UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

PJM Interconnection, L.L.C.	)	**Docket No. ER21-___-000**

AFFIDAVIT OF PETER CRAMTON
ON BEHALF OF PJM INTERCONNECTION, L.L.C.

1. My name is Peter Cramton. My business address is 901 Highland Avenue, Del Mar CA 92014. I am a professor of economics at the University of Cologne. I am submitting this affidavit on behalf of PJM Interconnection, L.L.C. ("PJM"). PJM asked me to comment on the proposed change to the PJM minimum offer price rule (MOPR). The proposal is outlined in PJM (2021a,b). This affidavit presents my comments on the proposal. PJM has compensated me for providing this affidavit. The views are my own and not those of any organization I may be associated with.

Qualifications

2. I am a professor of economics at the University of Cologne (since 2018) and the University of Maryland (Emeritus since 2018). For twenty-eight years, I have researched auctions and market design, focusing on the design of complex markets to best achieve goals. Applications include electricity markets, financial markets, and auctions for radio spectrum. I have introduced innovative market designs in many industries. I have advised many governments on market design and dozens of bidders in major auctions. I am an advisor and chief economist to several companies. Since 1998, I have advised regulators and system operators on electricity market design in North America, South America, and Europe. From 2015-2021, I was an independent director of the Electric Reliability Council of Texas (ERCOT) board. I received my B.S. in Engineering from Cornell University and my Ph.D. in Business from Stanford University.

Summary

3. MOPR is a feature of capacity markets intended to mitigate the exercise of buyer market power. It does so by requiring that units receiving out-of-market payments bid no lower than an administratively determined minimum offer price.

4. A capacity market is a means to ensure that an electricity system has adequate resources to satisfy electricity demand reliably. It also is a means to coordinate investment and manage risk. Many restructured electricity markets include a capacity market (PJM, New York Independent System Operator, Inc. (NY ISO), and ISO New England Inc. (ISO New England).

5. Capacity markets have been a focus of my research since ISO New England initially proposed one in 1998. The initial designs had flaws so severe that I, together with Robert

Wilson of Stanford University, recommended that ISO New England eliminate their proposed capacity market until flaws could be fixed (Cramton and Wilson 1998). Subsequent research described the deficiencies of early capacity markets (Cramton 2003) and how to fix them (Cramton and Stoft 2006; Cramton et al. 2013).

6. The critical elements of a modern capacity market are the forward procurement, typically three years in advance, of capacity consistent with an administrative demand curve, representing consumers' preference for reliability. The connection between the demand curve and reliability is seen when one considers the impact of shifting the demand curve to the right so that at every price more quantity is demanded. The shift brings more capacity to the market, and the additional resources make it more likely that the market will avoid shortage. The demand curve reflects the marginal value of resources in avoiding shortage. The capacity product is both a physical capability and financial obligation to provide energy during shortages. The financial obligation provides strong performance incentives. The system operator settles any deviation from the supplier's load-following responsibility at the administrative shortage price—the value of lost load. The current PJM capacity market is consistent with this framework.

7. From January 2020 to the present, together with my colleagues, Emmanuele Bobbio at the University of Cologne, David Malec at the University of Maryland, and Pat Sujarittanonta at Chulalongkorn University, I developed a multi-decade model of the energy transition in PJM (Cramton et al. 2021). The research was supported by PJM, the University of Cologne, the University of Maryland, the German Research Foundation (DFG), and the European Research Council (ERC). The model allows researchers to study the market impacts of alternative market rules and policies. Each year, investors decide which resources enter and exit, given forward-looking consistent expectations about energy profits, prices, and costs. The model is unique in modeling investment decisions at the individual unit level based on precisely calculated profits from energy, reserves, and capacity markets. These profits depend critically on the resource structure, which changes each year with investor decisions. New and essential elements of electricity markets, such as battery storage, are fully integrated. The model provides insights into how market rules and policies impact market outcomes, including reliability and cost. My analysis of PJM's MOPR proposal is informed from this model.

8. I begin with some background on MOPR and its role in capacity markets and electricity markets generally. MOPR attempts to mitigate the exercise of buyer market power in capacity markets. I then analyze PJM's MOPR proposal. I compare the likely market impact of the broad MOPR articulated in the December 2019 order of the Federal Energy Regulatory Commission (FERC) and PJM's current MOPR proposal. I refer to these two approaches as broad MOPR (FERC 2019) and narrow MOPR (PJM 2021a,b).

9. In my view, PJM's narrow MOPR is an essential improvement over the broad MOPR.

10. The broad MOPR casts too wide a net. It has a broad definition of subsidized resources—virtually any new resource procured or supported by the state—and mandates a minimum offer price for these resources. The rule could potentially keep an active energy resource from receiving capacity revenue indefinitely. These excluded resources are contributing to

reliability yet are ignored in the capacity market. The result is consumers buying more capacity than is consistent with their preference for reliability as expressed in the capacity demand curve.

11. Moreover, these extra resources will reduce spot market prices and thereby amplify the missing money problem. As more state-sponsored resources enter the market, this creates counter-productive feedback. The reserve margin increases, yet capacity prices rise due to more excluded resources, and spot prices fall. The capacity price no longer reflects the cost of supplying energy during shortage.

12. By contrast, the narrow MOPR acknowledges the state's role in policy. The minimum offer price rule is triggered only when there is reason to suspect a resource's offer is an exercise of buyer market power or its state support depends on clearing in the capacity market. Active energy resources are only excluded from the capacity market in response to identified conditional state support or buyer market power. The rule's clarity will likely discourage such misconduct, thus leading to the preferred outcome of deterring such attempts instead of mitigating the effort via administratively determined offer price revisions that may fail to clear. Under this approach, therefore, there will likely be few resources excluded in equilibrium. PJM's approach also eliminates the broad MOPR's disconnect between the capacity resources and those providing reliability. Ideally, the capacity market is a financial derivative of the real-time energy market. The capacity price primarily reflects the financial cost of the reliability obligation.

13. The design of the minimum offer price rule must weigh two types of errors. Too broad of a rule excludes some new resources from receiving capacity revenues; too narrow of a rule could drive premature exit of economic resources or could permit noneconomic new entry. To me, the broad rule is riskier.

14. The integrity of the capacity market is better served with the narrow MOPR. The narrow MOPR protects against buyer market power without presuming that states' specific support for their resource preferences, in and of themselves, represents an abuse of buyer market power. The narrow MOPR presumes sellers are not submitting improperly low-priced offers but includes protections, allowing PJM and the independent market monitor to identify the exercise of buyer market power and apply the MOPR. The rule enables PJM to bring to FERC instances of conditioned state support and PJM's proposed MOPR mitigation in such a case, which PJM would implement with FERC approval.

15. My conclusion is reinforced when one recognizes the long-run implications of the broad MOPR. When the minimum offer price excludes some energy resources from capacity revenues, the practical result is available supply, supporting reliability, exceeds the reserve level cleared in the capacity auction. This shifts revenues from the energy and reserves markets to the capacity market, increasing the role of the capacity revenues in investment decisions. This result moves the market further from the ideal where the capacity revenues reflect the financial cost of the obligation to deliver energy and reserves during shortages.

16. Identifying inappropriate conditional state support and mitigating buyer market power remains important, and the narrow MOPR retains these protections. My point is that the

broad MOPR goes too far and would do more harm than good. The risk is significant that the broad MOPR will bring too many resources to PJM by paying a capacity price greater than the consumers' preference for reliability.

17. The narrow MOPR addresses market power abuse without interfering with price formation and efficient entry and exit. The narrow MOPR respects the states' resource preferences and better supports an effective energy transition.

18. From an economic perspective, the first-best policy would include the marginal social cost of each pollution externality in the electricity price. Regulators can achieve that first-best policy only with an effective national policy. The social cost of carbon would be best established and imposed at the federal level since it is a global pollutant. Even local pollutants like nitrogen oxides, sulfur dioxide, and particulates cross state borders, so national pricing of these pollutants is efficient. Absent federal leadership, states have intervened with policies that reflect state preferences. Although a coherent national policy would provide the best approach, the narrow MOPR would better accommodate states' preferences until a good federal policy arrives.

Background

19. The MOPR is a feature of the capacity market. However, it is helpful to start with the spot market for energy and reserves, consisting of a day-ahead market for scheduling and a real-time market for dispatch. The spot market is the backbone of restructured electricity markets.

The spot market for energy and reserves

20. In theory, an electricity market can provide ideal investment incentives with an efficient spot market that accepts demand bids and supply offers for energy and reserves. The system operator takes these bids and offers and finds the day-ahead schedule of resources and real-time dispatch that maximizes as-bid social welfare subject to resource and grid constraints. PJM uses the day-ahead and real-time prices in this optimization to maximize welfare and keep supply and demand balanced.

21. One challenge with this approach is a limited response of the demand side to price. Most consumers neither see nor feel the real-time price. As a result, there is too little reduction in demand as prices rise. In times of limited supply, this may make it difficult or impossible for the system operator to balance the system. Shortages can and do occur.

22. The possibility of shortage creates a problem for the market. What should the price be in circumstances where no price can balance supply and demand? The answer is that the regulator must specify an administrative shortage price that reflects the value of lost load. The shortage price represents consumers' preference for reliability in a world without robust demand response. The higher the shortage price, the stronger the incentive to invest in resources that perform well during shortages and a lower risk of shedding load.

23. There are practical benefits from making the performance incentive smooth as the system moves near shortage. Continuity is achieved with reserve demand curves that increase

steeply to the value of lost load as reserve quantities fall to the point where the system operator must start shedding load (Hogan 2013). In this way, the reserve demand curves cause prices to escalate quickly to the value of lost load as the market moves from near-shortage to shedding load. PJM recently adopted, and FERC approved, this best practice in their spot market for implementation on May 1, 2022.

24. One implication of adding reserve demand curves to the spot market is that, when correctly set, they restore missing money. With the demand curves administratively set to reflect consumers' preference for reliability, the spot market yields prices sufficient to motivate efficient investment despite the absence of robust demand response. Some markets, such as ERCOT, stop at this point—the so-called energy-only market.

Capacity market

25. Some markets, such as PJM, NY ISO, and ISO New England, include a capacity market. Absent reserve demand curves, a capacity market is necessary to restore missing money. But even when the day-ahead and real-time markets have reserve demand curves, a well-designed capacity market can play a role, helping to bring adequate resources, coordinate investment, and manage risk.

26. Like the reserve demand curves, the capacity market is an administrative construct. But while the reserve demand curves directly address an energy market's imperfect shortage pricing, a capacity market is indirect. Indeed, a capacity market that succeeds in bringing about adequate resources may even blunt the incentive for energy market reforms.

Capacity demand curve

27. A critical feature of the capacity market is the capacity demand curve—known as the variable resource requirement curve in PJM. The demand curve specifies the quantity of capacity procured as a function of the capacity price. The demand curve is centered at the target capacity level when the price is net cost of new entry (CONE), the cost of new entry for a benchmark resource less the expected revenues earned in the spot market. For prices above net CONE, less capacity is purchased; for prices below net CONE, more capacity is purchased. This price response is consistent with the consumers' demand for reliability. When reliability is more expensive, customers buy less of it. Like all demand curves, the capacity demand curve reflects the incremental value of the capacity resource. As additional capacity is added, its marginal value falls.

Price formation

28. Early capacity markets had a vertical demand curve at the target level of capacity. Vertical demand created a boom-bust tendency where the capacity price would oscillate between floor and ceiling prices or persist at the floor price even if capacity only minimally exceeded the target level. This approach sent a poor price signal that did not reflect the incremental value of capacity.

29. More commonly today, capacity markets have a downward-sloping demand curve that better reflects the marginal value and reduces price volatility. The sloped demand curve provides a smooth response to changes in quantity, consistent with the reliability benefit the marginal resource brings. As additional resources are added to the market, the capacity

price falls since the resource's marginal reliability contribution is less when more resources are in the market. Similarly, as resources are removed from the market, the capacity price increases, reflecting the higher reliability contribution in a tighter market. This price response is the purpose of the capacity demand curve and the essence of price formation.

30. A downward-sloping demand curve also weakens the incentive to exercise market power. With the vertical demand curve, the sellers could reduce supply so that the capacity price would be equal to the price ceiling. Similarly, the vertical demand curve creates incentives for the buyer to expand supply to push the capacity price to the price floor. The sloped demand curve mitigates both incentives. Changes in supply have a more modest impact on the capacity price under the sloped curve than they would with the vertical curve.

Mitigating market power

31. Even with a sloped demand curve, the exercise of market power remains a concern. In every electricity market, there are some suppliers of significant size. These suppliers can exercise market power by withholding only a small fraction of their capacity. Whether they have an incentive to do so is another matter. The price impact may not be large, and competitors' capacity at least partially replaces their withheld capacity. The supplier might enjoy that higher capacity price only for a single year yet faces greater competition in future years in the capacity, energy, and reserves markets.

32. All capacity markets have protections to mitigate supplier market power. Typically, these measures restrict how high incumbent capacity can offer in the capacity market. It is large incumbents that have the most to gain from the exercise of market power.

33. The focus on supplier market power is natural since the buyer is obligated to purchase. However, buyers can impact the capacity price through the competitive procurement of additional resources and then offer those resources in the capacity market at low prices. Some utilities that serve load are not suited to benefit from the exercise of buyer market power. For example, a utility with a division that owns generation may have supply resources and pass on capacity costs to consumers. However, states, cooperatives, and other large buyers may have an interest in reducing capacity prices. MOPR is intended to mitigate the adverse impact of the exercise of buyer market power.

The minimum offer price rule

34. The minimum offer price rule prevents some state-sponsored resources from offering below a minimum offer price. The minimum offer price depends on whether the resource is new or existing. New resources are defined as those that have never cleared in the capacity market. The minimum offer price for new resources is much higher than that for existing resources to reflect the higher cost of a new resource. The rule is intended to mitigate the exercise of buyer market power. In some state procurements of resources, the payment of the competitive procurement price was made conditional on the resource clearing in the capacity market. This conditional support may force some noneconomic resources to stay in the capacity auction regardless of price, thereby causing the capacity price to fall.

35. In December 2019, after reviewing PJM's filing to expand MOPR, FERC went further and ordered a significant expansion of MOPR—a broad MOPR covering a large set of state actions. The broad MOPR finds specific business models such as public power to be a subsidy that could trigger MOPR going forward. The broad MOPR extends the minimum offer price rule to virtually all state-sponsored resources. These resources would be required to offer at least the minimum offer price unless granted an exception based on PJM's and the independent market monitor's review of the resource's specific costs and revenues.

36. Some argue that the broad MOPR is appropriate because state actions to address resource externalities result in some resources receiving extra compensation. They claim this may unjustly reduce the capacity price and undermine the competitive entry of new resources.

37. I disagree. Even if one assumed that state programs directing additional funds to resources based on environmental or other favored attributes could exert downward pressure on capacity prices, the broad MOPR's efforts to reverse that situation would worsen matters. By clearing resources that duplicate resources favored by state policy, the broad MOPR results in downward pressure on energy prices, the largest source of resource revenues. The broad MOPR also increases the capacity price, slows the energy transition, and disrespects states' policy preferences.

PJM's MOPR Proposal

38. The PJM MOPR proposal prohibits the exercise of buyer market power. It mitigates the exercise of market power and provides vehicles for parties to bring matters to FERC for final resolution. The approach is simple and transparent. It begins with a clear definition of buyer market power and its exercise.

39. Buyer market power is the ability of a market participant with a load interest to suppress market-clearing prices for the overall benefit of the participant's portfolio. The exercise of buyer market power requires both the ability and incentive to materially reduce capacity clearing prices by offering capacity or directing another to offer capacity below cost.

40. Conditioned state support is clearly defined as out-of-market payments in exchange for the sale of a FERC-jurisdictional product conditioned on clearing in any PJM capacity market.

41. Market participants must certify whether they have received conditioned state support and whether they intend to offer their resources to exercise buyer market power. PJM and the independent market monitor examine the certifications to confirm that they appear correct. Where PJM, or the independent market monitor, has reason to doubt the certification of a lack of buyer market power, PJM can require the seller to provide further information. If concerns remain, PJM can require the seller to offer no lower than the minimum offer price as defined by MOPR. In instances where PJM, aided by the independent market monitor, identifies conditioned state support, PJM can seek FERC approval to require the seller to offer no lower than the minimum offer price.

42. Market participants that do not receive conditional state support and do not exercise buyer market power can offer below the minimum offer price.

43. The minimum offer price differs between new and existing units. New units—resources that have never cleared in a capacity auction—cannot offer below the cost of new entry less estimated revenues. Existing units—resources that have cleared in a prior capacity auction—cannot offer below the resource's net going forward cost.

44. The narrow MOPR identifies those instances of either conditional state support or the exercise of buyer market power and then applies the appropriate minimum offer price. The approach is narrowly tailored to circumstances. Circumstances are identified either by the market participant or by PJM or the independent market monitor with review by FERC.

Market Impact of Broad MOPR vs. Narrow MOPR

45. To evaluate the market impact of the alternative MOPR approaches, I study entry and exit in PJM from 2019 to 2040 using the model described in Cramton et al. (2021). The model has been carefully calibrated based on the resources in PJM as of 2019. The model examines the equilibrium entry and exit of resources on an annual basis. The model estimates resource revenues from the capacity, energy, and reserves markets to determine the net present value of entry or exit. I model PJM's day-ahead and real-time markets to form these estimates. The expectations are roughly consistent; that is, the realization of cash flows over the life of the resource are approximately equal to the estimates. The investors do a good job of anticipating the future and therefore do not regret the decisions made. Each year profitable resources enter, and unprofitable resources exit, as coordinated by the capacity market conducted three years ahead.

46. Battery storage is fully integrated in the model. The battery resources are optimally scheduled and dispatched to maximize profits. For simplicity, only two-hour batteries are considered.

47. Climate policy is modeled with a carbon price. Investors in long-lived energy projects have an internal carbon price used in decision-making. A carbon price is the most coherent way to model climate policy. I employ a modest carbon price of $2/ton in 2019, which increases by $3/ton each year. In 2020, the implicit carbon price is $5/ton; in 2040, the carbon price is $65/ton.

48. As described in Cramton et al. (2021), the modeling requires extensive computation. The modeling was done on 22 computational servers running 24x7 for many months, creating an extensive database of market outcomes at the 5-minute level as a function of the resource structure and other parameters. Once the database of market outcomes is built, I can run the model much more quickly to analyze, for example, possible market rule changes. To correctly compute net present values for long-lived assets, the analysis extends into 2100. I only report results through 2040.

49. PJM has proposed endogenous capacity values based on resources' effective load carrying capability (ELCC). Given the forward-looking nature of our modeling, the model assumes endogenous capacity values as in the ELCC approach.

50. I consider two scenarios:

Narrow MOPR—This scenario fits the narrow MOPR proposed by PJM. As applied here, the model assumes the clear, narrowly targeted rule is effective and deters both the exercise of buyer market power and attempts at conditioned state support. The model thus assumes that resources do not receive conditional state support and do not exercise buyer market power.

Broad MOPR—This is the broad MOPR scenario established by FERC's December 2019 Order. The minimum offer price applies to all renewable resources.

51. Thus far, I have argued from logic that the broad MOPR may lead to excessive resources in PJM and higher costs to consumers. The logic does not determine the magnitude of these impacts. This is where the simulation adds value. It can test the logic and estimate the magnitude of the differences between policy choices.

52. There are two main hypotheses.

Hypothesis 1: The PJM market is reliable with either a broad or narrow MOPR.

Hypothesis 2: The broad MOPR brings more resources to PJM. However, these extra resources do not make the market more reliable.

53. As with any simulation of this complexity, I have made many assumptions. See Cramton et al. (2021) for details. Calibration of the model is imperfect. Miscalibration is especially apt to impact absolute results, such as price levels. It is less prone to affect relative results, such as comparison between scenarios. Thus, the reader should focus primarily on the differences between the broad and narrow MOPR scenarios.

54. I now discuss the results from the analysis of these two scenarios. The figures are at the end of this document.

Resource mix and entry and exit

55. Resources enter and exit the market on an annual basis. Some resources exit because they reach the end of life. Others exit because profits going forward turn negative. New resources enter based on forward-looking profit expectations.

56. Figure 1 shows how the energy mix evolves from 2019 to 2040. Given the modest carbon price, thermal resources continue to play an important role. Coal gradually exits, as do the legacy gas resources. These resources are replaced with storage, wind, and solar. Combined cycle with carbon capture does not enter until about 2035. The differences between the broad MOPR and narrow MOPR cases are modest.

57. Figure 2 shows the annual net entries (entries minus exits) in GWs averaged over 2019-2040. Over the next two decades, the model predicts that coal, legacy gas, and combustion turbines will be replaced with solar, wind, storage, and combined cycle gas (with carbon capture in the later years). Combined cycle units remain a critical component in the mix

and increases, offsetting the reduction in combustion turbines. These portfolio changes over the next twenty years are similar under the narrow and broad MOPR scenarios.

58. Figure 3 shows the detail of entry and exit by year.

Capacity prices and reserve margin

59. Figure 4 shows capacity prices and reserve margins by year. Interestingly, MOPR has little impact on capacity prices. There is no evidence of "price suppression" with narrow MOPR.

60. By contrast, the broad MOPR results in a higher reserve margin—about two percentage points higher in most years. The reserve margins may seem low. This is because a unit's capacity is defined as its nameplate capacity times its capacity value. Capacity values can change substantially based on performance. For example, a long period of little wind and high demand can cause a significant drop in wind capacity values. After such an event, the same set of resources has a lower reserve margin. The reader should interpret reserve margins relatively, as I do so here.

61. The main implication of broad MOPR is not to raise the capacity price. Instead, broad MOPR brings in some extra resources without letting the capacity price decrease. The main result is a higher reserve margin. The additional resources might be desirable if they improved reliability; however, we will find they do not.

Energy and reserves prices and reliability

62. Figure 5 shows the average annual prices for energy and reserves by year. Energy prices are similar in the broad MOPR and narrow MOPR cases. Reserve prices are also similar in narrow and broad MOPR scenarios.

63. Figure 6 shows price duration curves by decade. The broad MOPR and narrow MOPR cases again are similar. Note that Figure 6 also indicates that load is reliably served in all cases. Shortage rarely occurs. To better see this fact, Figure 7 zooms in to the right tail of the duration curves, showing 99.5% and above. Narrow MOPR does have a slightly higher incidence of high prices in both day-ahead and real-time markets. Shortage never occurs day-ahead and is extremely rare in real-time. This demonstrates the robustness of the capacity market to make sure there are sufficient resources to serve load. As most relevant to the present topic, a broad MOPR is not needed to preserve the long-term reliability of service to load.

64. Figure 8 shows the frequency of price spikes—five-minute intervals with prices more than $100/MWh. The price spikes are similar in narrow and broad MOPR cases. Regardless of the MOPR choice, as the share of renewables grows, price spikes become more frequent, and real-time price spikes are more frequent and more extreme than day-ahead price spikes. Figure 9 zooms in to see the frequency of prices more than $400/MWh. The conclusion is the same. Price spikes primarily occur in real-time and grow in frequency with higher renewable penetration. Interestingly, the frequency of extreme price spikes above $1600/MWh does not increase as renewable resources are added. Batteries step in to provide the flexibility required with more renewable resources.

Components of the electricity price

65. Figure 10 shows the electricity price components by year. I split energy into base energy when the energy price is less than $200/MWh and peak energy when the energy price is more than $200/MWh. The main components of price are capacity and base energy. Uplift, reserves, and peak energy are much less significant. The broad MOPR and narrow MOPR cases are similar.

66. Figure 11 shows the electricity cost components by year. The all-in price consists of capital costs, operating costs, generation costs, and profits. Profits are initially negative due to excessive resources. Once the surplus resources exit, profits return and are maintained through 2040. The broad MOPR and narrow MOPR cases are similar, although there is a drop in profits and all-in cost for the broad MOPR case toward the end of the analysis period.

Supplementary figures

67. Figure 12 shows the average performance of resources by decade in the five-minute intervals used to measure performance. These are five-minute intervals with a real-time price of at least $200/MWh. I used fixed capacity values for thermal resources since this simple approach is apt to be more consistent with the ELCC method. For renewable resources and storage, capacity values are calculated using exponential smoothing. The broad MOPR and narrow MOPR cases show very similar performance results by resource type.

68. Figure 13 shows the average annual net entries by decade.

69. The entry and exits are determined based on consistent expectations of going forward profits, summarized in a net present value calculation. The net present value of incumbent resources is shown in Figure 14. Figure 15 shows the net present value for new entrants. The narrow MOPR and broad MOPR cases are again similar. The broad MOPR slightly harms solar and wind in the early years.

70. Figure 16 shows the profit breakdown by year.

71. The model uses an econometric proxy model to determine profits as a function of resource structure and other parameters. To check the quality of the proxy model, I ran the energy market model for each year along the equilibrium path. Figure 17 shows the difference between the energy proxy results and the results computed from the energy market model along the equilibrium path by decade. The profit difference is relative to the annualized gross cost of entry for the resource in 2019. Profit differences are negligible in 2019. For the 2020s and 2030s, profit differences are small relative to the cost of energy. Performance differences are more prominent.

72. The quality of the results can be improved with additional computation and improvement of the proxy model. However, I believe the results are sufficient for my conclusions.

Conclusion

73. Both logic and analysis lead me to conclude that PJM's proposed MOPR is an essential improvement. The PJM rule is narrowly tailored to address buyer market power. By contrast, the current rule is too broad. It imposes a minimum offer price in circumstances where such intervention is unwarranted. The cost of the broad MOPR stems primarily from having some resources that provide reliability excluded from the capacity market. This exclusion causes the capacity price to clear too high and not correctly reflect the marginal value of reliability to consumers expressed by the capacity demand curve.

74. My analysis of entry and exit in PJM over the next two decades confirms this conclusion. Although both the broad MOPR and narrow MOPR bring reliability, the broad MOPR results in more resources and more expense for consumers. The difference is not dramatic. The main reason for the modest impact is little change in the resource schedule and dispatch. Energy and reserves prices stay about the same. Capacity prices are also about the same because the broad MOPR prevents the extra resources from reducing the capacity price. Thus, the advantage of narrow MOPR is reduced consumer cost. Narrow MOPR avoids carrying additional resources that do not contribute to reliability.

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PJM Interconnection LLC (2021b) "Flow Diagrams to Support the PJM MOPR Proposal."

Figure 1: Energy mix by year, 2019-2040

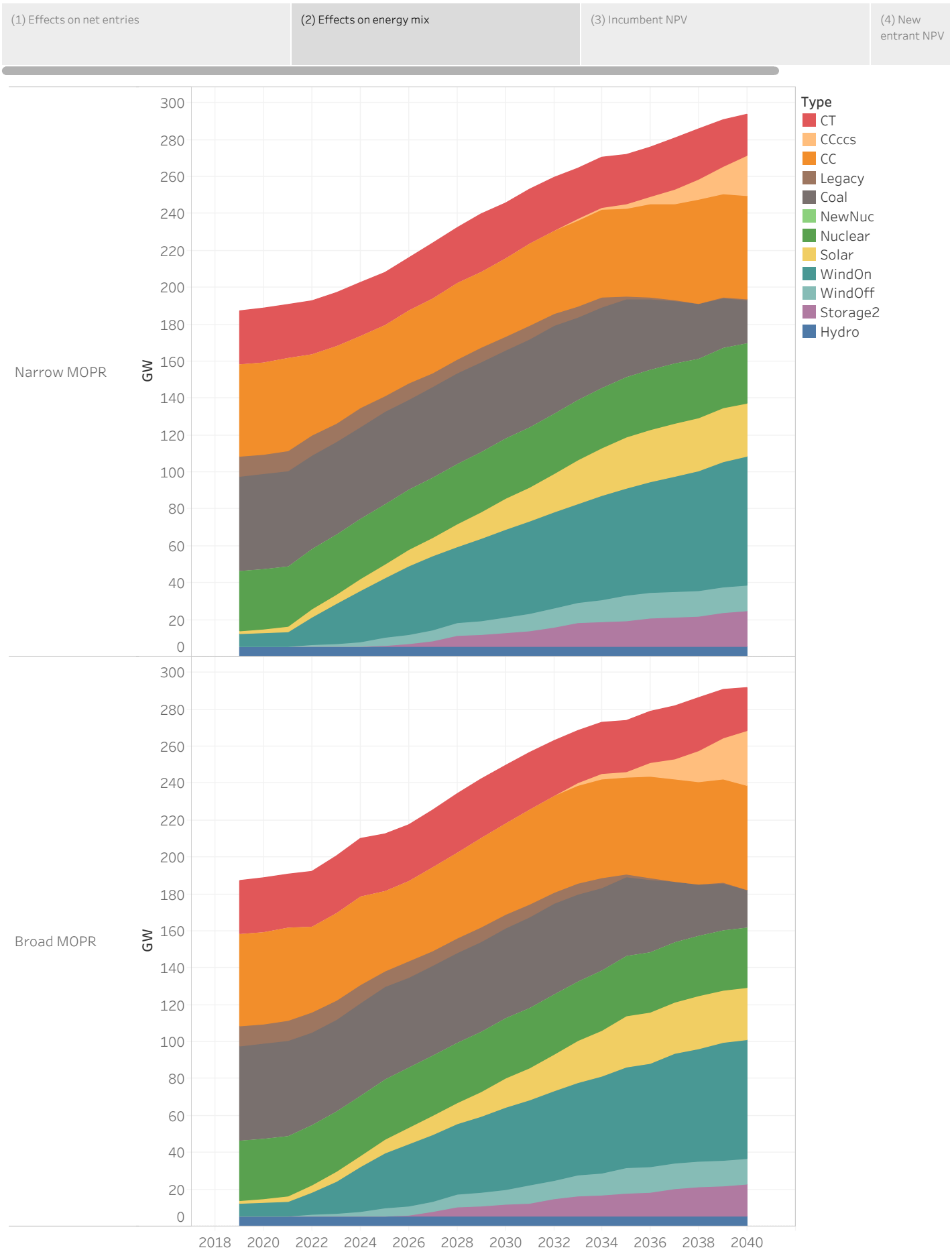


Figure 2: Average annual net entries, 2019-2040

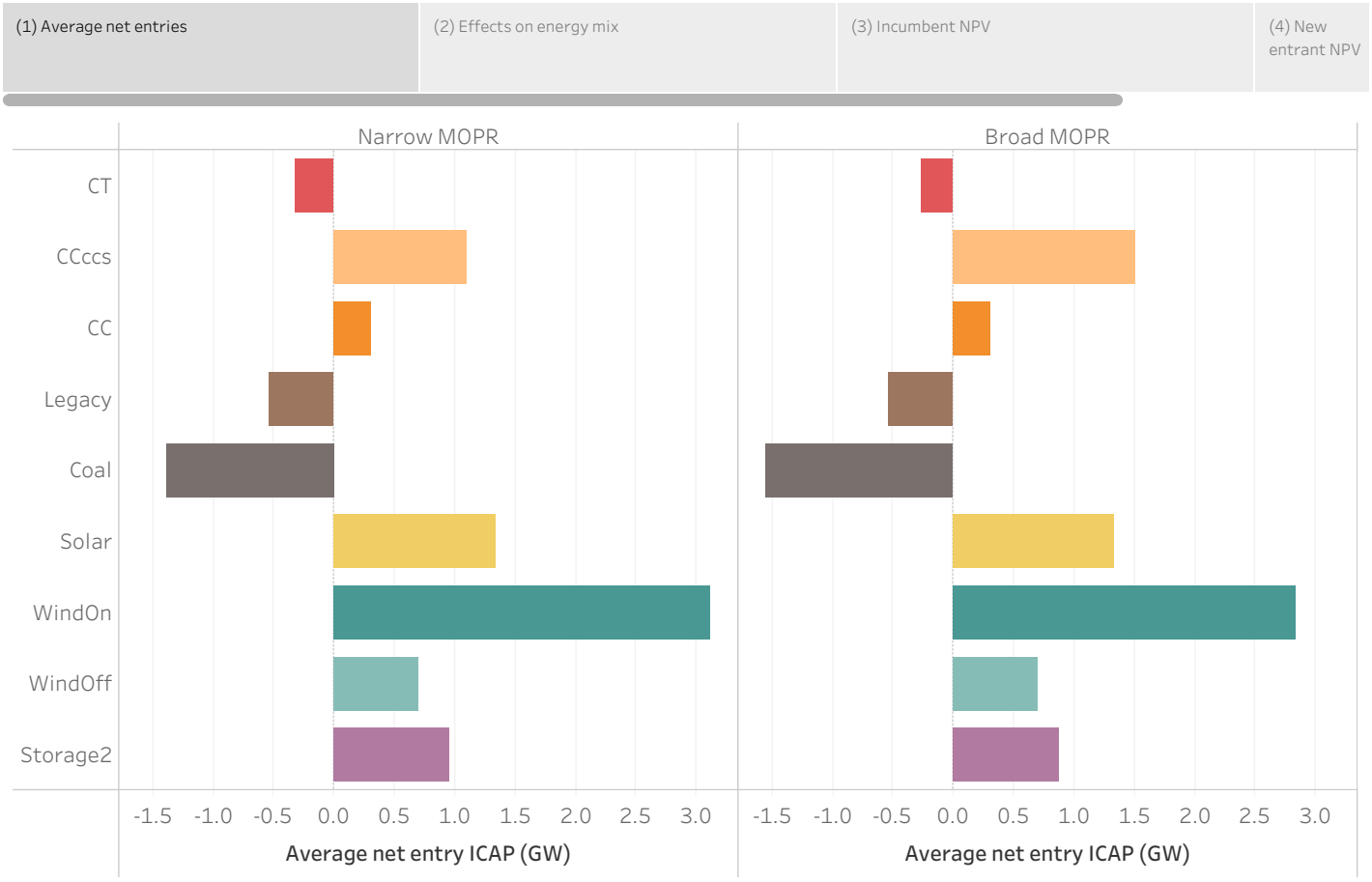


Figure 3: Entry and exit by year, 2019-2040

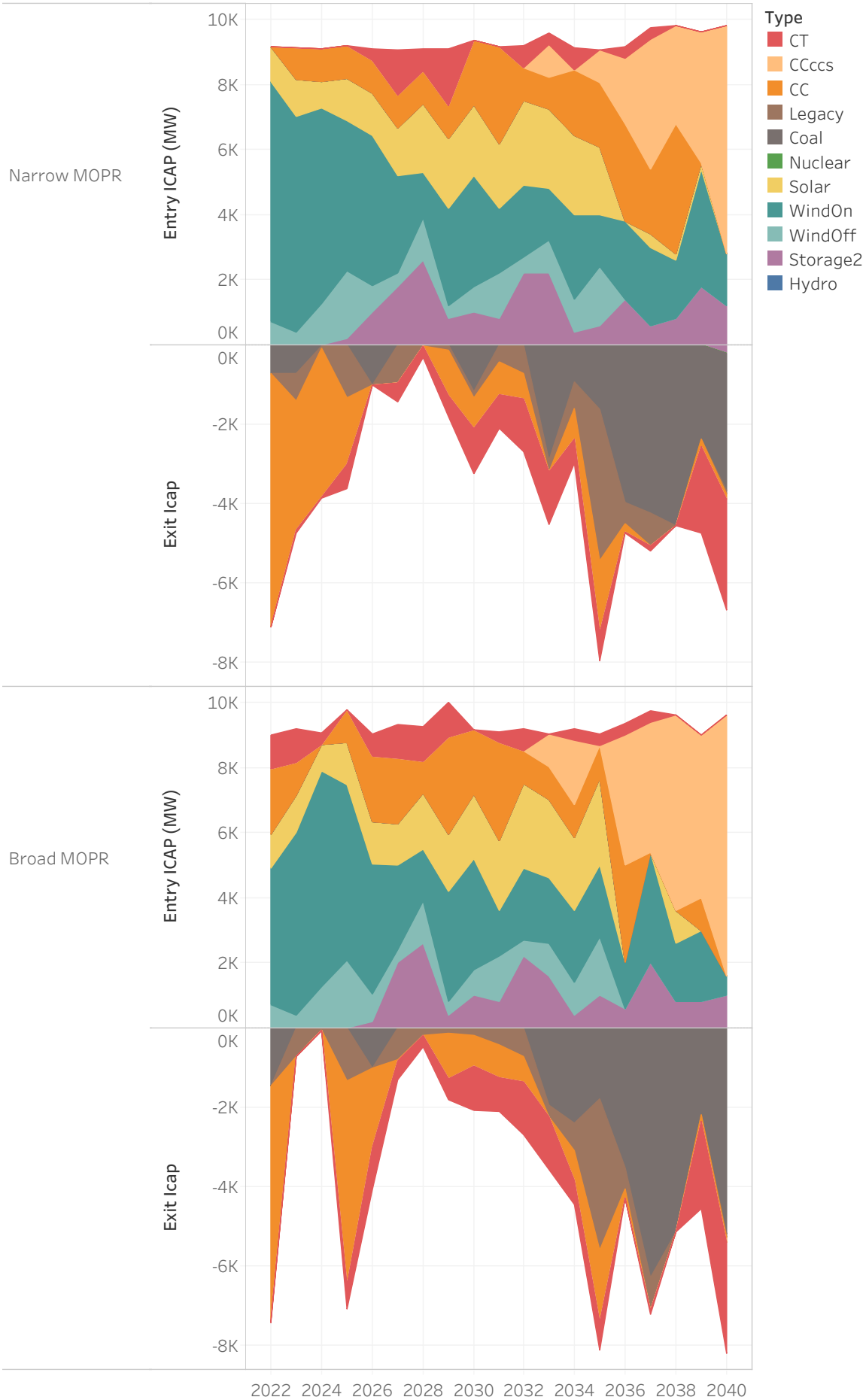


Figure 4: Capacity price and reserve margin by year, 2019-2040

Capacity price and reserve margin (capacity is defined as nameplate times capacity value)

Figure 5: Generation and reserve prices by year, 2019-2040

(1) Generation & reserve prices | (2) Duration curves for generation price and shortage | (2b) Duration curves (right tails) | (3) Price spikes | (3b) Price spikes (>$400/MWh)

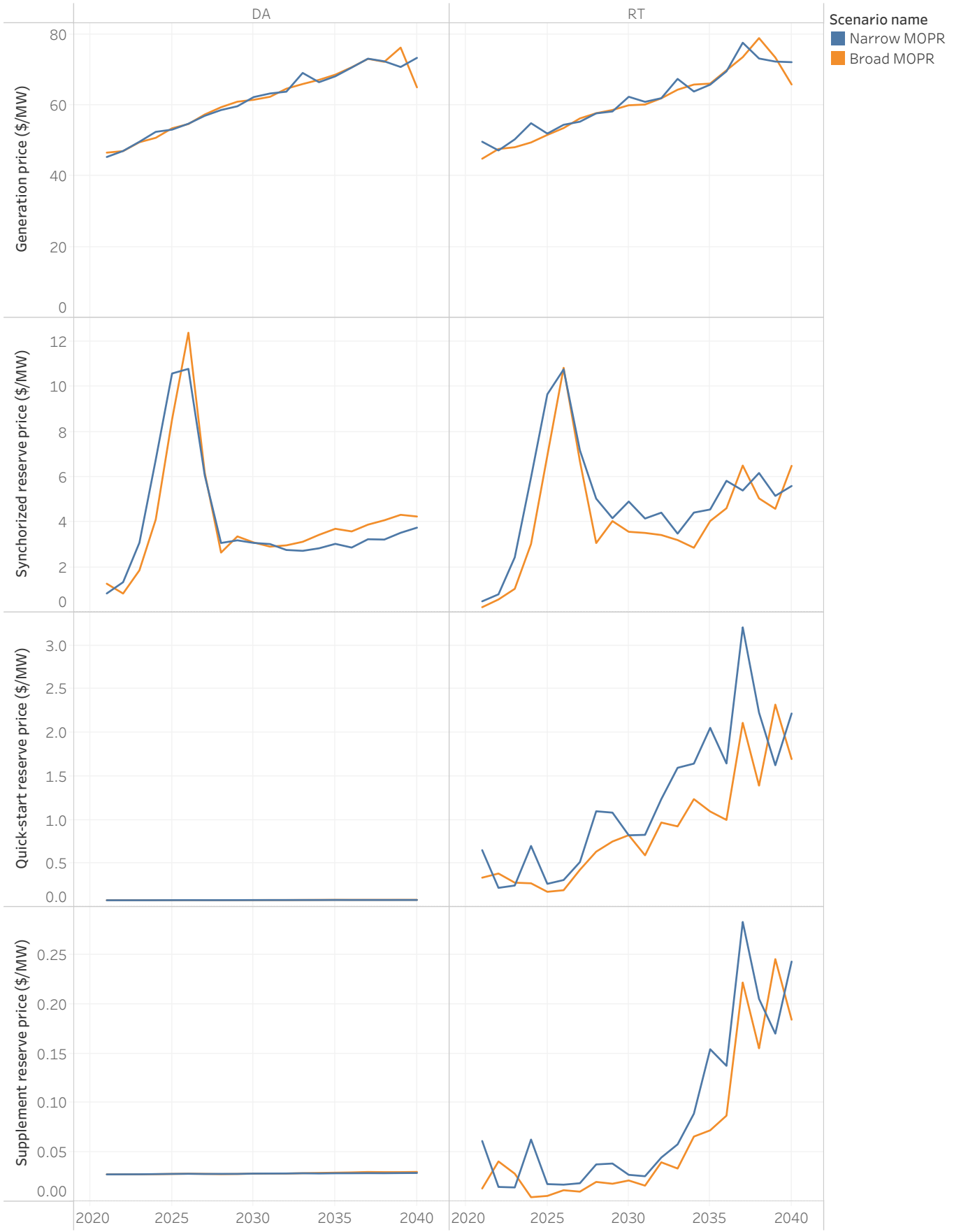


Figure 6: Duration curves for generation price and shortage by decade

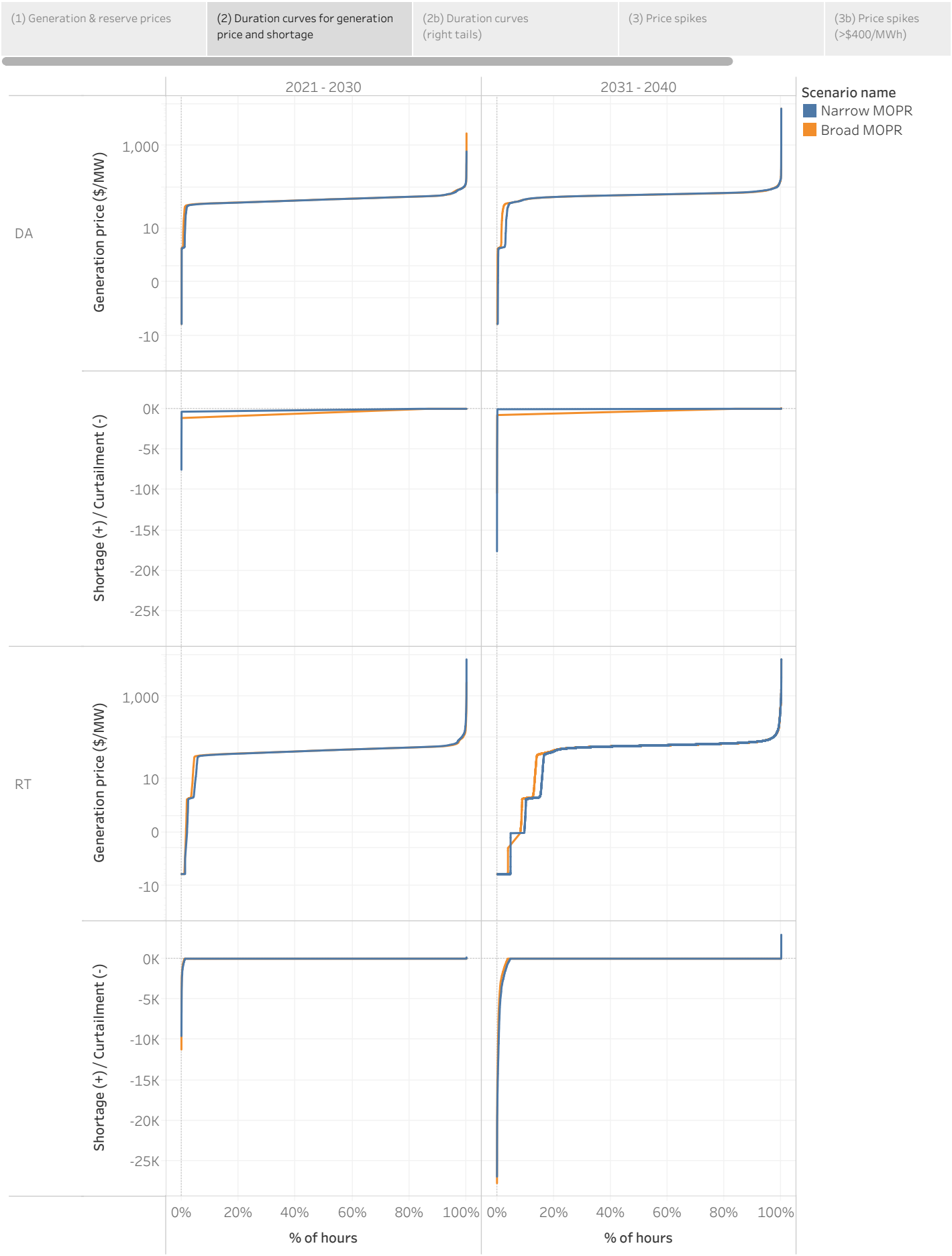


Figure 7: Right tail duration curves for generation price and shortage by decade

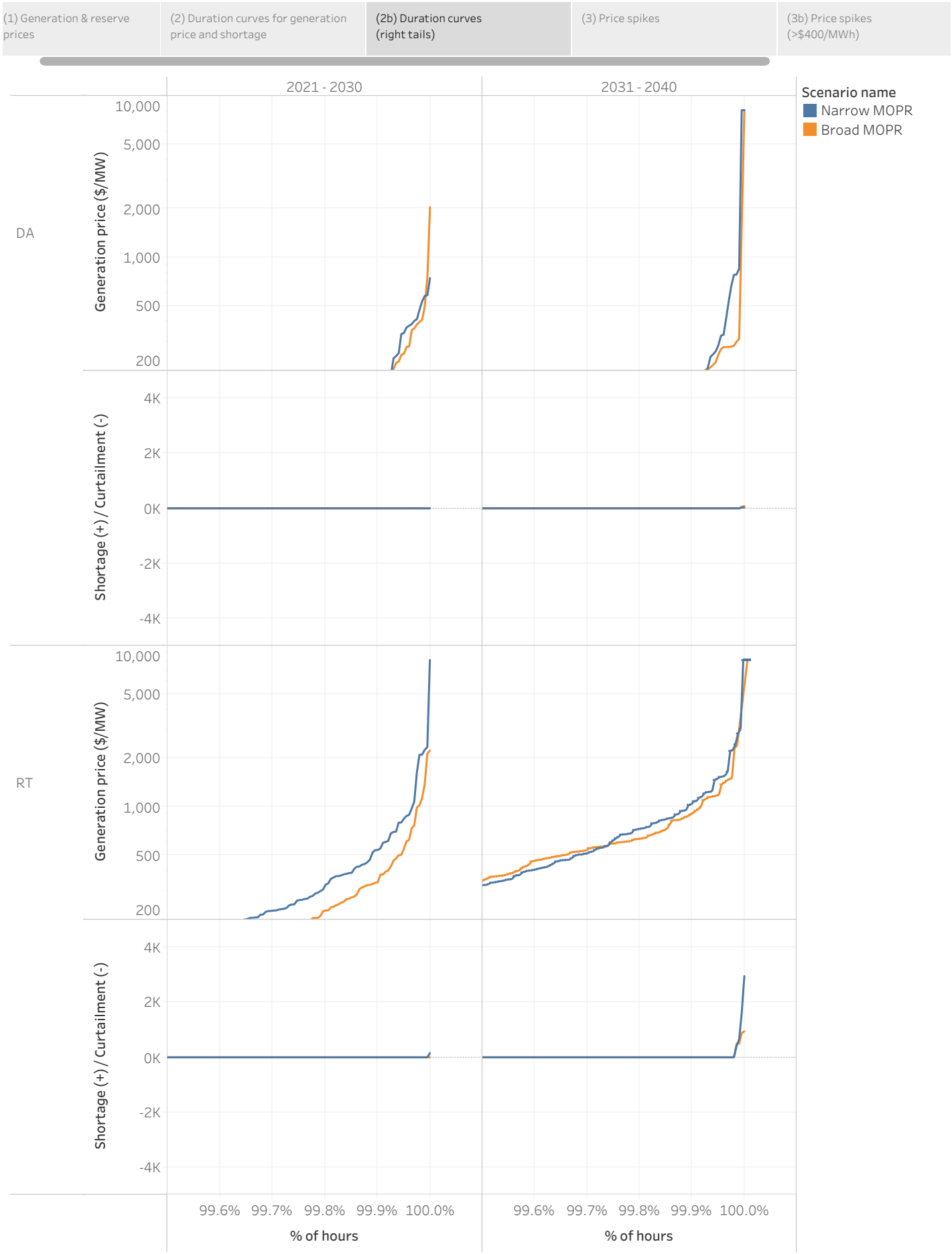


Figure 8: Price spikes in day-ahead and real-time markets by year, 2019-2040

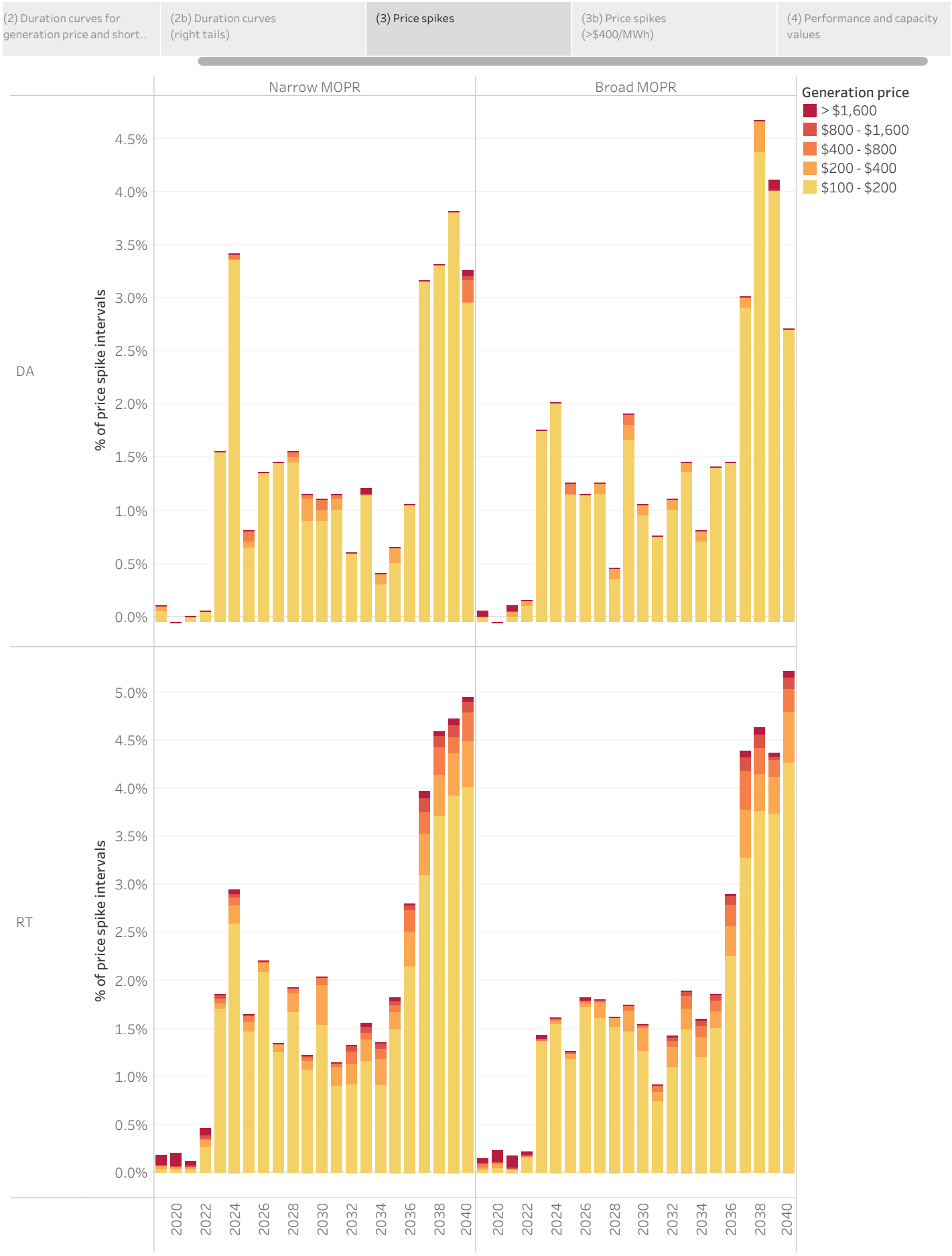


Figure 9: High price spikes in day-ahead and real-time markets by year, 2019-2040

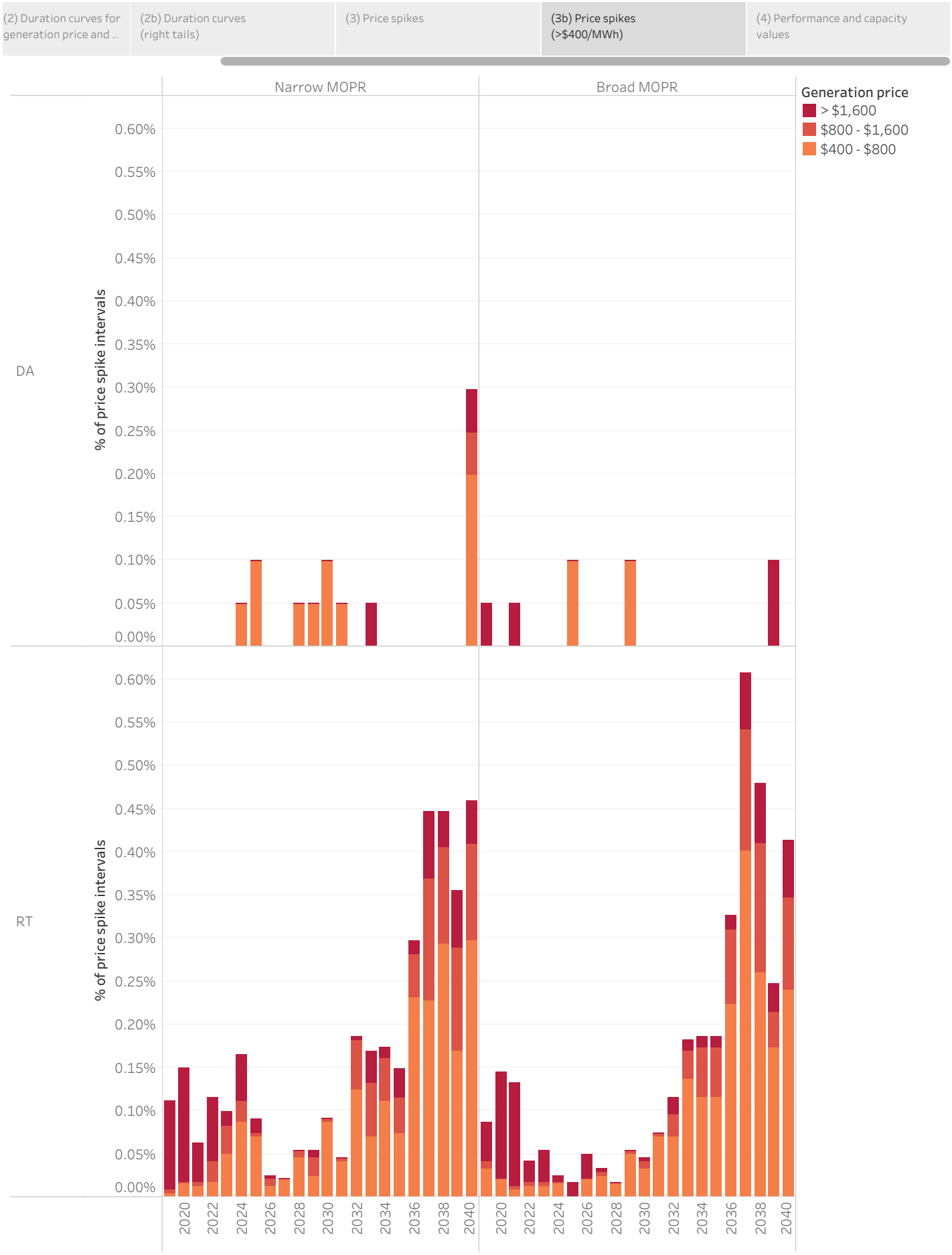


Figure 10: Electricity price components by year, 2019-2040

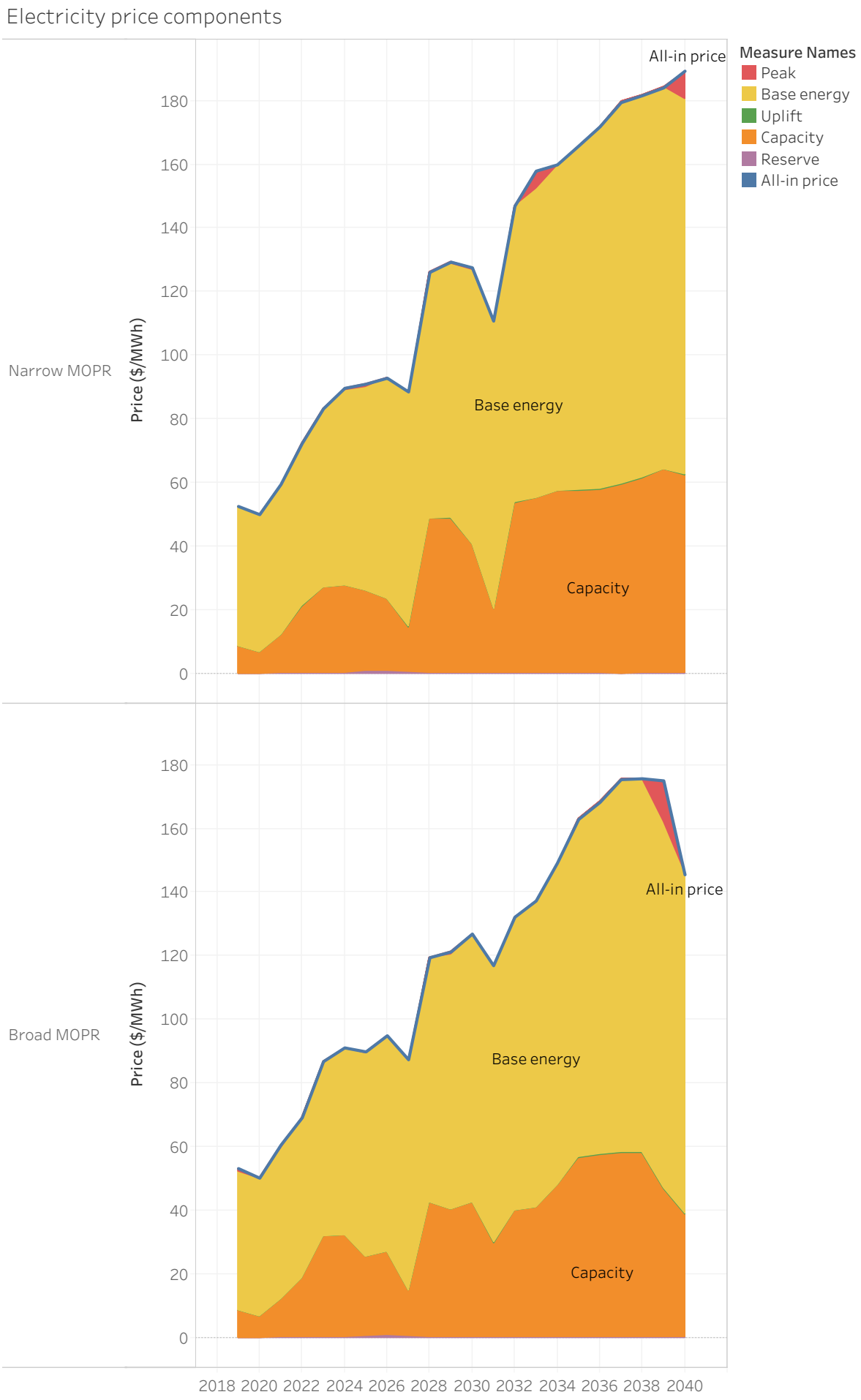


Figure 11: Electricity cost components by year, 2019-2040

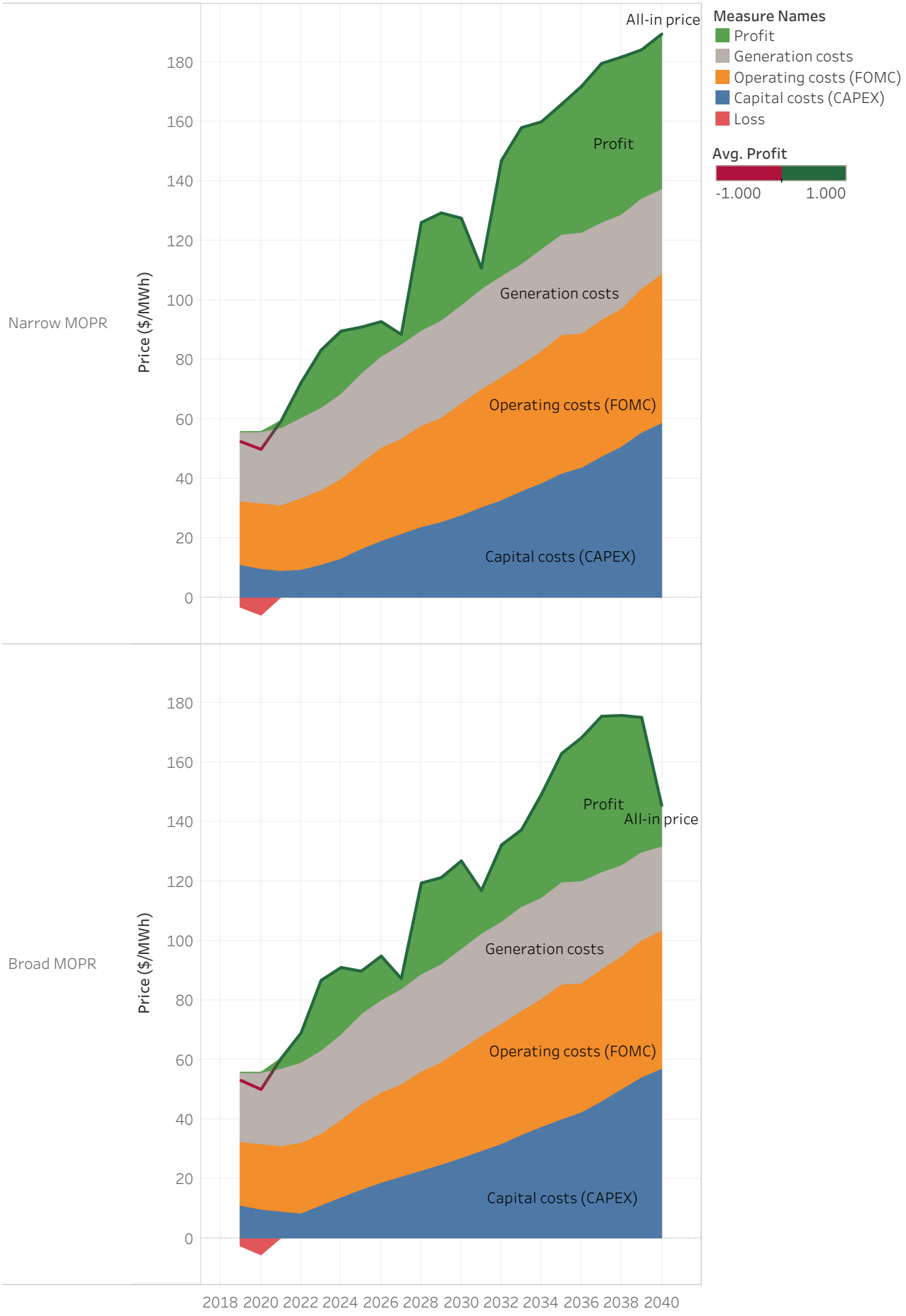


Figure 12: Performance and capacity values by decade

Figure 13: Average annual net entries by decade

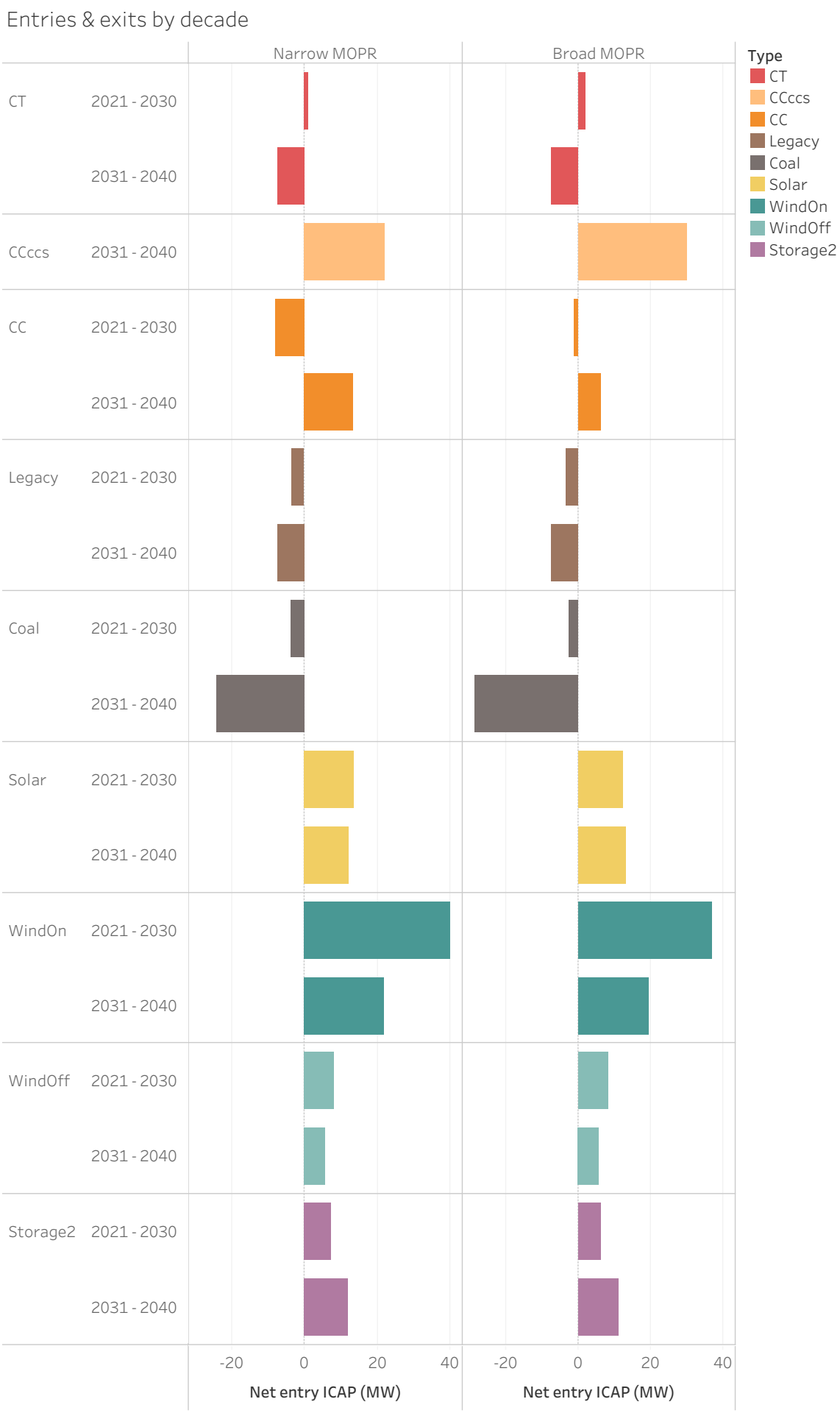


Figure 14: Net present value of incumbent resources by year, 2019-2040

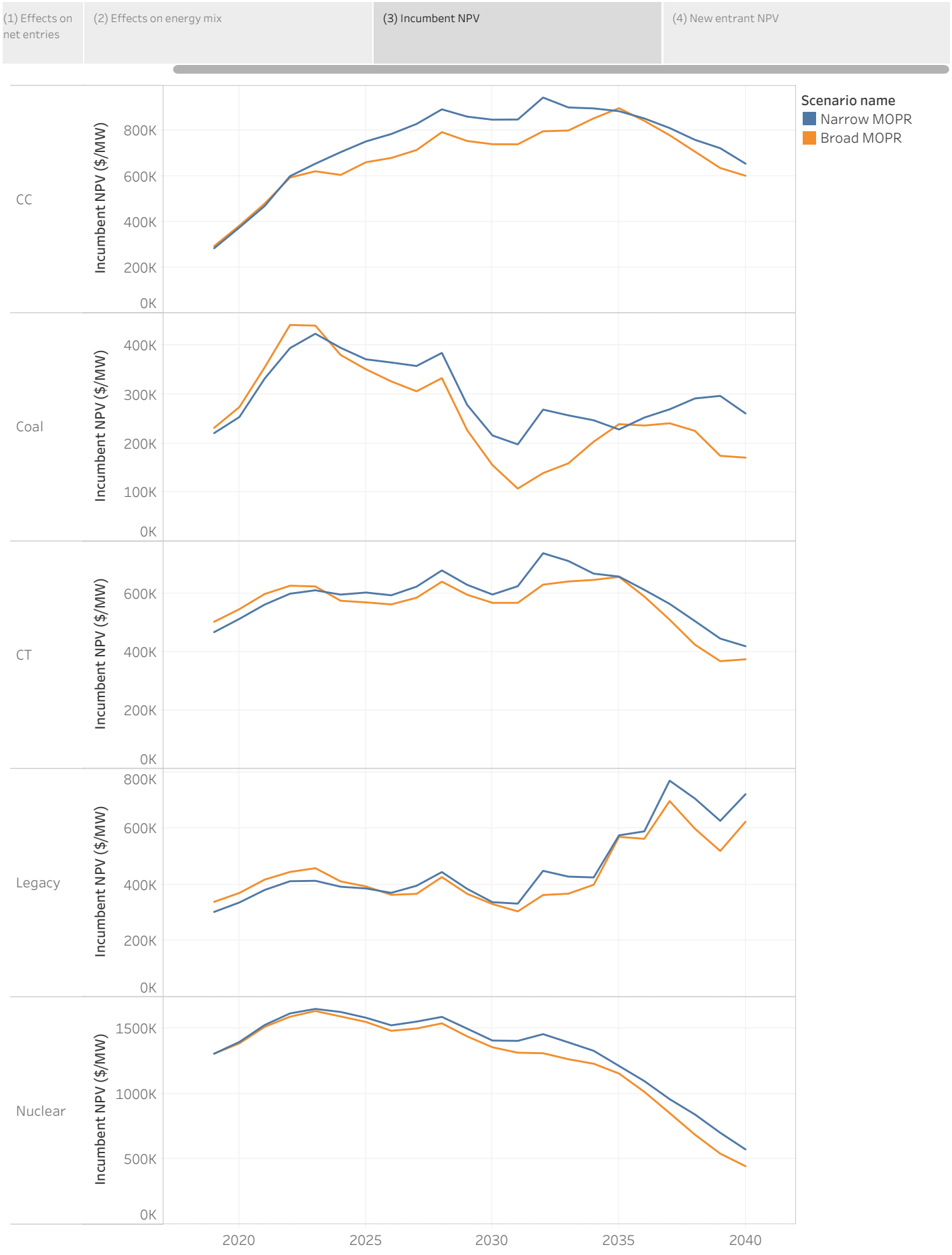


Figure 15: New entrant net present value by year, 2019-2040

(1) Effects on net entries | (2) Effects on energy mix | (3) Incumbent NPV | (4) New entrant NPV

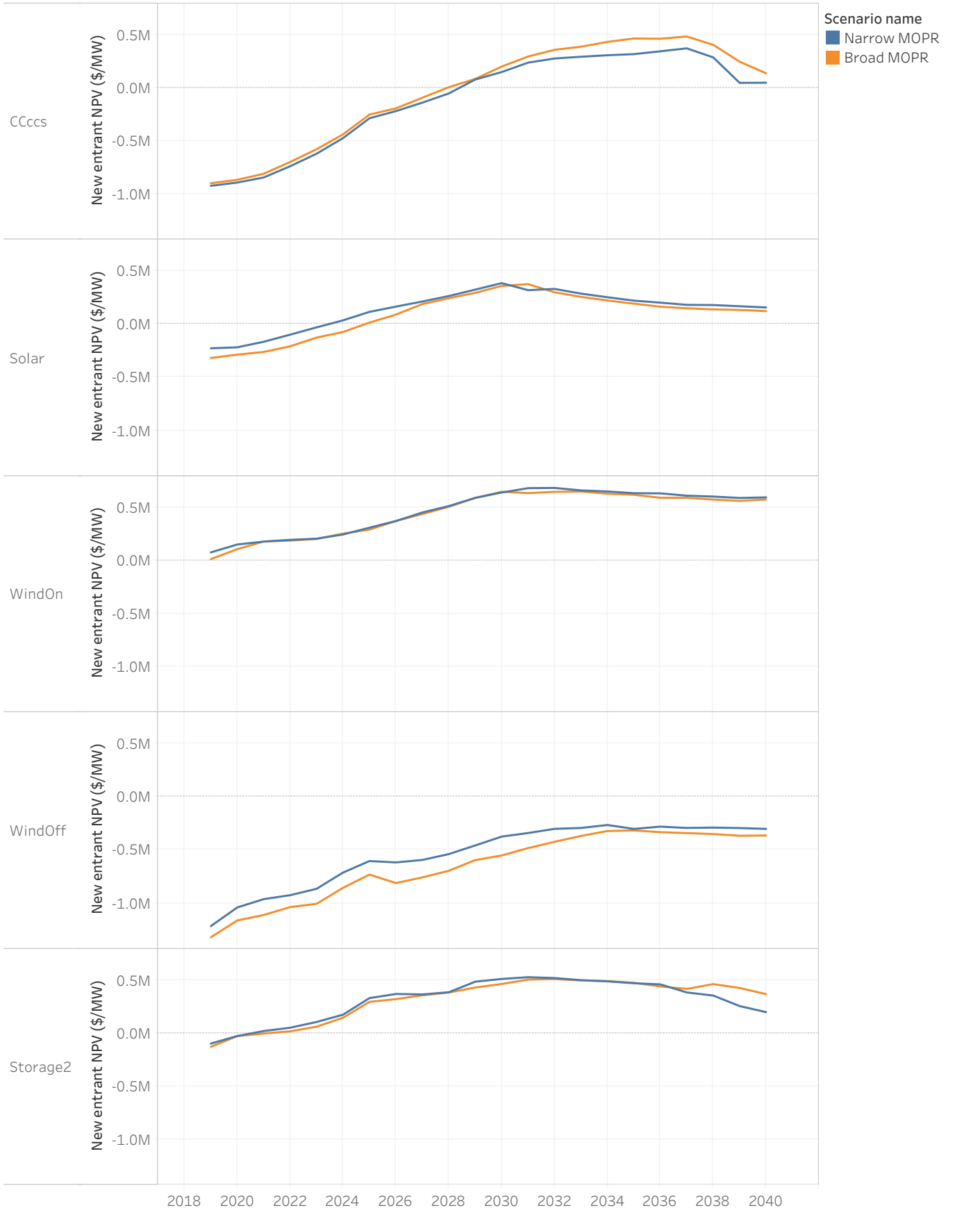


Figure 16: Profit breakdown by year, 2019-2040

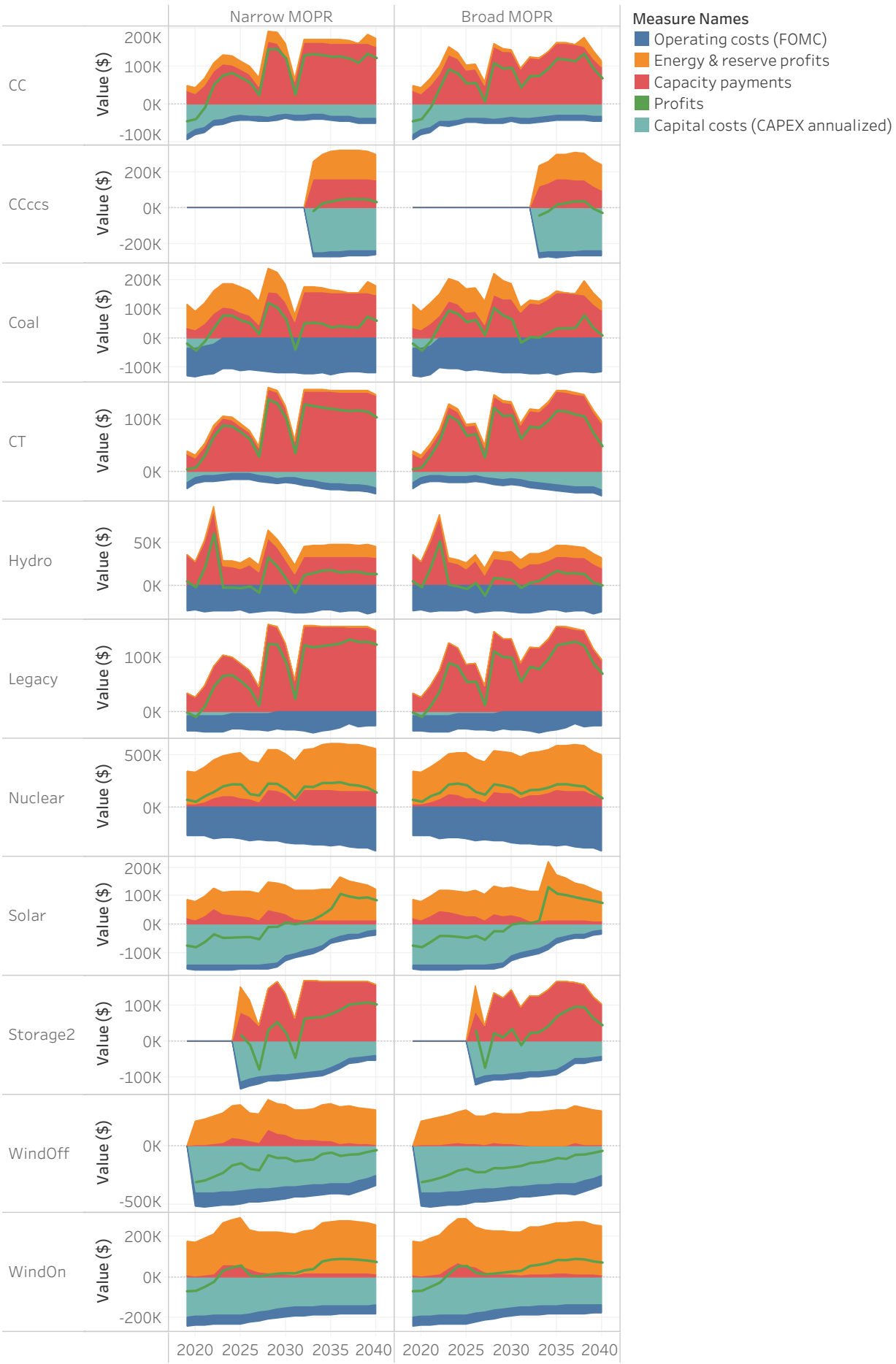
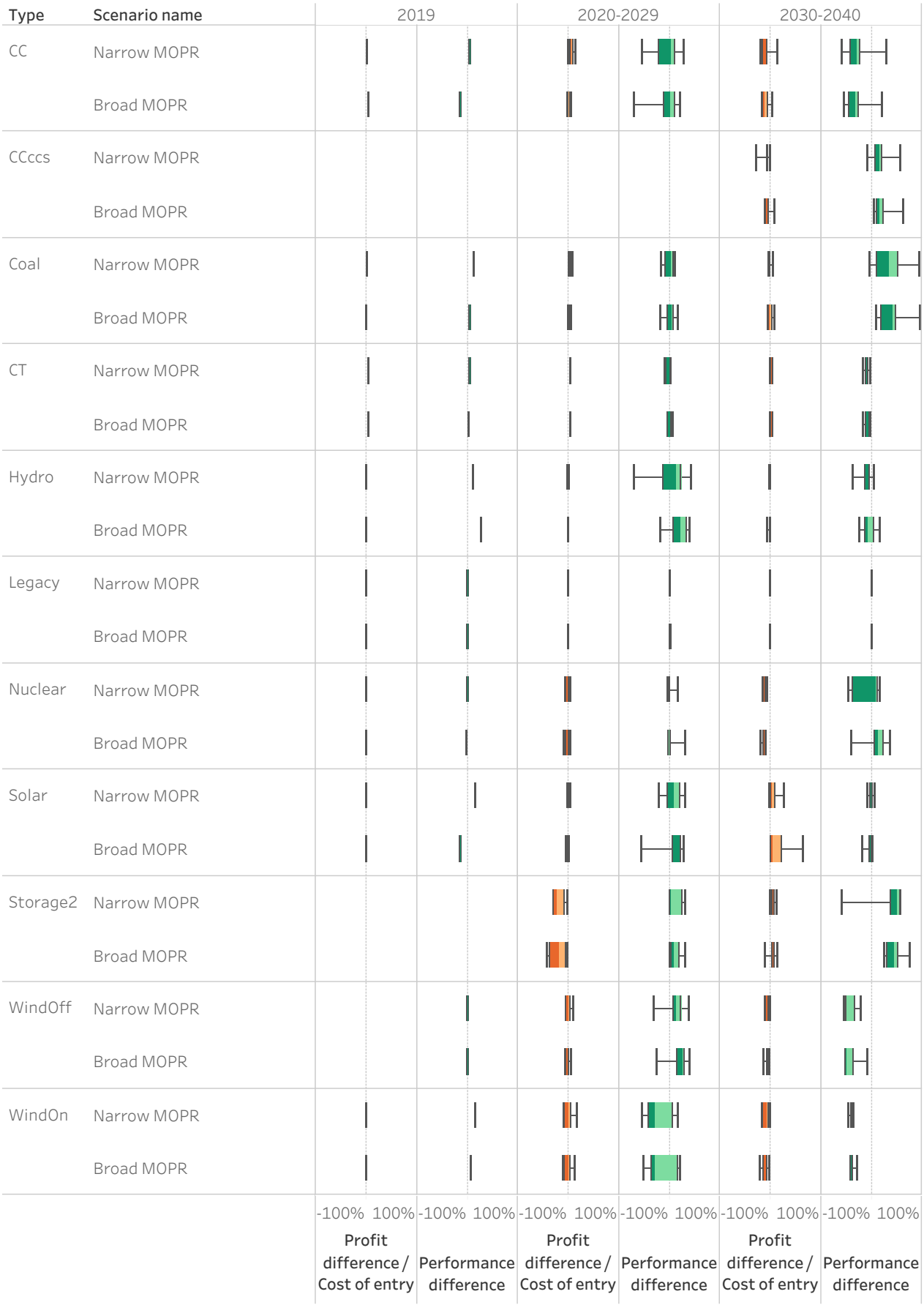


Figure 17: Deviations of proxy model and energy market model along the equilibrium path

Profits and performance predicted by the energy proxy minus actual profits and performance generated by the energy market model along the equilibrium path (profits are divided by the annualized cost of entry in 2019)



Document Accession #: 20210730-5166 Filed Date: 07/30/2021

UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

PJM Interconnection, L.L.C.	)	**Docket No. ER21-____-000**

VERIFICATION

Peter Cramton, being first duly sworn, deposes and states that he is the Peter Cramton referred to in the foregoing document entitled "Affidavit of Peter Cramton on Behalf of PJM Interconnection, L.L.C." that he has read the same and is familiar with the contents thereof, and that the facts set forth therein are true and correct to the best of his knowledge, information, and belief.

/s/ Peter Cramton

Peter Cramton
Professor of Economics
University of Cologne