWh]	(0.8,4.4]; (4.4,7.9]; (7.9,11.5]; (11.5,15.1]; (15.1;18.6].	Level of ceiling price	Ceiling prices
Lead time	[months]	(6.0,16.8]; (16.8,27.6]; (27.6,38.4]; (38.4,49.2]; (49.2,60.1].	Realisation period	Lead time to build
Support duration	[years]	12, 15, 20, 25	Support duration	Support duration
Financial prequalification	-	Yes, No.	Financial prequalification	Bidder requirement

Table A-2: Units and categories for the analysed context factors.

Context factor	**Unit**	**Categories**
Country	Price / multi-criteria	Hungary, Poland, Spain, UK, Greece, Slovenia, Estonia, Italy, Ireland, the Netherlands, Denmark, Germany, France
Year	[€-ct/kWh]	2011, 2014, 2015, 2016, 2017, 2018, 2019, 2020
Winning Technology	[months]	Offshore, Onshore, PV, Bioenergy, Other
Subscription	[years]	Oversubscribed, undersubscribed

Appendix B : Full results of one-way ANOVAs

Table B-1 to Table B-9 show the one-way ANOVA results.

Table B-1: ANOVA for the winning technology. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***

(Intercept)	27.94	1	27.94	0.03	.854
Winning technology	884.27	4	221.07	0.27	.894
Error	38155.93	47	811.83		

Table B-2: ANOVA for the year. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	1.72	1	1.72	0.00	.963
Year	3970.32	7	567.19	0.71	.662
Error	35069.89	44	797.04		

Table B-3: ANOVA for the country. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	3.89	1	3.89	0.01	.932
Country	18233.50	12	1519.46	2.85	.007
Error	20806.70	39	533.51		

Table B-4: ANOVA for the subscription state. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	3861.86	1	3861.86	10.00	.003
Subscription State	121.86	1	121.86	0.32	.577
Error	15831.72	41	386.14		

Table B-5: ANOVA for the award criterion. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	14.28	1	14.28	0.02	.892
Award criterion	672.21	1	672.21	0.88	.354
Error	38367.99	50	767.36		

Table B-6: ANOVA for the ceiling price level. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	3.89	1	3.89	0.00	.946
Ceiling price level	1566.38	4	391.60	0.47	.758
Error	28420.23	34	835.89		

Table B-7: ANOVA for the lead time. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	8.16	1	8.16	0.01	.922
Lead time	617.52	4	154.38	0.18	.946
Error	29520.21	35	843.43		

Table B-8: ANOVA for the support duration. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	Sum of squares	*df*	Mean square	*F-value*	*p-value*
(Intercept)	12.15	1	12.15	0.02	.899
Support duration	3501.67	3	1167.22	1.58	.207
Error	35538.53	48	740.39		

Table B-9: ANOVA for the financial prequalifications. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	Sum of squares	*df*	Mean square	*F-value*	*p-value*
(Intercept)	1351.56	1	1351.56	1.76	.191
Financial prequalification	613.78	1	613.78	0.80	.376
Error	38426.42	50	768.53		

Appendix C : Full results of two-way ANOVAs

Tables Table C-1 to Table C-3 show the two-way fixed-effect ANOVA results, based on a smaller sample than the one-way ANOVA.

Table C-1: Two-way ANOVA for the award criterion and country. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	Sum of squares	*df*	Mean square	*F-value*	*p-value*
(Intercept)	396.45	1	396.45	0.84	.367
Country	10090.70	4	2522.68	5.34	.002
Award criterion	1430.12	1	1430.12	3.03	.092
Error	14643.60	31	472.37		

Table C-2: Two-way ANOVA for the ceiling price level and country. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	Sum of squares	*df*	Mean square	*F-value*	*p-value*
(Intercept)	1.94	1	1.94	0.00	.962
Country	5966.30	3	1988.77	2.43	.097
Ceiling price level	500.54	3	166.85	0.20	.893
Error	15557.93	19	818.84		

Table C-3: Two-way ANOVA for the lead time and country. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	Sum of squares	*df*	Mean square	*F-value*	*p-value*
(Intercept)	396.45	1	396.45	0.68	.421
Country	4216.08	3	1405.36	2.40	.100
Lead time	2395.86	2	1197.93	2.04	.157
Error	11147.27	19	586.70		

Table C-4: Two-way ANOVA for the lead time and winning technology. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	110.40	1	110.40	0.12	.731
Technology	1180.36	4	295.09	0.32	.861
Lead time	1112.91	4	278.23	0.30	.873
Error	28339.85	31	914.19		

Table C-5: Two-way ANOVA for the financial prequalification and winning technology. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	19.22	1	19.22	0.02	.879
Technology	866.99	4	216.75	0.27	.899
Financial prequalification	596.51	1	596.51	0.73	.397
Error	37559.42	46	816.51		

Table C-6: Two-way ANOVA for the ceiling price and winning technology. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***
(Intercept)	1.35	1	1.35	0.00	.969
Technology	1499.85	4	374.96	0.42	.794
Ceiling Price Level	902.90	4	225.72	0.25	.906
Error	26920.39	30	897.35		

Table C-7: Two-way ANOVA for the award criterion and winning technology. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of Squares**	***df***	**Mean Square**	***F***	***p***
(Intercept)	274.51	1	274.51	0.34	.563
Technology	1114.45	4	278.61	0.34	.847
Award criterion	902.39	1	902.39	1.11	.297
Error	37253.55	46	809.86		

Table C-8: Two-way ANOVA for the support duration and winning technology. Fixed-Effects ANOVA results using skewness as the dependent variable.

Predictor	**Sum of squares**	***df***	**Mean square**	***F-value***	***p-value***

(Intercept)	0.04	1	0.04	0.00	.994
Technology	416.42	4	104.11	0.13	.970
Support Duration	3033.81	3	1011.27	1.27	.297
Error	35122.12	44	798.23		

Appendix D : Significant contrasts

Table D-1: Significant results of the contrast analysis, with significance level $p<0.05$.

Contrast	Estimate	SE	df	t-ratio	p-value
Hungary - Netherlands	94.8	24.1	39	3.93	0.013
Poland - Slovenia	59.7	14.8	39	4.02	0.013
Hungary - Slovenia	89.8	23.9	39	3.75	0.015
Hungary - Italy	80.9	24.4	39	3.32	0.038
Hungary - United Kingdom	81.3	25.1	39	3.24	0.038
Poland - United Kingdom	51.2	16.7	39	3.07	0.050