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Resilience Auctions for Net-Zero Technologies

An Effective Market-based Measure to Shield the Green Transition?

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Europe's rapid transformation to a climate-neutral economy has put a limited set of renewable energy technologies like heat pumps and solar modules into the spotlight of the EU industry strategy. For some of these "net-zero" technology goods, the EU exhibits significant import dependencies on a few third countries, foremost on China. This exposes European supply chains to hardly manageable risks. The Net-Zero Industry Act (NZIA) has set the stage for a new market-based instrument to overcome critical dependencies and internalize resilience contributions: the introduction of resilience criteria in public procurement and renewable energy support auctions. This cepInput investigates its design and expected effects, drawing on a Case Study of PV support in Germany.

Key results:

- Adding resilience criteria to public tenders is an effective means to stimulate demand for net-zero technologies from alternative suppliers. To limit cost uncertainty and maintain competition among bidders, they should be designed exclusively as award criteria, not as pre-qualification criteria. Moreover, for greater precision, they should be implemented in a vertically differentiated manner, i.e. as a value-based weighting of the resilience contributions of each main component.
- Consequences of specific calculation principles need to be thoroughly tested through scientific experiments and EU-wide pilot auctions. If implemented successfully, the Commission should push for a homogeneous application by Member States, to avoid distortions of the internal market.
- To increase its effectiveness and reduce implementation risk, the measure should be accompanied by intensified supply-side initiatives. This should include joint efforts to overcome domestic resource constraints, the development of specialized industry clusters to foster large-scale factories and a new focus on promoting breakthrough innovation.

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1 Background

The fate of Europe's transformation towards climate-neutrality will hinge on the availability of a limited set of renewable energy technologies. On global markets for some of these key net-zero technologies like storage batteries and photovoltaic (PV) modules, European manufacturers only play a minor role. In the future, their position is threatened to be further weakened by structural cost disadvantages in resources like labor and electricity. This not only jeopardizes Europe's significant innovation capacity in these fields, it also cements its dependence on imports from a small number of supplier countries, most notably China. Such a scenario exposes the EU to a high risk of trade disruptions and political blackmail. It is also at odds with the EU's idea of international trade being governed by comparative advantages, given that China's dominant market positions is partly a consequence of targeted industry subsidies.[1]

Against this background, the EU has formulated an ambitious target. In 2030, domestic manufacturing capacity for net-zero technologies shall reach a level of 40% of the EU's annual deployment needs.[2] The corresponding supply-side measures agreed upon at EU level so far – mainly a shortening of approval procedures for manufacturing projects and a streamlining of existing funding channels – fall far short of the ambition of this target. Therefore, hopes are pinned on a new demand-based support instrument, the introduction of resilience criteria in public procurement and support auctions for renewable energies. In presence of strong import dependencies on specific third countries, maximum thresholds for the share of net-zero technology equipment obtained from dominant suppliers are imposed. This incentivizes bidders to diversify their procurement channels, thereby creating demand for inputs from alternative supply sources. Such criteria can be implemented both as binding participation requirements (pre-qualification) and award criteria.

The Net-Zero Industry Act defines basic framework conditions for such procedures, to be specified further by subsequent Implementing Acts. Moreover, in her political guidelines for the next European Commission 2024-2029, President Ursula von der Leyen announced proposals to change the Public Procurement Directive to give preference to European goods in strategic sectors, potentially implying an extension of resilience rules beyond the scope of net-zero technologies.[3]

However, the implementation of such new criteria is not without economic and political risk. This cepInput investigates design issues and their likely consequences, both on a general theoretical level and empirically through a Case Study of PV support in Germany. Based on the economic reasoning, recommendations for the specification of resilience criteria and their embedding in a holistic support framework are formulated.

[1] Bickenbach, F., Dohse, D., Langhammer, R. J., & Liu, W. H. (2024). Foul play? On the scale and scope of industrial subsidies in China (No. 173). Kiel Policy Brief.

[2] European Union (2024). Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724

[3] Von der Leyen, U. (2024). Europe's Choice - Political Guidelines for the next European Commission 2024-2029.

2 Resilience criteria in current EU legislation

2.1 Public procurement

In its Article 25, the Net-Zero Industry Act (NZIA) regulates the application of environmental sustainability and resilience criteria in public procurement procedures where contracts involve technologies that belong to the list of net-zero technologies defined in Article 4(1) of the same act.

Regarding environmental sustainability, minimum mandatory requirements shall be defined (Article 25(1)), whose detailed specification will be spelled out later by an Implementing Act (Article 25(4)). In formulating the specific requirements, the Implementing Act will consider the following elements (Article 25(5)):

- The market situation at Union level of the relevant technologies;
- provisions regarding environmental sustainability set out in other Union legislative and non-legislative acts applicable to public procurement procedures covered by the obligation set out in Article 4(1);
- the Union's international commitments, the World Trade Organization (WTO) Agreement on Government Procurement (GPA) and other international agreements of which the Union is bound.

Moreover, the NZIA formulates concrete preconditions for the application of resilience criteria (Article 25(7-11)). In contrast to the sustainability criteria, these shall not be applied to all listed net-zero technologies but only to those where supply dependence on specific third countries exceeds at least one of two thresholds (Article 25(7)):

- The proportion of a specific net-zero technology or its main specific components originating in a third country accounts for more than **50%** of the supply of that specific net-zero technology or its main specific components within the Union;
- the proportion of supply within the Union of a specific net-zero technology or its main specific components originating in a third country has increased by at least **10 percentage points** on average for two consecutive years and reaches at least **40%** of the supply within the Union.

If these thresholds are exceeded, Member States shall include an obligation in public procurement contracts that not more than **50%** of the value of the net-zero technology and not more than **50%** of the value of its main specific components are supplied by providers from a single third country. A disregard of the obligations shall result in the payment of a charge of at least **10%** of the value of the relevant net-zero technologies.

Hence, even though the main goal of the NZIA is to foster the build-up of EU-internal production capacities of net-zero technologies, it avoids formulating resilience criteria in the form of explicit local content requirements. Instead, criteria refer to the goal of diversifying supply channels, i.e. reducing dependence on dominant supplier countries like China, not necessarily reducing import dependence in general.

At the same time, the NZIA provides room for some cost- and feasibility related exceptions (Article 25(8-11)). Contracting authorities may decide not to apply the resilience criteria if the net-zero technology can under fair procurement conditions only be provided by a single supplier, if no suitable tenders have been submitted in similar procurement procedures in the past two years or if the application would result in disproportionate equipment costs (defined as an estimated cost difference above **20%**). Moreover, the criteria may not conflict with international trade agreements, i.e. supply from third countries that have entered such agreements with the EU is excluded.

Hence, maintaining the proportionality of the resilience rules is considered important, in particular with regard to the cost-effectiveness of competitive procurement procedures.

2.2 Promotion of renewable energy

In its Article 26, the NZIA defines concrete criteria for auctions supporting the deployment of renewable energies. First, this includes the application of specific types of pre-qualification criteria (Article 26(1)). When designing renewable energy support auctions, the list of pre-qualification criteria applied by Member State Projects shall include preconditions on responsible business conduct, the maintenance of cyber and data security as well as ability to deliver the project fully and on time. Moreover, criteria for the auction's sustainability and resilience contribution, which could take the form of pre-qualification criteria or of award criteria.

The details will be spelled out by a further Implementing Act (Article 26(3)). The NZIA itself is defining some basic preconditions (Article 26(2)). Accordingly, criteria shall be objective, transparent and non-discriminatory. In analogy to public procurement procedures (see Subsection 2.1), the provision of **more than 50%** of a net-zero technology or of its main specific components by a single third country shall be applied as a yardstick for the resilience criterion. Thus, resilience is supposed to be achieved through a diversification of existing supply channels.

In the case of applying sustainability and/or resilience contributions as award criteria, the NZIA sets requirements for the weighting of these criteria. In the awarding decision, Member States shall give to each of the two aspects a minimum weight of **5%** and a combined weight **between 15% and 30%** (Article 26(4)). Member States can totally refrain from applying sustainability and resilience criteria if the application would be associated with disproportionate costs. Disproportionate costs are defined as an estimated cost difference of **more than 15%** (Article 26(5)). In this way, the trade-off between resilience and the goal of a cost-effective renewable energy promotion is supposed to be kept in check.

Yet, significant details remain to be clarified by the announced Implementing Act. First, this concerns the exact degree of freedom in specifying sustainability and resilience criteria as either pre-qualification or award criteria. Second, in the event of a specification as award criteria, it concerns the measurement basis underlying the weighting prescriptions defined in Article 26(4). For instance, the decision to measure the resilience contribution as either a binary criterion (contribution: yes/no) or a metric criterion (extent of resilience contribution, e.g. as diversification index) could drastically affect its variation among projects, and thus its effective impact on the awarding procedure for any given formal weight. Given the key role of renewable energy deployment for decarbonization aims, this could seriously affect the fate of Europe's turn to climate-neutrality in total.

Therefore, further careful analysis is required before formulating any concrete implementation conditions. For this reason, we will put the case of renewable energy support auctions in the spotlight of our following discussions.

3 Economic motivation for resilience criteria

An intuitive justification for binding resilience criteria could be the wish to overcome monopolies or oligopolies on markets for critical technologies. The introduction of these criteria directly diverts demand away from currently dominant producers. If investors consider that permanent adherence to these criteria is credible, this can stimulate investments in alternative production locations, helping to overcome the entry barriers imposed by scale economies. The result would be intensified competition. In this way, the resilience criteria could become superfluous over time. However, as resilience criteria are only linked to the geography of production, they lack precision as pro-competition instruments. As the example of PV modules shows, a high geographical concentration of supply may well be associated with fierce price competition between suppliers from the same region (in this case: China).[4] This benefits European importers in the form of low world market prices. Rigorously formulated resilience criteria could even reduce the intensity of competition if they restrict the number of accepted suppliers significantly.

Instead, a more convincing economic argument for resilience criteria is the presence of policy-related supply risks. A high concentration of the global supply of critical technologies in a single country means that global markets are highly dependent on that country's industrial and trade policies. First, this strengthens the geostrategic power position of that country, as it can use its own economic policy as diplomatic leverage. Second, it creates direct economic risks for value chains in importing countries. While price risks can potentially be hedged, physical procurement risks at least in the short-term cannot. If the product in question is an upstream technology that is difficult to substitute, these procurement risks can extend across entire supply chains. From an investor's perspective, risk diversification is particularly difficult when the corresponding technology, due to its wide range of applications, forms the basis for supply chains in a large number of different sectors, as is the case with some renewable energy technologies. This implies highly positively correlated sector risks. For basic renewable energy technologies like PV modules and heat pumps, this will certainly hold in the years to come.

For this reason, practical measures aimed at overcoming such dependencies can be seen as a form of positive externality. By contributing to the creation of spatially diversified production capacities, they reduce the risk exposure of all importers. Due to the external character of this contribution, the individuals' willingness to pay is insufficient from a welfare perspective. This can be a fundamental justification for resilience requirements. However, this externality needs to be weighed against the costs of establishing alternative supply channels, which will be reflected in higher purchase prices in the short term. These higher prices may in turn affect the price competitiveness of domestic downstream technologies in importing countries. The medium-term price effect is a priori unclear. In a positive scenario, the demand impulse would cause a reduction in production costs of alternative suppliers through scale economies. In a negative scenario, incentives for technological leapfrogging, i.e. research into completely new technologies, would be thwarted, because domestic producers would be tempted to rely on the protective shield of resilience requirements.

The actual impact will be sensitive to the design. First, a basic question is whether the requirements are designed as local content requirements, as in the US Inflation Reduction Act, or as general diversification criteria, as the EU has done in the NZIA. First, WTO law argues directly against local

[4] Crooks, E. (2024). China's solar growth sends module prices plummeting. Wood MacKenzie. Blogpost, 05 April, 2024.

content requirements. The GATT national treatment principle prevents WTO members from imposing local content requirements on the production of goods. The origin-based distinction that necessarily comes with such a requirement represents a violation of Article III of the GATT.[5] The EU, which defined preserving a rules-based trading system to be a priority of its trade policy strategy, should feel bound by this. There is also a risk of a backlash in the form of restrictive countermeasures by the currently dominant producer countries. Instead, a formulation as a diversification criterion that does not exclusively discriminate against certain countries of origin, appears far less protectionist.

A second key issue is the scope of the criteria. In addition to their application in public procurement and renewable energy auctions, resilience criteria could also be made mandatory for access to other forms of government support. This could apply, for example, to access to public investment or research funding. Such an application of resilience criteria in areas beyond competitive bidding requires the development of new forms of implementation. In particular, it is important to ensure that any cost implications of the criteria do not run counter to the funding objectives.

Initially, there are arguments in favor of focusing the application of binding resilience criteria on support auctions for renewable energy carriers like wind power and PV electricity. One advantage of this scenario is that no direct cost risks for downstream industries are to be expected. This is because the costs incurred by supported project developers are fixed costs and thus have no direct influence on pricing on electricity markets. Therefore, the resilience criteria are unlikely to jeopardize the success of the green transformation as a whole by putting pressure on energy costs. Nevertheless, potentially significant costs will arise for taxpayers in the form of public funding requirements. When specifying specific resilience criteria, interactions with the existing design of renewable energy tenders should therefore be carefully analyzed. In the following, we analyze how resilience criteria can best be integrated into existing support systems for renewable energies.

4 Designing resilience criteria in renewable energy support auctions

4.1 Overview on design criteria

Internationally, a large number of countries within and outside the EU award subsidies for renewable energies in the form of auctions. However, the national systems differ significantly with regard to numerous design aspects. Haelg (2020) divides design options into five categories: auction scope, pre-qualification requirements, allocation process, contract design and auxiliary policies.[6] Regarding the **auction scope**, a key question is whether the auctions are designed to be technology-specific or multi -technology. In Germany, as in many other Member States, the promotion of electricity from wind power and PV is tendered separately. This facilitates the technical specification of supply chain-related resilience.

The **pre-qualification requirements** define the conditions that project developers must meet in order to be eligible to participate in the auctions. First, criteria are formulated to ensure that projects can actually deliver the quantities of electricity offered. These include technical eligibility criteria relating to the experience of the developer, proof of the project's feasibility, the legal steps taken to obtain

[5] Figueiredo, N. D. L. (2022). Local Content Requirements in WTO Law: Between Free Trade and the Right to Development. PhD Thesis.

[6] Haelg, L. (2020). Promoting technological diversity: How renewable energy auction designs influence policy outcomes. Energy Research & Social Science, 69, 101636.

permits and the quality of the materials used. It also includes criteria to ensure the financial viability of project developers in the form of financial statements, evidence of investor support or the direct provision of financial guarantees against non-compliance (bid bonds).[7]

The **allocation process** can be differentiated according to the rules for submitting bids, the type of bids submitted and the award criteria. Bids can be submitted as sealed bids or in the form of several bidding rounds with disclosure of the results of the previous round. The bids can either contain only a bid price or also other relevant components such as resilience criteria. In addition to the number and weighting of such components, the award criteria also include rules of payment distributions. Uniform price auctions provide for a homogeneous payment per unit electricity to all bidders, equal to the highest successful bid value (marginal bid). Pay-as-bid auctions, instead, remunerate all successful bidders according to their respective bid value.

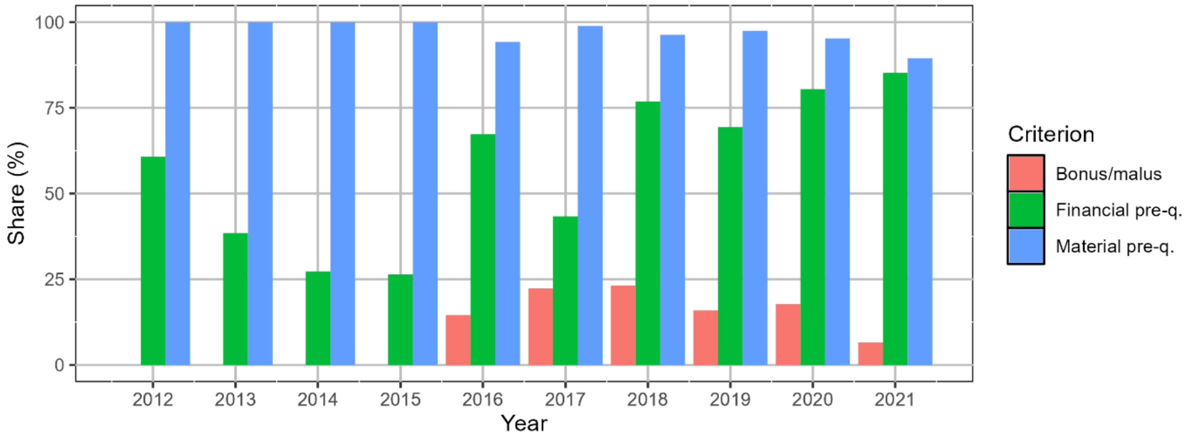
The **contract design** defines the form of remuneration paid by the government to the project developer. This includes the basis of assessment (typically one kWh of electricity produced), the conditionality of the subsidy paid (fixed vs. sliding premium on wholesale electricity prices), time specifications for the duration of the subsidy and the time allowed for construction (lead time to build). Finally, **auxiliary policies** include measures that do not directly affect the auction design, but influence auction outcomes through their direct impact on participants' revenues and costs. These include, for example, investment support measures that influence the capital costs of project developers and reduce the administrative costs of project approval procedures. If resilience criteria are introduced, the interaction with such auxiliary measures must be carefully assessed.

4.2 Experience with non-price auction criteria

Non-price-related criteria in the form of both prequalification criteria and award criteria are already applied in the support auctions of Member States. The AURES II Database reports the characteristics of all national Renewable Energy (RE) support auctions in the EU.[8] Accordingly, while bonus/malus adjustments of bid prices have not been a frequent phenomenon in past years, pre-qualification criteria have been standard instruments. In particular, material pre-qualifications were present in a clear majority of auctions (see Figure 1). These typically took the form of documentation requirements relating to technical feasibility or to the existence of building permits.

[7] Matthäus, D. (2020). Designing effective auctions for renewable energy support. Energy Policy, 142, 111462.
[8] Aures II (2022). Auction database. Auctions for Renewable Energy Support II Project.

Figure 1: Frequency of non-price criteria in renewable energy support auctions in Member States



Source: AURES II (2022)

By now, no Member State has introduced specific local content requirements in its renewable energy tenders. The measure that comes closest to an indirect form of local content support is a carbon footprint threshold applied to projects In France.[9] However, on a global scale, the picture looks quite different. In a global comparative study from 2021, del Rio & Kiefer (2021) identified the presence of local content requirements to be frequent in renewable energy auctions in Africa (50% of all auctions), America (40%) and Asia (40%), albeit in each of these regions with a shrinking tendency over time.[10] In Turkey and some African countries, local content is not mandatory, but corresponding projects are favoured in the auctions through premia or other mechanisms.[11]

The impact of pre-qualification requirements on bid prices, and thus on the societal costs of promoting renewable energy, is not a priori clear. There are usually costs associated with meeting the requirements. Some of these costs are incurred prior to participation in the auction, such as the administrative work involved in preparing and submitting evidence. Given their characteristic as sunk costs, these costs should not have a direct impact on the bid price. However, their deterrent effect could indirectly lead to higher bid prices if the level of competition is reduced through a decrease in the number of participants.[12]

In other cases, the requirements impose additional costs on the implementation stage, such as the costs of meeting certain environmental requirements. Bidders will try to offset some of these costs through higher bid prices, i.e. to pass them on to the general public. Chances depend on the heterogeneity of the costs and the degree of competition in the process. It is also conceivable that specifications could, under certain circumstances, lead to lower bid prices. This would be the case if

9 IEA (2023). Trends in photovoltaic applications 2023. International Energy Agency – Photovoltaic Power Systems Program (PVPS).

10 Del Río, P., & Kiefer, C. P. (2021). Analysing patterns and trends in auctions for renewable electricity. Energy for Sustainable Development, 62, 195-213.

11 See IEA (2023).

12 Anatolitis, V., Azanbayev, A., & Fleck, A. K. (2022). How to design efficient renewable energy auctions? Empirical insights from Europe. Energy Policy, 166, 112982.

strict technology requirements reduced technological uncertainty for project developers and thus lowered decision costs.[13]

Binding resilience criteria are likely to put upward pressure on bid prices. Input diversification requirements, if they require a change in input suppliers, lead to higher capital costs for project developers in the short term. This is because alternative supply routes will typically be more expensive. These additional costs are mostly (i.e. apart from search costs) not sunk costs. They only arise once the project is implemented. Resilience criteria are therefore likely to increase the societal costs of renewable energy support auctions, at least in the short term. It is therefore crucial to design resilience criteria in such a way that an efficient relationship between resilience effects and societal costs is achieved.

4.3 Implementation options for resilience criteria

In an ideal scenario, resilience criteria would directly reward projects for their contribution to reducing collective supply risks. In reality, however, there is a lack of concrete information to quantify both the magnitude of risks and their concrete consequences from a value chain perspective. Resilience criteria must therefore be based on measurable proxies and take into account their interaction with the other auction characteristics. In the following, we provide an overview of the hierarchical sequence of decision steps in the specification of the criteria.

The first feature is the criterion's position in the auction process. Resilience criteria can be specified as pre-qualification criteria defining participation requirements or as award criteria complementing the bid price. **The second feature is the point of reference**. The most direct form of spatial discrimination consists of local content requirements. The most indirect form consists of requirements that are not directly spatial but are expected to be met only by producers in certain regions (or not to be met by producers in certain regions). These could be rigid environmental requirements for the production of certain components, or limits on the carbon footprint of entire supply chains. A third approach sets specific geographical requirements for the origin of equipment, but does not link these directly to specific countries, but rather to the overall degree of diversification. This is the approach chosen by the NZIA (see Section 2).

The third feature is the choice of the unit of measurement. In principle, supply thresholds could be measured in value terms or in weight terms. With varying value-to-weight ratios between components, this can make a big difference to the overall impact of the resilience criterion. In the case of an application as award criterion, the measurement choice concerns the type of bonus granted for meeting the criterion. For instance, it could be an absolute or a percentage discount on the bid price applied in the award procedure. Alternatively, bid price and resilience bonus (as well as potential further non-price criteria) could be assigned points and then be summed up to determine the total award criterion.

The fourth feature is the horizontal scope of the criterion. In the case of pre-qualification criteria, this concerns the level of a threshold bidders may not exceed. Its definition differs depending on the spatial reference. For instance, it could be defined as a maximum market share of individual supplier countries or a maximum value for a spatial concentration measure. In the case of an application as award

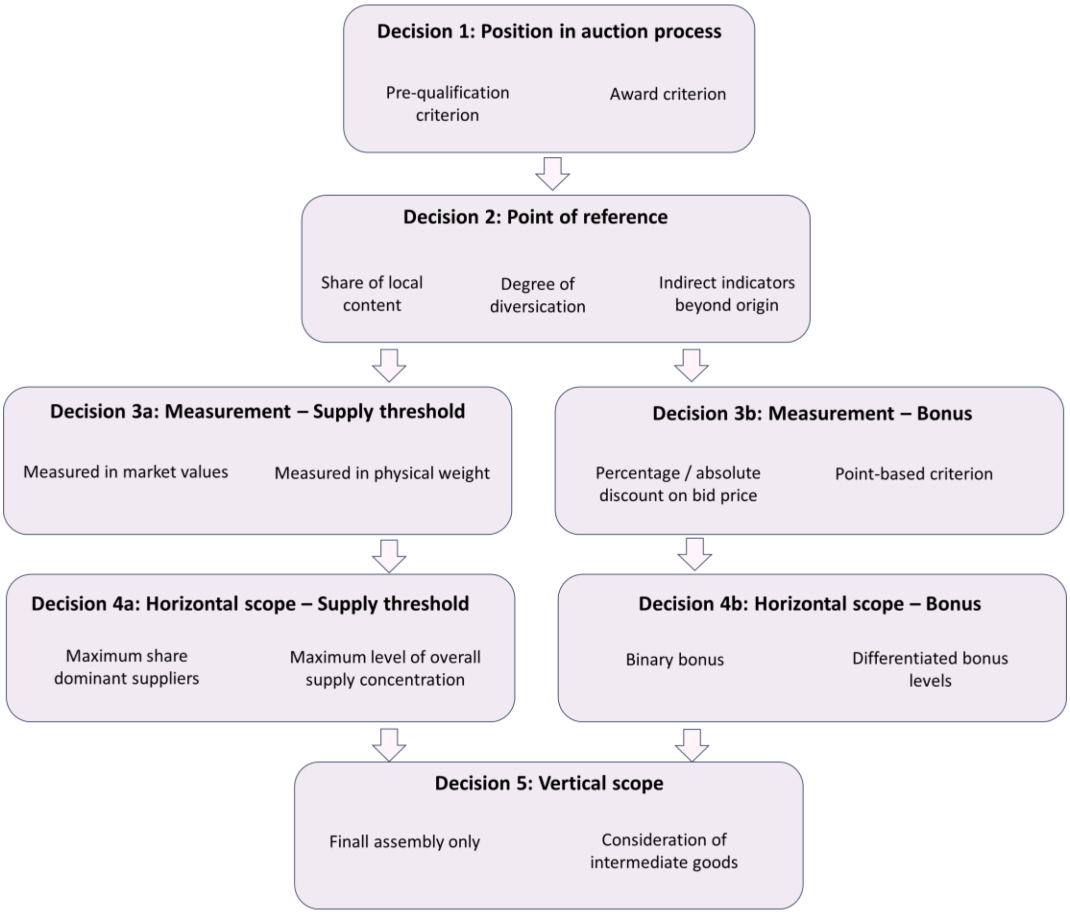
[13] Kreiss, J., Ehrhart, K. M., & Haufe, M. C. (2017). Appropriate design of auctions for renewable energy support–Prequalifications and penalties. Energy Policy, 101, 512-520.

criterion, the horizontal scope represents the range of bonuses associated with meeting the resilience criteria. Bonuses can be formulated as binary (yes/no) criteria – which also requires the definition of a threshold - or on an ordinal scale, reflecting different degrees of resilience contributions (e.g. based on the individual level of supply diversification).

Finally, the fifth feature is the vertical scope of the criterion. It defines which steps in the supply chain are targeted by the resilience requirements. For example, requirements could be formulated only for the location of the final assembly of the technology, or also for the origin of the raw materials or intermediate products used.

Figure 2 summarizes the decision steps.

Figure 2: Steps in designing tender-based resilience criteria



Source: own illustration

A general advantage of pre-qualification criteria is the more direct control of policy targets. Mandatory input diversification requirements ensure that all subsidized plants contribute to the resilience target. In RE support schemes that feature a fixed annual volume of subsidized generation capacity, the expansion of alternative supply channels can be directly steered. Instead, with resilience criteria designed as award criteria, it is uncertain whether bidders decide to make use of a resilience bonus or not. This uncertainty is particularly high if auctions are characterized by strategic bidder behavior and strong cost heterogeneity across bidders.

However, award criteria offer greater flexibility to bidders. This reduces the risk that the introduction of resilience criteria will lead to a disproportionate increase in financing costs. The bidding mechanism ensures that bidders will only choose alternative supply channels if this improves their expected net pay-off, taking into account the resilience bonus. This avoids the creation of unintended windfall profits for equipment manufacturers.

With pre-qualification criteria, on the other hand, there is a risk that over-ambitious resilience targets could significantly increase the price of equipment from alternative channels, due to the additional price-inelastic demand. This risk is particularly acute in the early stages, when alternative production capacities first need to be built up. The resulting additional costs would then be borne by the general public through higher bid prices. In a worst-case scenario, this could even slow down the expansion of renewable energy if investment in equipment production cannot keep pace with the induced demand.

In order to avoid this risk, a high level of information (e.g. regarding the cost structure of equipment production, investment volumes in equipment markets) is required for the definition of pre-qualification criteria. They would also have to be adapted frequently to actual market developments in order to maintain the balance between impact and cost. Award criteria, on the other hand, allow a gradual entry into alternative procurement channels through the competition mechanism and require less design adjustments.

Finally, the impact on incentives to innovate is a relevant factor in the long run. In this respect, pre-qualification criteria also appear to be more problematic. This is particularly true if competition between alternative equipment manufacturers is initially limited. The guaranteed demand created by mandatory resilience requirements could then become a cushion for equipment manufacturers, which would reduce incentives for R&D and thus for long-term efficiency-enhancing innovation. By contrast, in the case of award criteria, the weighing of additional costs and benefits of the auction bonus creates incentives for cost-reducing innovation in the equipment sector. Falling equipment prices may encourage a greater number of bidders to take advantage of the resilience bonus, thereby increasing the market share of alternative equipment manufacturers.

The effectiveness and costs of different designs can hardly be assessed in isolation, as they depend on the interaction with the remaining auction criteria (see Subsection 4.1). In particular, the pricing mechanism might play a role. In the case of competitive uniform price auctions, the additional costs resulting from resilience requirements can be expected to be fully passed on to the bid prices. In the case of pay-as-bid schemes, as applied in Germany and some other Member States, the effect is more complex due to incentives for strategic bidding behavior. In what follows, we analyze this scenario in a Case Study, considering public support to industry-scale PV electricity in Germany as example.

5 Case study: Support of solar power

5.1 PV supply chain characteristics

The basis of electricity generation from PV technologies represents the individual PV cell. It contains semiconductor material. When being exposed to sunlight, the semiconductor absorbs the light energy and transfers it to electrons. These electrons are made to flow through the different layers of the semiconductor material, thus creating electric current. Before entering the electric grid, the electric current is converted from direct current to alternating current by means of an inverter device.[14] As chosen semiconductor material, silicon dominates the global market. It is applied in crystalline form. Its market share in 2023 is estimated at 95%.[15] Before entering cell production, the crystals are cut into very thin wafers. These are further processed to form diodes and equipped with metal contacts on back and front surface, to collect the current and transfer it out of the cell.[16]

Variants of these cells are typically distinguished in two categories: monocrystalline (mono c-Si) and polycrystalline (poly c-Si) cells. Mono c-Si cells exhibit a single-crystal structure. In recent years, they have become the dominant cell technology (market share in 2023 of more than 90%)[17], mostly due to their superior conversion efficiency and thus their ability to generate a high electricity yield under increasingly though area restrictions.[18] The market share of the cheaper, but less efficient poly c-Si cells, composed of a number of small crystals, have shrunk to slightly below 5%. The remaining 5% of the global PV cells market is currently covered by the more recent thin film technologies. They come in many different variants, with the common characteristic that the thickness of the surface material is much smaller than in the case of c-Si cells, thus promising material savings. However, due to small production capacities, production costs tend to be quite high. The currently most common types of thin film cells on the global market are cells based on Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS) or amorphous silicon as semiconductor materials.[19] Moreover, a wide range of other materials and processing technologies are currently researched and tested.[20]

Cells are further distinguished by the number and combination of layers applied. Traditional modules featured only two layers of silicon, which contributed to excessive heat buildup and other forms of efficiency losses. Over the years, different methods for minimizing these losses have been developed. Until recently, a mainstream method has been the placement of another layer on the backside of the module (Passivated Emitter and Rear Cell (PERC)). It raises the cell efficiency by reflecting parts of unused sunlight back into the cell.[21] Other solutions include the Hetero-Junction Technology (HJT), where crystalline and amorphous silicon are combined in a hybrid cell.[22] In the Tunnel Oxide Passivated Contact Technology (TOPCon), a PERC is combined with an additional insulating layer of silicon oxide, between the silicon layer and the metal connect, to avoid efficiency losses caused by recombination.[23] In interdigitated Back Contact (IBC) solar cells, both the positive and the negative contacts are located on the backside of the cell, to minimize shading losses.[24]

To achieve a sufficient generation capacity, the single solar cells are strung together, placed on a back sheet and covered with glass to form modules (or panels). Together with the inverter and mounting structure, which optimize the orientation of panels towards the sun, they form the PV system.[25]

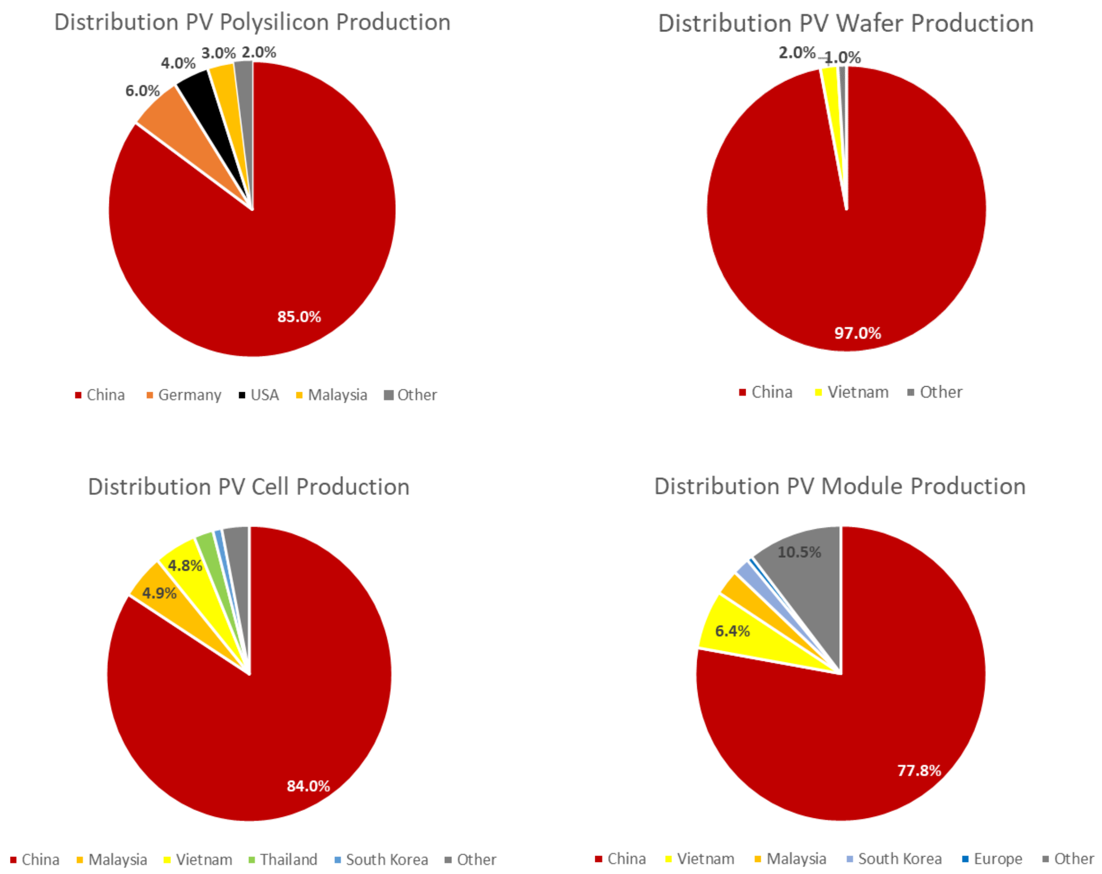
[14] Energy.gov (2024). Solar Photovoltaic Technology Basics. US Office of Energy Efficiency & Renewable Energy.
[15] VDMA (2023). International Technology Roadmap for Photovoltaic (ITRPV) 2022 Results.
[16] See Energy.gov (2024).
[17] Fraunhofer ISE (2024). Recent Facts about Photovoltaic in Germany. Version of 3.4.2024. Fraunhofer Institute of Solar Energy Systems.
[18] See Energy.gov (2024).
[19] See Fraunhofer ISE (2024).
[20] George, S. D. B., Soosaimanickam, A., & Sundaram, S. (2024). Third-generation photovoltaics: Introduction, overview, innovation, and potential markets. In Photovoltaics Beyond Silicon (pp. 75-110). Elsevier.
[21] Aurora (2024). What you need to know about PERC solar cells.
[22] Solar Power World (2019). What are heterojunction technology (HJT) solar panels?.
[23] Solar Power World (2022). What is TOPCon solar panel technology?
[24] ELAT SOLAR (2024). TOPCon vs IBC solar panels: a comparison of the highest energy yielding performance technologies.
[25] See Energy.gov (2024).

5.2 Global market situation

The current international supply chains are characterized by a strong dominance of producers from East Asia, mostly from China. This starts with the primary stages of natural resource extraction and processing (e.g. crystallization of silicon). While future resource needs will be subject to the uncertain technological development, it is clear that silicon and gallium will remain essential for the time to come.[26] According to the US Geological Survey (USGS), China is a dominant producer of both materials, accounting in 2023 for global production shares of 79% and 98%, respectively.[27]

In the subsequent steps of wafer production, cell production and module assembly, China has continuously expanded its leading position over the past decades. According to IEA estimates, China reached in 2022 global production shares of 97% in wafer production, 84% in cell production and 78% percent in module production. The accumulated shares of European countries were in all three segments below 1% (see Figure 3).[28] In terms of annual turnover, the Chinese PV module industry eclipsed with a 2022 turnover of 79 billion USD the rest of the world (23 billion USD in total).[29]

Figure 3: Distribution of global production volumes in PV supply chain stages in 2022

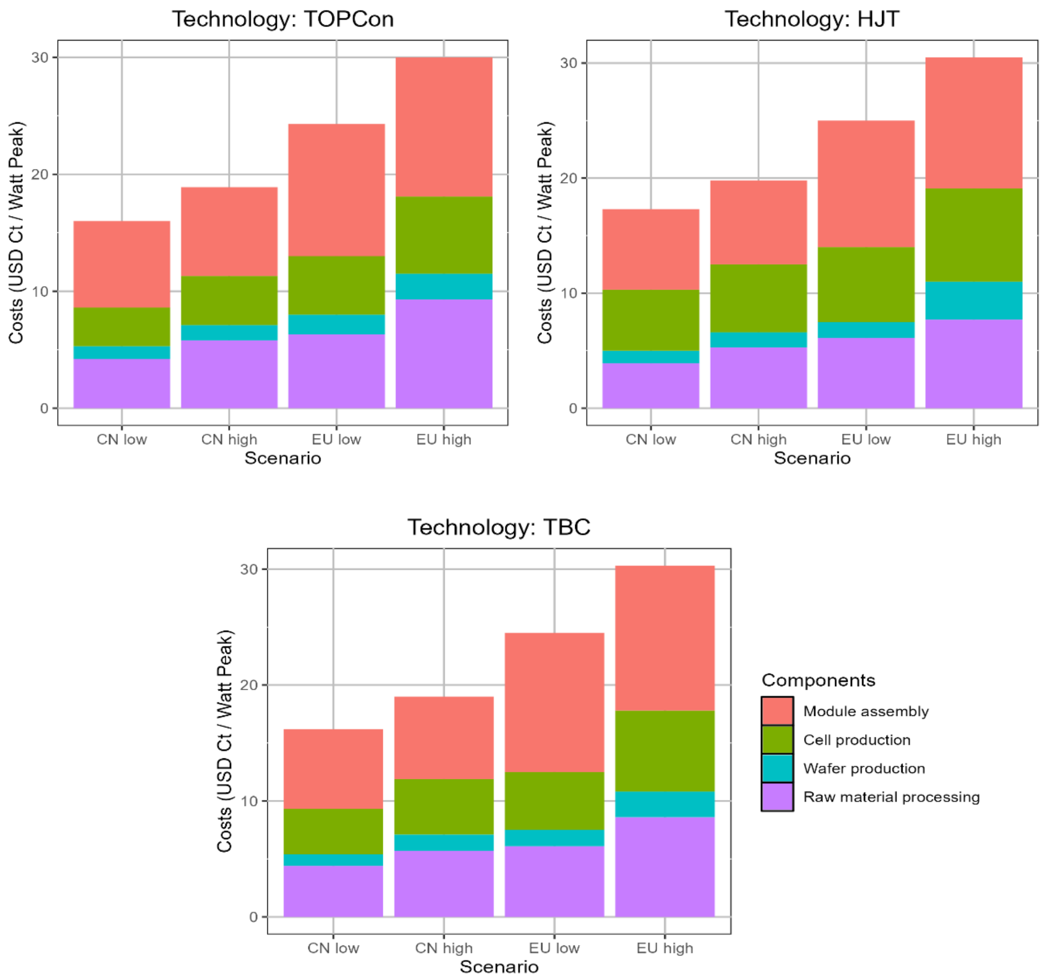


Source: IEA (2023); own representation.

[26] See Energy.gov (2024).
[27] USGS (2024). Mineral Commodity Summaries. US Geological Survey.
[28] IEA (2023). Trends in photovoltaic applications 2023. International Energy Agency – Photovoltaic Power Systems Program (PVPS).
[29] See IEA (2023).

According to estimates by JRC, this resulted in 2022 in an EU trade deficit for PV modules and components of almost 22 billion Euros compared to the rest of the world. About one billion Euros exports stood against 23 billion Euros imports from third countries. 83% of imports came from China, which almost exclusively consisted of the final product, i.e. assembled PV cells.[30] This further highlights China's tight grip on the whole supply chain. From the perspective of EU regulation, it is interesting that the 83% clearly exceed the 50% benchmark set for EU import dependence on single third countries in the NZIA (see Subsection 2.1). Hence, the newly established rules could provide an impetus for action. The data suggests that switching to other third countries as suppliers will at least in the short-term not be viable option, as capacities outside China are very limited. Instead, much of the diversification impulse will have to come from boosting production inside the EU. Against this background, the European Solar PV Industry Alliance (ESIA) has formulated the goal to reach 30 GW of committed European manufacturing capacity by 2025 across all PV value chain segments (polysilicon, ingots, wafers, cells, modules, recycling).[31]

Figure 4: Estimated cost discrepancies between module production in China and the EU



Source: ETIP (2024); own representation.

[30] JRC (2023a). Photovoltaics in the European Union 2023. Joint Research Centre of the European Union. Clean Energy Technology Observatory.

[31] ESIA (2022). High level launch conference of the European Solar PV Industry Alliance - Joint statement. European Solar PV Industry Alliance.

However, the cost situation could represent a barrier to a wide-scale market breakthrough for European module producers. As part of a feasibility study for PV supply chains in Europe, the Libertas project produces detailed bottom-up estimates of comparative production costs and its components.[32] Figure 4 depicts published preliminary results for three popular module technologies (see previous Subsection) for the setup of a 10 GW integrated PV factory. Accordingly, current total module production costs in the EU are estimated to be between 26% and 97% higher than total module production costs in China. Regarding the single production steps, the largest percentage cost discrepancies are estimated for the early production stages, i.e. silicon processing and wafer production. As explanation of Europe's tremendous cost disadvantage, the researchers refer to a variety of cost components. Both different components of OPEX (labour, electricity, material) and CAPEX (equipment, building) are estimated to be significantly higher than in the case of production in China.[33]

5.3 Design analysis of resilience auctions

5.3.1 Method

To assess the impact of introducing resilience criteria in renewable energy auctions, we apply a technoeconomic simulation model. As Member States differ in scope and characteristics of auction-based support schemes, we abstain from providing EU-wide estimates. Instead, we focus on the national system in Germany as a specific Case Study. As Germany is the by far largest market for renewables among Member States,[34] introducing resilience criteria in the German support system can be expected to cause a significant impulse for the EU in total. As technology, we consider PV-based electricity production, due to the particularly high external dependence in PV module supply chains (see above). In Germany, support to PV-based electricity is allocated via auctions only for plants with a capacity of at least 1 MW (industry-scale). Smaller PV plants are still promoted through a conventional scheme consisting of a guaranteed fixed price per kWh produced and fed into the grid.[35]

The auctions are organised as PV-specific tenders with guaranteed minimum prices per kWh produced. This results in a sliding mark-up on the (time-varying) electricity wholesale market prices. For rooftop and ground-mounted PV plants, separate auction formats are organized. Both are designed as single-round pay-as-bid auctions for a fixed total production capacity. Participating project developers submit sealed bids that include an individual production capacity and a desired price per kWh produced. Bids are ranked according to increasing bid prices. Participants are then allocated their individual desired prices until the total production capacity is used up. For both technology types, three auctions are taking place each year.[36]

So far, unlike in the case of offshore wind in Germany, allocation in the current system is purely price-based. We simulate the impact of adding an additional resilience criterion in the auctions for ground-mounted PV. Cost estimates for industry-scale PV plants are usually provided for ground-mounted

32 Libertas (2024). Project Libertas.
33 ETIP (2024). PV Manufacturing in Europe: Ensuring resilience through industrial policy. White Paper. The European Technology and Innovation Platform for Photovoltaics.
34 See IEA (2023).
35 EEG (2023). Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz).
36 See EEG (2023).

plants. Moreover, the auction volumes for ground-mounted PV are much higher than for rooftop PV, thus promising a bigger demand pull for PV module production.[37]

As discussed in Subsection 4.3, a resilience criterion could take the form of a pre-qualification or an award criterion. We will focus on the latter, as it requires less adjustment by policymakers over time and is more responsive to the evolution of module price differentials. This entails a transformation of the auction scheme into a multi-criteria system. In this respect, we assume the simplest possible design. Producers of PV electricity can choose to purchase PV modules from two different sources: the incumbent dominant player or an alternative source. If they choose to buy from the alternative source, they receive a certain resilience bonus (in € Ct / kWh) in the auction system. Promotion contracts are awarded in ascending order of net bid values among participants, defined as gross bid value minus the potential resilience bonus. Thus, by choosing an alternative procurement channel, bidders are able to improve their probability of success for any given gross bid level. In this setup, bidders have to make at least two auction-related decisions: the desired price per kWh and the procurement channel for the PV modules used to generate the electricity.

In a pay-as-bid system, there is no uniform reward for successful bids. Consequently, the incentives to bid strategically are higher than in an alternative uniform auction price system. The individual profit from the bidding process is maximised when the net bid level is just below the maximum threshold (hereafter referred to as the "marginal bid"), provided that this profit is positive. However, in a sealed-bid auction, the level of the marginal bid is a priori unknown to the participants. Individual optimisation decisions are therefore made under uncertainty. To formulate a decision rule, we follow the approach of Federico & Rahman (2003).[38] They assume producers to be risk-neutral, i.e. aiming to maximize their expected profit. The level of strategic interaction between bidders is restricted by assuming that each bidder regards the success probability as a given function of his/her individual bid level. The shape of this function depends on the entirety of bids made. This corresponds to the situation of a competitive bidding process with many participants, which appears to be an adequate reflection of the German PV auction scheme.

Under these conditions, individual decisions by bidders are subject to multiple trade-offs. For instance, raising the bidding price would increase the net reward received in case of success but could lower the success probability. Buying the PV module from an alternative channel raises the success probability but (due to higher procurement prices) lowers the net reward in case of success. Due to differences in the unit costs of generating electricity (caused e.g. by site-specific solar radiation levels), the individual optima are likely to differ among PV projects in reality. To introduce such heterogeneity in our simulations, we follow Bichler et al. (2020)[39] and treat the unit costs of the single bidders stochastically, we combine data on past project locations with data on regional generation conditions in Germany (see next Subsection). Likewise, discrepancies in generation capacities among projects are modelled stochastically based on information from past auctions.

37 Federal Network Agency (2024). Ausschreibungen für EE- und KWK-Anlagen.

38 Federico, G., & Rahman, D. (2003). Bidding in an electricity pay-as-bid auction. Journal of Regulatory Economics, 24(2), 175-211.

39 Bichler, M., Grimm, V., Kretschmer, S., & Sutterer, P. (2020). Market design for renewable energy auctions: An analysis of alternative auction formats. Energy Economics, 92, 104904.

To simulate concrete auction outcomes, we apply an iterative approach. It first consists of repeated calculations of optimal bid levels and PV module procurement decisions[40] for different distributions of unit costs and project capacities among bidders. The resulting distributions of marginal bids are used to update the function of success probabilities. This updated function, in turn, is used as an input for the next round of repeated calculations of optimal bid levels and procurement decisions. The process is continued until convergence is reached, i.e. assumed and resulting success probabilities approach each other and the probability function is thus no longer subject to measurable changes.[41]

Finally, the resulting distributions of auction outcomes are analysed in terms of several characteristics: the average levels of winning bids, the associated costs of electricity generation and the total demand for PV modules obtained from the alternative source. In this way, the simulations give an impression of the effectiveness of resilience criteria for the EU diversification goals as well as their costs in the form of higher subsidy payments to electricity producers.

5.3.2 Data

To simulate the German support auctions for ground-mounted PV, we draw upon several data sources. First, we use a report by the German Federal Network Agency on past auction outcomes.[42] The distribution of project capacities is specified based on the available information on minimum, maximum and median capacities in 2023 auctions. As distribution type, a PERT Distribution is chosen, which proves to be a good approximation of the real-world size distribution. Moreover, the report includes information on the number of submitted bids by federal state. Following the approach of Bichler et al. (2020), we use these numbers to fix the shares of projects from different federal states in our simulated auctions. Compared to the reported numbers for 2023, the total number of projects is adjusted upwards based on the percentage increase in auctioned capacities over time foreseen by the EEG.[43]

Estimates of the costs per kWh generated electricity – the so-called Levelized Costs of Electricity (LCOE) – are derived based on further sources. Differences in regional generation conditions are modelled through region-specific capacity factors, i.e. the ratio of expected annual electricity generation to installed capacity. The ENSPRESO-Database of the Joint Research Centre (JRC) at the European Commission provides estimates of capacity factors for PV plants at the level of EU NUTS-2 regions.[44] These are used to specify the range of capacity factors at federal state level, defining the minimum and maximum values of NUTS-2 regions within each federal state as boundaries of state-specific Uniform Distributions.

To investigate the specific influence of module costs, the Capital Expenditures (CAPEX) per MW installed capacity were split in two parts. The first part consists of the costs of PV module manufacturing. We distinguish the cost performance of a dominant producer and of an alternative producer. For this, we draw upon the estimates of the Libertas project (see Figure 4 in Subsection 5.2). The unit costs of the dominant producer are defined by the range of estimates for China, reflecting the

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40 As the functions of success probabilities are non-differentiable, the optimal decisions are determined numerically.

41 Hence, we assume each bidder to know generation costs and participation probabilities of PV producers in different German regions, but not the composition of its competitors in the specific auction.

42 Federal Network Agency (2024). Statistiken: Solaranlagen Freiflächen-Ausschreibungen.

43 EEG (2023). Gesetz für den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz).

44 JRC (2023b). ENSPRESO - an open data, EU-28 wide, transparent and coherent database of wind, solar and biomass energy potentials. ENSPRESO - SOLAR - PV and CSP dataset. Joint Research Centre of the European Union.

current market situation (see above). Precisely, we consider the minimum and maximum estimates of costs per MW reported by Libertas across the three module technologies investigated as boundaries of a Uniform Distribution, thus reflecting technology-induced cost heterogeneity. The cost distribution of the alternative producer is defined by the minimum and maximum estimates reported by Libertas for the EU, thus enabling us to evaluate the chances of a growth effect on European production.[45]

The remaining part of the CAPEX – including the costs of inverters, installation, grid connection and permitting – is obtained by estimates on the total installed costs of utility-scale PV in Germany from a current market report by Fraunhofer ISE[46], subtracting the part of the module costs.[47] The estimate of Operational Expenditures (OPEX) – including inspection and repair work– stems from Fraunhofer ISE (2021)[48]. To obtain annual costs per installed MW, CAPEX are annualized assuming a plant lifetime of 20 years and an annual discount rate of 6%. Converting these costs by applying individual capacity factors yields project-specific estimates of generation costs per kWh. Variation in the simulated auctions is thus driven by three forces: differences in capacity volumes, capacity factors and module costs between projects.

To model the evolution of LCOE over time, several assumptions are made. The future cost decrease for Chinese modules is treated as exogenous, assuming the German auction scheme to have no sizeable impact on the global sales potential for Chinese producers. We assume an annual decline in PV module manufacturing costs of the existing supply route based on the forecasts made by VDMA/ITRPV (2023) for the period 2023-2033.[49] Likewise, the annual decline in residual CAPEX is calibrated based on forecasts from the same source. The cost decline for module assembly in Germany is treated endogenously, thus allowing to assess the dynamic cost effects of introducing resilience criteria in the German support scheme. Following a standard procedure, this is parameterized by means of a learning rate, indicating the percentage cost decline with each doubling of the cumulative production volumes of PV modules over time. For an average of module technologies, Fraunhofer ISE (2024) estimate a long-term learning rate of 24.9%.[50] This value reflects the influence of a wide range of factors such as technological disruption, learning-by-doing and changes in resource costs. To isolate an estimate of the expected effect of pure scale economies (static fixed cost degression, learning-by-doing)-from unpredictable innovation effects, we draw upon the work of Kavlak et al. (2018).[51] They estimated that static scale economies and learning-by-doing accounted jointly for about 30% of the total long-term cost decline of PV modules. When being applied to the Fraunhofer ISE figure, this gives a rough estimate of 7.5% for a scale economy-related learning rate. Finally, past cumulative production volumes of EU module producers were derived from production time series published in Fraunhofer ISE (2024).

[45] This does not imply that we were favoring resilience criteria in the form of local content requirements. Rather, it reflects the notion that, due to limited manufacturing capacity outside China, any short-term diversification strategy will need to rely heavily on domestic production.

[46] See Fraunhofer ISE (2024).

[47] As our focus is on long-term cost trends, the impact of short-term price fluctuations in resources, in particular silicon, is not considered in our setup.

[48] Fraunhofer ISE (2021). Levelized cost of electricity renewable energy technologies. Fraunhofer Institute of Solar Energy Systems.

[49] See VDMA (2023).

[50] See Fraunhofer ISE (2024).

[51] Kavlak, G., McNerney, J., & Trancik, J. E. (2018). Evaluating the causes of cost reduction in photovoltaic modules. Energy policy, 123, 700-710.

Table 1 summarizes the parameter choices and corresponding data sources.

Table 1: Overview parameters for simulation analysis

Parameter	Value	Source
General		
Annual discount rate	6 %	Fraunhofer ISE (2021)
Costs electricity generation (PV industry-scale)		
PV plants: Lifetime	25 years	Fraunhofer ISE (2021)
PV plants: CAPEX	573,180 EUR/MW	Fraunhofer ISE (2021;2024)
PV plants: OPEX (O&M)	13,300 EUR/MW/year	Fraunhofer ISE (2024)
PV plants: Capacity factors	region-specific	JRC (2023b)
Costs PV module production		
China: Final module assembly	62,790 EUR – 69,160 EUR	ETIP (2024); Converted to Euro (0.91 EUR/USD)
EU: Final module assembly	100,100 EUR – 113,750 EUR	ETIP (2024); Converted to Euro (0.91 EUR/USD)
China: Full supply chain	145,600 EUR – 172,900 EUR	ETIP (2024); Converted to Euro (0.91 EUR/USD)
EU: Full supply chain	221,130 EUR – 277,550 EUR	ETIP (2024); Converted to Euro (0.91 EUR/USD)
Annual learning rate (scale-related)	7.5 %	Fraunhofer ISE (2024); Kavlak et al. (2018)
Global market PV modules		
Annual price decline	3 %	VDMA (2023)
Cumulative production volume Europe	30 MW	Fraunhofer ISE (2024); Own aggregation
Design PV support auctions		
Annual volume	9,900 MW	EEG (2023)
Allocation	Pay-as-bid	EEG (2023)
Modus	Single-round	EEG (2023)

Source: own illustration

5.3.3 Scenarios

Two scenarios are compared in our simulations, distinguished by the vertical scope of the resilience bonus. In the scenario “*domestic module assembly*” a resilience bonus is granted if the PV modules used by a PV plant are assembled domestically. The mark-up on PV plant CAPEX caused by producing the module at home instead in China is specified as the percentage cost difference between EU-based and China-based module assembly published in ETIP (2024). In the scenario “*integrated domestic production*” a resilience bonus is only granted if the whole supply chain from raw material processing to module assembly is shifted home. Accordingly, the mark-up on PV plant CAPEX caused by producing all components at home instead in China is specified as the percentage difference in total cost estimates of EU-based and China-based supply chains published in ETIP (2024):

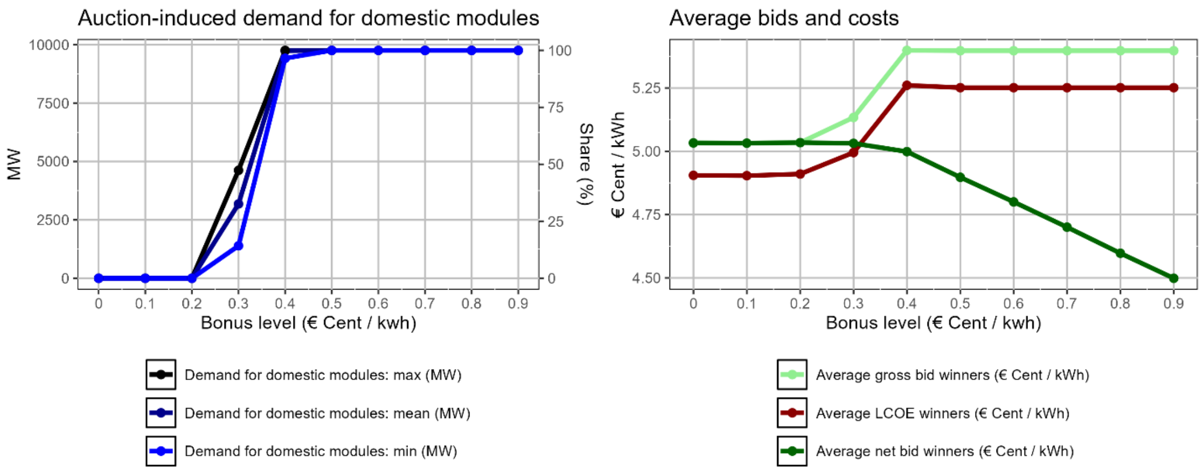
The two scenarios are first compared concerning their responsiveness towards the extent of a resilience bonus in the period of its introduction period (by assumption: the year 2025). Then, we analyse the impact of a resilience bonus over time, simulating a time period of 15 years (years 2025-2039).

5.3.4 Results

Before analysing the impact of the adjusted auction scheme on cost dynamics, we consider the role of the chosen bonus level when the scheme is put in place. Starting with the "*domestic module assembly*" scenario, Figure 5 reports simulated auction outcomes in the first auction period for different bonus levels. Due to strategic interdependence and rational behaviour of auction participations, the influence is of a highly non-linear nature. For bonus levels below 0.3 € Cent/kWh, the bonus scheme proves to be ineffective: no auction participant is opting for European modules. The bonus is simply insufficient to compensate bidders for the cost gap between Chinese and European PV modules.

This changes quite drastically with slightly higher levels. First, bidders with LCOE close to the average marginal bid will switch to European modules. Their success probabilities are most sensitive towards the offered bonus. Hence, they are the first willing to pay an extra amount for modules to reduce their net bid. With higher bonus levels, this tendency spreads towards bidders with lower LCOE. The reason is the stronger competitive pressure caused by higher bonus levels. The number of bidders with medium-level LCOE aiming to reduce their net bids through the resilience bonus exerts a downward pressure on the distribution of marginal bids. This reduces success probabilities of the most efficient bidders, inducing them to switch to European modules as well. As a consequence, our simulations expect for bonus levels of already 0.4 € Cent/kWh all successful bidders to opt for European modules. Hence, strategic interaction can induce a "domino effect", implying that already small changes to the resilience bonus granted can have drastic consequences.

Figure 5: Sensitivity of module demand and bid prices (Scenario: "domestic module assembly")

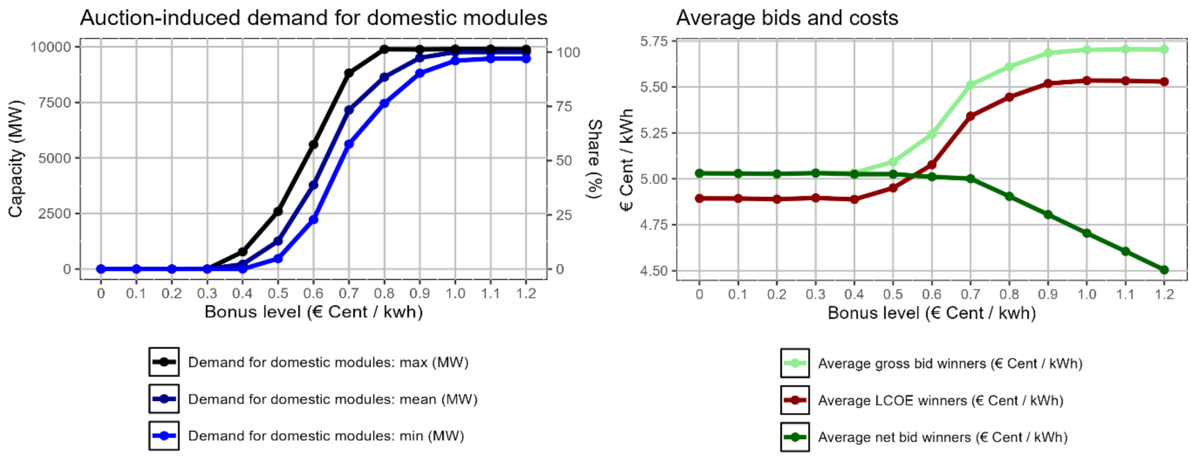


Source: own calculations

This mechanism is also reflected in the distribution of average gross and net bids of auction winners (right-hand graph in Figure 5). In the absence of an effective bonus scheme, average bids are covering the LCOE resulting from Chinese modules plus some mark-up resulting from strategic bidder behavior. The most efficient bidders can afford to demand high margins without reducing their probability of success, as none of the less efficient bidders will be willing to bid below their high LCOE. For bonus levels larger than 0.2 € Cent/kWh, bidders are switching to European modules. This results in a split of gross and net bids. Average gross bids get higher, to cover the increase in LCOE caused by buying European modules. With a higher number of bidders receiving the resilience bonus, competitive pressure on marginal bids is increasing. As a consequence, at bonus levels high enough to urge every bidder to choose European modules (in this case: 0.4 € Cent/kWh), any further increase in the bonus only results in an equivalent fall of net bids. From this point onwards, gross bids thus remain unchanged. In all, average net pay-offs to winners are not significantly affected by the bonus scheme. Hence, a resilience bonus allows PV project developers to pass on the higher module costs also under the conditions of a pay-as-bid auction.

The simulation results for the " *integrated domestic production* " scenario show a qualitatively similar picture (see Figure 6). In this case, the impact of the bonus scheme only starts to be felt at higher bonus levels, due to the larger cost gap resulting from producing all components in Europe. For the same reason, the scheme also has a stronger effect on average gross bids than in the “*domestic module assembly*” scenario. In addition, the spectrum of bonus levels for which only a fraction of winners choose European modules is wider. This is due to the greater variance in total module costs, a consequence of cost uncertainty in the individual stages of domestic module production. Although the sensitivity to bonus levels is not exactly as extreme as in the “*domestic module assembly*” scenario, this scenario confirms the qualitative features noted above: the potential for a “domino effect” in module investment and a decline in net bids due to competitive pressure.

Figure 6: Sensitivity of module demand and bid prices (Scenario: “integrated domestic production”)

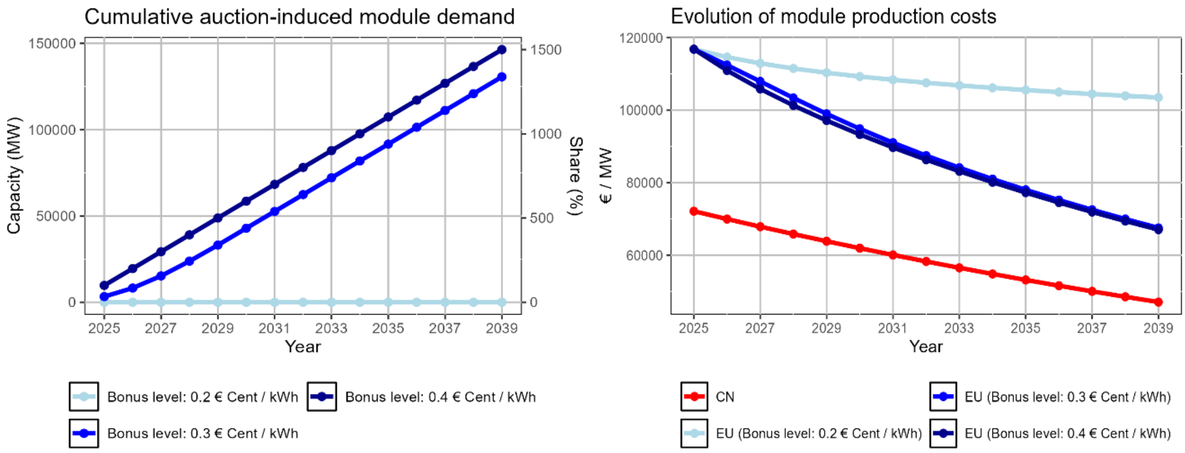


Source: own calculations

Of course, in reality, such a bonus scheme cannot be expected to run that smoothly already in its introductory phase. PV project investors will need to gather the necessary additional market information. They will also need to become familiar with the increased complexity of decision making and its impact on the bidding rationale. However, in the medium term, assuming responsive bidders, accumulated bidding experience should induce well-designed and competitive tenders to converge to the features demonstrated by our simulations.

To assess the long-term cost implications of such a bonus scheme, Figure 7 presents for the “*domestic module assembly”* scenario the evolution of the costs of European PV modules over time, comparing different bonus levels. At a bonus level of only 0.2 € Cent/kWh, the bonus scheme is expected to be ineffective throughout the observation period. It does not cause additional demand for domestic modules and thus does not contribute to reducing the cost gap to Chinese modules through scale economies. At a level of 0.3 € Cent/kWh, the dynamics are already remarkably different. The demand impulse created in the initial period induces a steeper cost decline for domestic modules, which in subsequent periods raises the attractiveness of the resilience bonus and thus contributes to a gradual expansion of domestic module demand. By 2030, this leads all bidders to opt for domestic modules. At a level of 0.4 € Cent/kWh, this already occurs instantly, implying even stronger cost dynamics in earlier periods.

Figure 7: Evolution of module production costs and demand for domestic modules



Source: own calculations

In any case, supporting the scaling of domestic module production comes at a cost for society. Despite accelerating a decline of module prices, domestic modules will remain the more expensive choice in the medium-term. From the perspective of taxpayers, this implies higher support costs for PV electricity per kWh. However, through the competition effect discussed above, these “resilience costs” can effectively be limited.

At the same time, no immediate effect on wholesale electricity prices is to be expected. From the moment the PV system starts operating, the resilience costs are sunk and have no impact on the (close to zero) marginal costs of producing electricity. They thus do not affect the merit order in electricity wholesale markets. As a consequence, the distribution of the additional support costs is exclusively determined by its financing mechanism. With financing provided by the general state budget, as is currently the case for Germany, the costs are borne by taxpayers as a whole. When put into relation to total electricity consumption, the resilience costs for PV modules appear to be of a rather modest nature. Assuming a resilience bonus of 1 € Ct per bid and an annual electricity consumption in Germany at the same level as in 2023, annual resilience costs for 2025 are estimated as 0.007 € Ct / kWh of total electricity consumed for the “*domestic module assembly*” scenario and 0.012 € Ct / kWh of total electricity consumed for the "*integrated domestic production* " scenario.[52] In absolute terms, this would imply additional support costs in a range from 36.8 million to 60 million EUR per year. Over time, with additional new PV plants being promoted, annual costs are going to increase. However, due to the cost-reducing scale effect, the support provided to each new plant will decline over time, thus limiting the rise in total resilience costs.

[52] In Germany, total annual electricity consumption in 2023 amounted to approximately 525 TWh. With an average capacity factor of about 0.11, the expected annual (1 year = 8460 hours) generation potential of the 9,900 MW PV capacity covered by the support auction amounted to about 9.54 TWh, i.e. about 1.8 % of total consumption. According to our simulation results, the resilience bonus is expected to cause an increase in average gross bids by 0.37 € Ct / kWh (scenario: domestic module assembly) or 0.67 € Ct / kWh (scenario: integrated domestic production). Applying the 1.8 % share to these numbers results in the reported estimates.

Finally, the results need to be reflected against their data-driven assumptions. First, due to the absence of detailed market data, we were not able to explicitly model the global markets for PV modules and their components, instead assuming the module supply to be fully responsive to demand changes. In reality, delays in capacity expansion and other market frictions could imply that domestic module producers will not be able to instantly meet the extra demand caused by resilience criteria. This could result in physical shortage and/or higher module producer margins, thus raising the costs of introducing resilience criteria. Second, as a source of a cost decrease per MW module capacity, only incremental improvements through scaling were considered, not disruptive innovation. This would ask for an extended model incorporating the impact of resilience criteria on incentives to invest in R&D. Finally, our scenario is limited in the sense that we only consider Germany and only industry-scale ground-mounted PV plants.

6 Policy recommendations

Successful decarbonization requires a watchful eye on supply risks. The EU's heavy reliance on imports of some key net-zero technologies from single supplier countries exposes climate neutral supply chains of the future to high trade policy risks. Traditional investment support alone will not be sufficient to reduce these risks. Creating sufficient incentives to invest in alternative production capacities requires clear sales prospects and, at least temporarily, compensation for current cost disadvantages. Market segmentation based on resilience criteria can provide the necessary demand impulse.

Tendering schemes in public procurement and renewable energy support are ideal as first areas of application. The inclusion of resilience criteria as additional award criteria (alongside the bid price) in tendering procedures allows for a sensible weighting of the costs associated with alternative supply channels. Compared to interventionist purchase obligations, this reduces the social cost risks of the instrument. In the long run, resilience criteria can also contribute to strengthening price competitiveness of alternative supply channels through economies of scale.

At the same time, side effects on incentives to invest in the transformation of the energy system need to be carefully checked. For this reason, the financing of the public good “resilience” should be sufficiently diversified. A one-sided distribution of the societal costs of resilience criteria could slow down the green transformation - either by restricting fiscal room for maneuver or by reducing private incentives to invest in renewable energy plants. In addition, compatibility with current WTO law must be ensured, also in order not to weaken Europe's credibility and strategic position in trade negotiations. Finally, the interaction of the resilience criteria with other transformation policy instruments should be carefully considered, requiring an overarching strategy. Against this background, we make the following concrete recommendations:

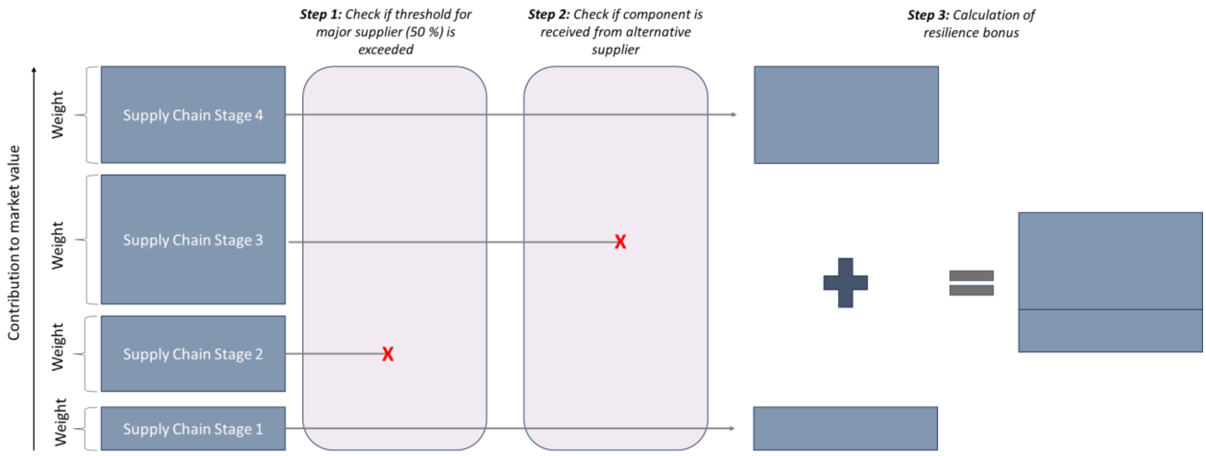
1. Application of resilience criteria as targeted bonus criteria in tendering schemes

To reduce asymmetric cost risks and properly steer economic incentives, we propose to implement resilience criteria as targeted bonus criteria within tendering schemes. This means resilience criteria should exclusively take the form of award criteria, to provide sufficient flexibility to bidders (see discussion in Subsection 4.3). Contrary to the conditions defined by the NZIA (see Section 2), we propose a vertically differentiated scheme: a separate decision on applying resilience criteria should be made for any single main component of a net-zero technology (instead simply for the main components as a whole). This decision should be based on the degree of EU-wide import dependence on single supplier countries for the specific component, applying the 50% maximum share foreseen in the NZIA as a threshold.

In this scheme, the calculation of a potential bonus occurs in three steps. First, the degree of dependence is assessed for each main component of the net-zero technologies employed to deliver the tendered service. Second, for those components where the conditions for applying the resilience criterion are fulfilled, bidders can apply for a resilience bonus by providing proof of the components' origin from a (EU or non-EU) country other than the dominant supplier. Third, the total resilience bonus granted to a bidder is calculated as a weighted sum of the bonuses granted to the single components, with the value shares of the components as weights. In this way, discrepancies in the economic relevance of components are accounted for in a targeted manner.

The measurement unit applied in calculating the bonus is necessarily service-dependent. In the case of renewable energy support auctions, it could take the form of a discount on the bid in Cent / kWh, as illustrated in our Case Study. In the case of public procurement, an intuitive general rule could be the application of a percentage discount on the bid price, or, as implied by the NZIA, a relative weighting of all criteria in a point-based evaluation system. In any case, consequences of specific calculation principles need to be thoroughly tested by scientific experiments and EU-wide test auctions. If implemented successfully, the Commission should push for a homogeneous application by Member States.

Figure 8: Proposal of a vertically differentiated resilience criterion



Source: own illustration

2. Promotion of supportive framework conditions for domestic manufacturing

While properly designed resilience criteria can provide a significant demand pull, they are unlikely to fully compensate the structural cost disadvantages and resource bottlenecks Europe is facing as a production location. In the worst case, a lack of resources thwarts the incentivized pull effect. Overcoming these deficiencies will continue to require coordinated effort and the willingness to bundle and focus existing resources. Foremost, the prioritization requirements for strategic net-zero projects set by the NZIA must be fully implemented by Member States. This requires the provision of sufficient administrative resource for the organization of one-stop shops and the acceleration of approval procedures. Threatening skill bottlenecks must be jointly addressed through cooperation in the development of common Master programs, the operation of specialized training centers and campaigns for the attraction of global talent. To exploit existing specialization potentials in net-zero technologies for regions with fitting industrial environment but weak investment dynamics, the EU should provide these regions with targeted support in modernizing their (tangible and non-tangible) public infrastructure. In particular, the emergence of efficient large-scale factories should be supported. To this end, the strategic policy goals set for the allocation of funds from the European Regional Development Fund (ERDF) and the EU Cohesion Fund should be supplemented by specific targets for infrastructure funding in dedicated Net-Zero Acceleration Valleys.[53] In combination, these measures could exert a significant push to supply, thereby complementing the demand effect of resilience criteria.

3. Additional support for research in groundbreaking innovation for net-zero technologies

To avoid any undesired harmful effects on incentives to invest in groundbreaking innovation in net-zero technologies, the introduction of resilience criteria should be accompanied by intensified efforts to strengthen Europe's innovation capacities. To this aim, existing funding channels at EU and Member State level should be streamlined by establishing joint strategic funding priorities. These should not be limited to support of laboratory-level development and testing, but should include early stages of commercialization. Funding programs should be coordinated with the financing of downstream technologies by the STEP platform. In funding research initiatives, a focus should be set on consortia that feature a high degree of value chain integration and an outreach to stakeholders from different kinds of institutions (e.g. private companies, universities, research centers). Moreover, technology partnerships with research-strong likeminded third countries should be strengthened and stabilized through reciprocal access to public programs of R&D support.

4. Stimulation of private demand through "Resilience Contracts-for-Difference"

In addition to an increased demand pull through public tenders, supplementary instruments to strengthen private demand should be considered as well. Alignment with efficiency goals must also be a requirement, especially for domestic downstream industries facing strong international competition. A suitable new instrument for this could be "Resilience Contracts-for-Difference", an analogue to the already implemented Carbon Contracts-for-Difference. In this model, domestic producers of net-zero technologies would conclude long-term supply contracts with domestic customers at a fair market price per unit supplied. The difference between the initially high unit costs of emerging domestic producers and the market price level would be covered partially by public grants to producers. The subsidy would have to be continuously reduced over an ex-ante defined path, to take account of expected future scaling advantages and to maintain incentives to improve efficiency.

[53] Wolf. A. (2024). Net-Zero Industry Valleys in Europe. cepStudy No. 5/2024.

7 Conclusion

At a time of particular vulnerability - the transformation of the industrial capital stock towards climate-neutral production - the EU is confronted with a global subsidy race for critical technologies. In particular, Europe as a production location has little to counter the planning and scaling capabilities of the Chinese industry strategy. This threatens to permanently cement existing import dependencies for key net-zero technologies, with potentially severe implications also for innovative strength. Europe is therefore faced with the challenge of maintaining its technological sovereignty in critical areas without betraying its identity shaped by the principles of internal competition and free international trade. In addition to increased cooperation with like-minded partners, this will require innovative, intelligent policy instruments.

This cepInput analyses the design requirements and impacts of a new demand-based support instrument, the introduction of resilience criteria in public procurement and renewable energy support auctions. It argues that by stimulating demand, such criteria can be an effective means of diversifying existing supply channels for net-zero technologies in the short term. In the medium term, by exploiting scale effects, they can contribute to a reduction of structural cost disadvantages compared to competitors. At the same time, however, the risks of such a new instrument need to be carefully managed. This concerns in particular the risks of new trade disputes and of high burdens on public budgets. Against this background, the precise design of the criteria will play a crucial role.

We plead for a specification that is consistently focused on the goal of supply diversification, without reference to local content and without discriminating against certain third countries. In this respect, the requirements specified in the Net-Zero Industry Act provide a sensible blueprint. In order to limit design risks through flexibility and initiate cost-reducing competition, resilience criteria should only be formulated as award criteria, not as pre-qualification criteria. Such award criteria should be differentiated vertically according to the origin of the main components of a net-zero technology, to ensure a targeted application. In the calculation of the resulting resilience bonus, individual components should be weighted based on their market value.

Before a widespread implementation, sufficient experience of the practical effects should be gained through scientific experiments and trial auctions. These should, where possible, be coordinated across the EU to enhance knowledge sharing. To reduce design risks and improve effectiveness, it is also essential to accompany such a demand-side instrument with increased complementary supply-side investment incentives. This should include joint efforts to overcome domestic resource constraints, the development of specialized industry clusters to foster efficient large-scale factories and increased support for breakthrough innovation. Finally, to mobilize private demand to strengthen resilience, the EU should consider additional market-based instruments for compensating cost disadvantages, ideally based on the contracts-for-difference approach.

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