The long-term impact of increased fossil fuel prices and market design on the market values of renewable generation

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Abstract

Following Russia's invasion of Ukraine in 2022, European countries took significant steps to reduce their reliance on energy imports from Russia, particularly in the gas and coal sectors. At the same time, to import less primary energy in the future, some countries have adopted new renewable energy targets. The question is to what extent the increase in gas and coal prices can contribute to refinancing renewable energy on the electricity wholesale market. To investigate this, an agent-based approach is used to examine the market values of renewable energies in several European countries until 2040. It is shown that increased expansion targets have a more substantial negative impact on the market values of renewable energies than increased gas and coal prices have a positive effect. In addition, it is observed that the introduction of capacity markets does not significantly influence market values and wholesale electricity prices in the medium term. However, by 2040, lower electricity prices and correspondingly reduced market values appear likely in the energy-only market.

Keywords*:* agent-based modeling, asset valuation, market value, renewable generation, energy crisis.

I. Introduction

The energy crisis in Europe in 2022 enormously impacted the short-term energy market [1]. It forced all European countries to take short-term actions to reduce the influence on households and the private sector energy prices (e.g. [2, 3]). Further measurements have been implemented to mitigate the mid and long-term effects of the trading sanctions against Russia. These include particularly multiple facilitation in approving renewable energy sources (RES) [4] and new RES expansion targets, e.g., [5–7]. These measures aim to reduce dependence on fossil energy imports from Russia as quickly as possible. Moreover, more liquefied natural gas (LNG) is being imported, and several new LNG terminals have been constructed or are being developed to replace Russian pipeline gas [8]. By importing LNG instead of Russian pipeline gas, the exchange price for natural gas in Europe will increase [9, 10]. EWI [10] also shows that the hard coal price will settle higher in the long term due to the sanctions.

It is widely investigated that the market values (see III.B) of fluctuating RES, such as wind and solar power, decline with increasing deployment [11–13]. It is also shown by Liebensteiner et al. [12] that higher carbon prices counteract this effect. The same can be assumed for higher fuel prices, as both affect the marginal costs of conventional power plants. This work addresses the question of how the changed fuel prices price and generation structure, resulting from the Russian invasion of Ukraine and the subsequent measures, will affect the market value of RES in the long term. It thereby also examines the research question whether market design and especially capacity markets impact the market value of RES.

Therefore, we provide a brief literature review in Section **Fehler! Verweisquelle konnte nicht gefunden werden.** and present the methodology of the agent-based approach and the data used in Section III, followed by the results (Section IV), which are then explained. In Section V we provide a summary, the conclusion of the findings, and possible improvements for further research.

II. LITERATURE REVIEW

With increasing RES penetration of the energy system, much research has been conducted regarding the cannibalization of RES. Hirth and Radebach [11] developed an analytical approach to determine the market value drop for wind and solar power in Germany. Within a given power plant portfolio, the value drops follow a linear equation, depending on the RES penetration in the power system and the variance of the RES production. In [14], Hirth used an optimization model to compare the effect of a hydropower-based system to a thermal power plant-based system. He showed that the more flexible Swedish hydropower-based system is beneficial for wind power. Another cost optimization model is described in [15]. Eising et al. analyzed the effect of the spatial distribution of wind power within Germany on the market values of wind and solar power. They showed that a high offshore quota supports the market values for both wind and solar power. In contrast, a more distributed onshore production has a negative impact compared to a production-optimized scenario. In contrast, Brown and Reichenberg see the promotion of RES through revenue subsidies as the main driver of the loss in the market value of RES. They showed that a CO_2 price also promotes RES but does not lead to a drastic market value reduction of RES [16]. This is in line with the findings in [12]. Bublitz and Keles have shown that the impact of fuel and CO_2 prices on the spot market price is twice as high as that of RES expansions for the period from 2011 to 2017 [17].

III. METHODOLOGY

A. PowerACE model

The agent-based electricity market model PowerACE is utilized to investigate this research questions. PowerACE represents various market participants and roles, such as generators, consumers and investors. To reduce complexity, the model exclusively approximates the different electricity market products through the spot market. Additionally, ancillary service markets are also included as revenue opportunities. The individual agents on the supply side act based on business considerations, taking into account technical and economic constraints. The market prices are determined based on the bids submitted by the generation agents. To account for cross-border trading, a welfare-optimizing market coupling algorithm is used for market clearing. Furthermore, the model can represent various market designs, such as energy-only markets (EOMs), strategic reserves, or capacity markets. A detailed description of PowerACE and the different approaches can be found in [18–22].

B. Market Values

The market value is a frequently used term in the energy industry, particularly in relation to RES. It indicates the average revenues that a specific technology or facility can achieve in the spot market. While for baseload power plants, the market value is equal to the average market price, for wind and solar power, these two values can differ significantly due to the simultaneity of production. The market value is typically specified for a specific technology and a specific period, such as a week or a month. In this study, the reference is based on a calendar year. The following formula is used to determine the market value:

$$MV = \frac{\sum_{h=1}^{j} p_h * E_h}{\sum_{h=1}^{j} E_h}$$

MV represents the market value in $€/\mathrm{MWh}$. p_h denotes the spot market price at hour h, and E_h represents the produced energy of the analyzed technology in that hour. j corresponds to the total umber of hours in examined period.

C. Used Data

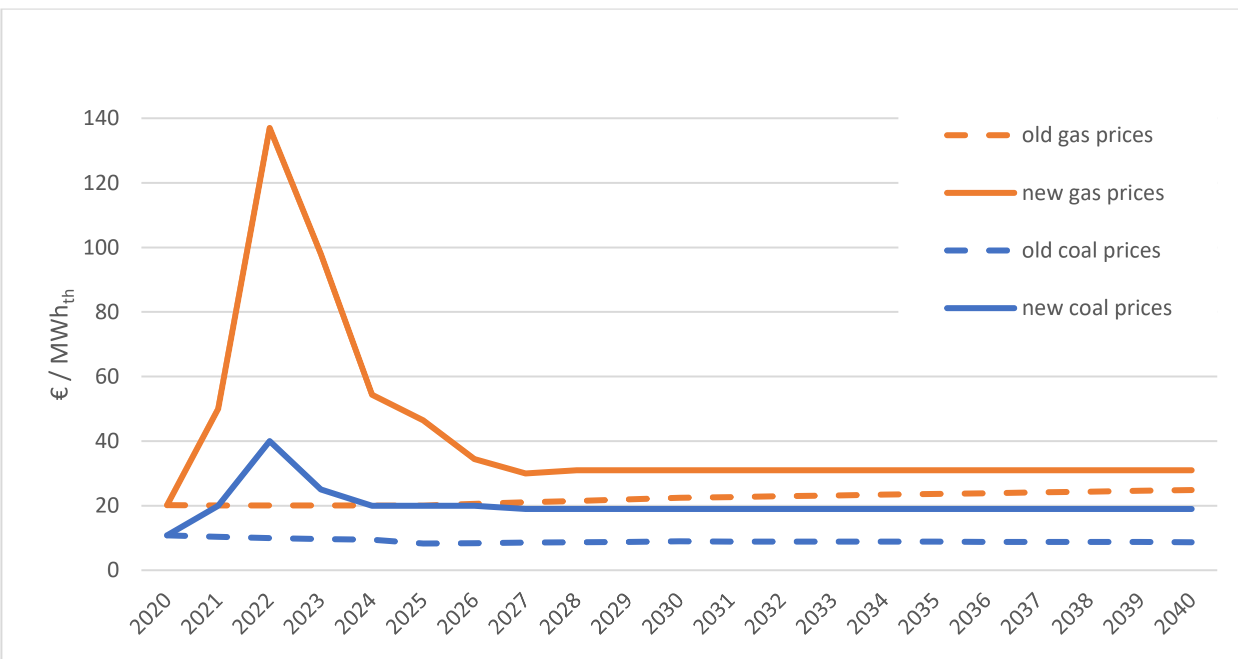

Figure 1: fuel price scenarios for gas and coal, nominal without inflation

The TYNDP 2022 National Trends scenario for the weather year 2008 was used as a reference scenario (referred to as “old” in the following) for consumption, RES deployment, and fuel prices [23, 24]. The National Trends scenarios represent the transformation path corresponding to the relevant legal framework for the report. The data from [25, 26] were used as the temporal profile for solar and wind generation. For the high-price scenario (referred to as “new” in the following), which reflects the price development following the Russian invasion of Ukraine, investigations by EWI were consulted for coal prices [10]. Gas prices were determined based on the EEX TTF Natural Gas Futures as of February 28, 2023 [9]. Since the oil price has only a minimal impact on wholesale electricity prices and is primarily influenced by the pricing policies of OPEC states, no adjustments were made in this regard. Lignite, still used primarily in Germany, the Czech Republic, and Poland, is not traded and, therefore, remains constant. Figure 1 illustrates the utilized price curves for gas and hard coal. Gas prices are projected to remain significantly higher until 2027. In the long term, the price differential amounts to approximately 6 €/MWh. As for hard coal, price stabilization is expected starting in 2024. These prices are approximately 10 €/MWh_{th} or about 110 % higher in the long term compared to the TYNDP reference-case. CO_2 prices are assumed to increase linearly and reach a cost of 350 €/tCO_2 by 2050. The modified RES expansion scenarios consider changes in the expansion targets of individual countries in 2022. In particular, Germany [5], Denmark [6], and the Netherlands [7] significantly increased their expansion targets in light of the energy crisis. Figure 2 depicts the modified RES installation targets for these countries in 2022. For the analysis of market designs, the EOM assumes that, apart from pure electricity market revenues, such as spot market and ancillary services, there are no investment incentives. In contrast, capacity markets (CRM) involve additional payments to finance the construction of new power plants. In Germany and Belgium, a strategic reserve removes existing power plants from the market and reserves them exclusively for periods of scarcity.

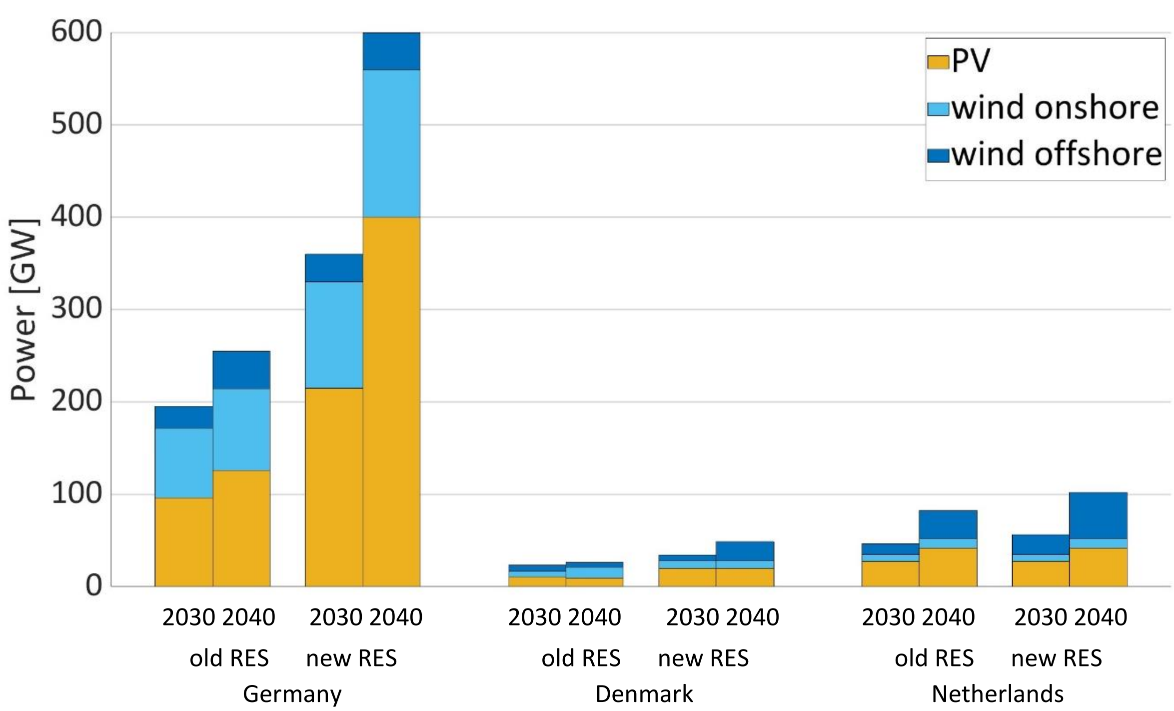

Figure 2: Comparison of RES Scenarios

The presented data was used to create the following eight scenarios:

Table 1: Scenario overview

EOM-OP-OR	Energy-only-market with old prices and old RES scenario
EOM-OP-NW	Energy-only-market with old prices and new RES scenario
EOM-NP-OR	Energy-only-market with new prices and old RES scenario
EOM-NP-NR	Energy-only-market with new prices and new RES scenario
CRM-OP-OR	Capacity remuneration mechanism with old prices and old RES scenario
CRM-OP-NW	Capacity remuneration mechanism with old prices and new RES scenario
CRM-NP-OR	Capacity remuneration mechanism with new prices and old RES scenario
CRM-NP-NR	Capacity remuneration mechanism with new prices and new RES scenario

IV. RESULTS

To compare the influence of different factors, such as RES scenarios, price scenarios, and market design, the differences in spot market prices and annual market values for 2030 and 2040 are examined. By 2030, the increased RES expansion targets already demonstrate a significant price-reducing effect in the spot market, as well as on the market values of wind and solar power. Conversely, scenarios with higher fuel prices clearly indicate higher prices and market values. However, the introduction of capacity markets does not exhibit a clear effect across scenarios and seems to play a subordinate role overall in 2030. Figure 3 provides an exemplary illustration for the year 2040, demonstrating a significant decrease in spot market prices in scenarios with the new expansion targets. This can be attributed to a substantially higher number of hours in which RES generation is sufficient to meet the total electricity demand. For the German market area, the simulation indicates that under the new expansion targets, approximately 3500 hours in 2040 have sufficient RES generation to cover the demand, resulting in the curtailment of RES generation and spot market prices of 0 €/MWh.

In contrast, this occurs in slightly over 200 hours under the old expansion targets. Simultaneously, the number of hours in which the demand is not met overall decreases, leading to a reduction in hours with very high prices (up to 3000 €/MWh). Additionally, from Figure 4, it can be observed that the market design has only a relatively minor impact on the market values of RES. Nevertheless, it is evident that in the long term, a lower average spot market price and lower market value for solar power emerges under the EOM. For wind power, a similar pattern is generally observed with higher market values emerging in the EOM for lower RES expansion scenarios, particularly in Belgium and France. The differences between EOM and capacity markets are primarily due to variations in power plant portfolios. Capacity markets incentivize investments in firm capacity, such as new gas power plants, which have high marginal costs to due higher fuel prices and CO_2 prices. In contrast, the EOM observes a significantly higher expansion of nuclear power plants. The lower marginal costs of nuclear power plants result in a rightward shift of the merit order, leading to lower market prices during periods of high RES generation. Both diagrams show some outliers, particularly in the Polish market area, which, due to its high number of thermal power plants and relatively low RES expansion, combined with rising CO2 prices, is expected to have very high market prices.

In both market designs, gas power plants become price-setting units during periods of low-RES generation. Over time, it becomes apparent that in the mid-2020s, due to the coal and nuclear phase-out in several countries, the capacities in the EOM experience a significant decline, which do not seem to be adequately offset through market mechanisms alone. Consequently, there is a notable increase in the number of hours with unmet demand. However, the resulting rise in electricity market revenues incentivizes more investments in the EOM. Nevertheless, until the end of the 2030s, the advantages of capacity markets are clear. Regardless of other parameters, capacity markets are rather able to meet the demand. A milder scarcity in the EOM during the mid-2030s triggers further substantial investments, enabling the EOM to fulfil the demand more effectively by the end of the 2030s (see Figure 5 and Figure 6).

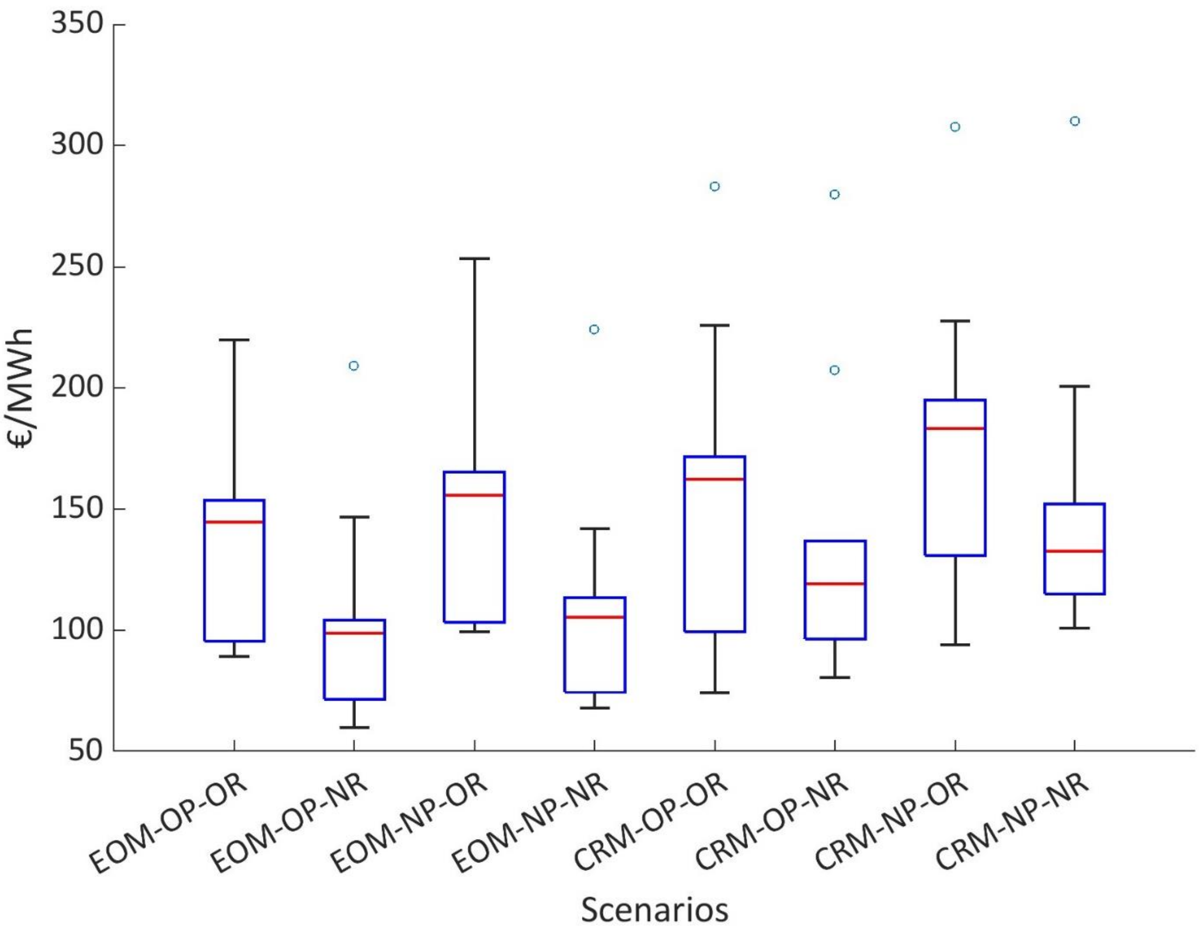

Figure 3: Average spot market prices in 2040, nominal without inflation

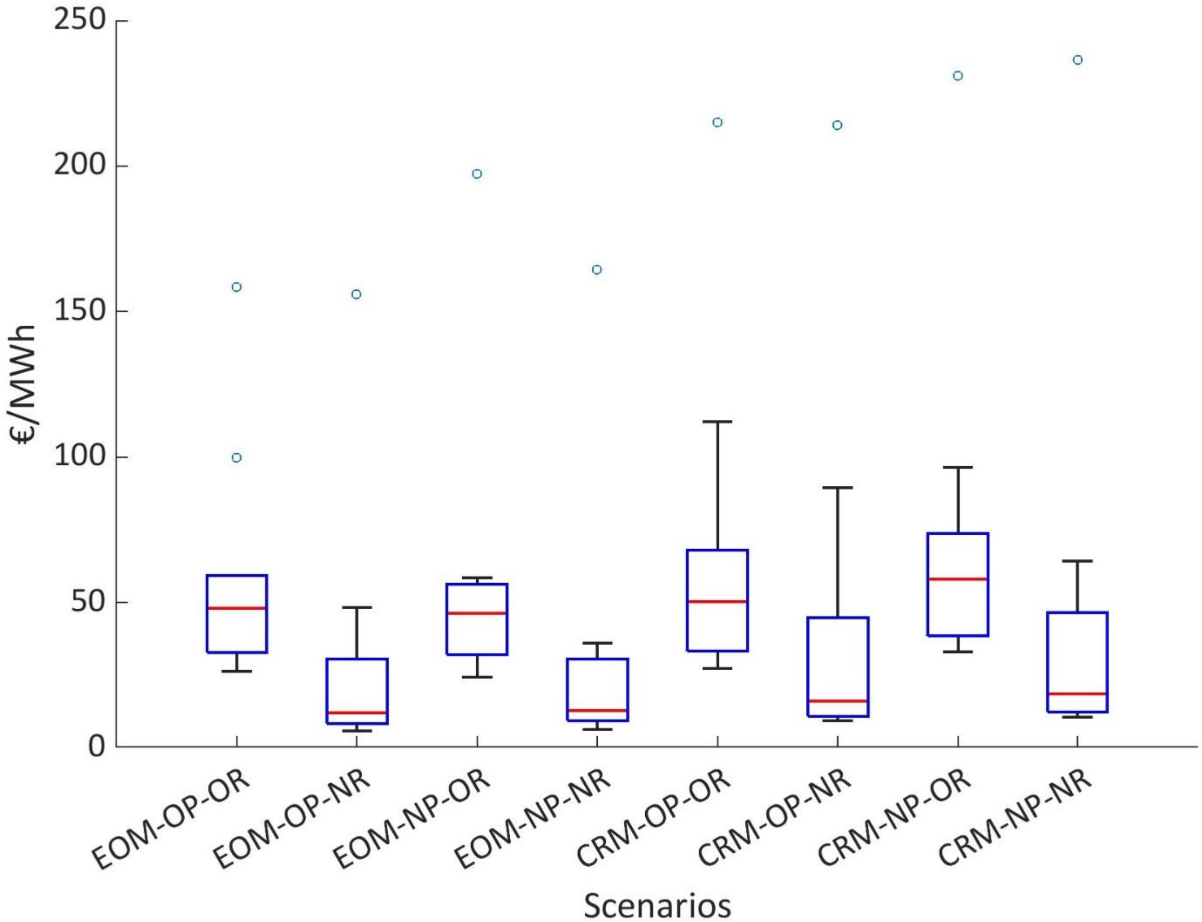

Figure 4: Market values solar power per MWh in 2040, nominal without inflation

V. SUMMARY AND CONCLUSIONS

This study examined the effects of expected long-term increase in fuel prices considering various RES expansion targets, taking into account two different market designs. The results indicate that higher fuel prices also lead to higher spot market prices in the long term.

At the same time, higher electricity prices incentivize investments in more flexible power plant capacities, resulting in a decrease in the LOLE values. The higher spot market prices also lead to an increase in the market values of RES, potentially stimulating more investments in RES in a market environment. From the late 2030s onwards, capacity markets will result in a more flexible power plant portfolio. However, the increased marginal costs associated with this flexibility have a negative impact on electricity prices. Nevertheless, as the revenues of RES also increase in the long term, capacity markets have a positive effect on the market in the context of the energy transition: Higher revenues potential incentivize more investments in RES, thus contributing to the advancement of RES technologies. However, given the current prices for solar and wind power plants, it is questionable whether the expected market values alone are sufficient to incentivize investments without further support for RES. In 2023, the feed-in tariffs for new wind and solar power projects in Germany are still several times higher than the expected market values in 2040 [27, 28].

It is important to note that the RES expansion was assumed according to the scenarios' specifications and does not account for market-based investment decisions. Considering this effects would provide a more comprehensive understanding of the dynamics and uncertainties associated with RES integration in the electricity market.

VI. ACKNOLAGEMENT

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References

[1] Directorate-General for Energy, unit A4, Market Observatory for Energy, “Quarterly report On European electricity markets,” vol. 15, no. 3. [Online]. Available: https://energy.ec.europa.eu/system/files/2023-01/Quarterly%20Report%20on%20European%20Electricity%20markets%20Q3%202022.pdf

[2] *COUNCIL REGULATION (EU) 2022/1854 of 6 October 2022 on an emergency intervention to address high energy prices: REGULATION (EU) 2022/1854*, 2022.

[3] *Real Decreto-ley 10/2022, de 13 de mayo, por el que se establece con carácter temporal un mecanismo de ajuste de costes de producción para la reducción del precio de la electricidad en el mercado mayorista: Real Decreto-ley 10/2022*.

[4] *COUNCIL REGULATION (EU) 2022/2577 of 22 December 2022 laying down a framework to accelerate the deployment of renewable energy: Regulation EU 2022/2577*, 2022. Accessed: Mar. 6 2023. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2022:335:TOC

[5] *Gesetz für den Ausbau erneuerbarer Energien: EEG 2023.* [Online]. Available: https://www.gesetze-im-internet.de/eeg_2014/

[6] Socialdemokratiet (Regeringen) *et al.,* “Klimaaftale om grøn strøm og varme 2022: Et grønnere og sikrere Danmark,” Danmark kan mere II, Jun. 2022. Accessed: May 23 2023. [Online]. Available: https://www.regeringen.dk/media/11470/klimaaftale-om-groen-stroem-og-varme.pdf

[7] R. A. A. Jetten, *Letter to Parliament on offshore wind energy 2030-2050.* [Online]. Available: https://english.rvo.nl/information/offshore-wind-energy/offshore-wind-energy-plans-2030-2050#:~:text=In%202022%2C%20the%20Government%20raised,of%20our%20current%20electricity%20consumption. (accessed: May 23 2023).

[8] Council of the EU and the European Council, *Liquefied natural gas infrastructure in the EU.* [Online]. Available: https://www.consilium.europa.eu/en/infographics/lng-infrastructure-in-the-eu/ (accessed: Mar. 7 2023).

[9] Intercontinental Exchange, Inc., *Dutch TTF Natural Gas Futures | ICE.* [Online]. Available: https://www.theice.com/products/27996665/Dutch-TTF-Gas-Futures/data?marketId=5519350 (accessed: Mar. 7 2023).

[10] Energiewirtschaftliches Institut an der Universität zu Köln (EWI), “Szenarien für die Preisentwicklung von Energieträgern,” 2022. Accessed: Mar. 7 2023. [Online]. Available: https://www.ewi.uni-koeln.de/cms/wp-content/uploads/2022/07/EWI-Studie_Preisentwicklung-von-Energietraegern_220714.pdf

[11] L. Hirth and A. Radebach, “The Market Value of Wind and Solar Power: An Analytical Approach,” *SSRN Journal*, 2016, doi: 10.2139/ssrn.2724826.

[12] M. Liebensteiner and F. Naumann, “Can carbon pricing counteract renewable energies’ cannibalization problem?,” *Energy Economics*, vol. 115, p. 106345, 2022, doi: 10.1016/j.eneco.2022.106345.

[13] J. López Prol and W.-P. Schill, “The Economics of Variable Renewable Energy and Electricity Storage,” *Annual Review of Resource Economics*, vol. 13, no. 1, pp. 443–467, 2021, doi: 10.1146/annurev-resource-101620-081246.

[14] L. Hirth, “The market value of wind energy - thermal versus hydro power systems,” Energiforsk AB, 2016. Accessed: Mar. 9 2023. [Online]. Available: https://energiforskmedia.blob.core.windows.net/media/19690/the-market-value-of-wind-energy-energiforskrapport-2016-276.pdf
[15] M. Eising, H. Hobbie, and D. Möst, “Future wind and solar power market values in Germany — Evidence of spatial and technological dependencies?,” *Energy Economics*, vol. 86, p. 104638, 2020, doi: 10.1016/j.eneco.2019.104638.
[16] T. Brown and L. Reichenberg, “Decreasing market value of variable renewables can be avoided by policy action,” *Energy Economics*, vol. 100, p. 105354, 2021, doi: 10.1016/j.eneco.2021.105354.
[17] A. Bublitz, D. Keles, and W. Fichtner, “An analysis of the decline of electricity spot prices in Europe: Who is to blame?,” *Energy Policy*, vol. 107, pp. 323–336, 2017, doi: 10.1016/j.enpol.2017.04.034.
[18] F. Zimmermann, E. Kraft, and W. Fichtner, “Modeling the Dispatch of Electrolyzers Using Agent-based Electricity Market Simulation,” in *2022 18th International Conference on the European Energy Market (EEM)*, 2022, pp. 1–10.
[19] F. Zimmermann and D. Keles, “State or market: Investments in new nuclear power plants in France and their domestic and cross-border effects,” *Energy Policy*, vol. 173, p. 113403, 2023, doi: 10.1016/j.enpol.2022.113403.
[20] C. Fraunholz, “Market Design for the Transition to Renewable Electricity Systems,” Karlsruher Institut für Technologie (KIT), 2021.
[21] A. Bublitz, D. Keles, F. Zimmermann, C. Fraunholz, and W. Fichtner, “A survey on electricity market design: Insights from theory and real-world implementations of capacity remuneration mechanisms,” *Energy Economics*, vol. 80, pp. 1059–1078, 2019, doi: 10.1016/j.eneco.2019.01.030.
[22] F. Zimmermann, A. Bublitz, D. Keles, and W. Fichtner, “Cross-border Effects of Capacity Remuneration Mechanisms: The Swiss Case,” *EJ*, vol. 42, no. 2, 2021, doi: 10.5547/01956574.42.2.fzim.
[23] European Network of Transmission System Operators for Gas and European Network of Transmission System Operators for Electricity, *Electricity modelling results.* [Online]. Available: https://2022.entsos-tyndp-scenarios.eu/wp-content/uploads/2022/04/220310_Updated_Electricity_Modelling_Results.xlsx (accessed: May 22 2023).
[24] European Network of Transmission System Operators for Gas and European Network of Transmission System Operators for Electricity, Eds., “TYNDP 2022 Scenario Report,” Apr. 2022. Accessed: May 22 2023. [Online]. Available: https://2022.entsos-tyndp-scenarios.eu/wp-content/uploads/2022/04/TYNDP2022_Joint_Scenario_Full-Report-April-2022.pdf
[25] S. Pfenninger and I. Staffell, “Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data,” *Energy*, vol. 114, pp. 1251–1265, 2016, doi: 10.1016/j.energy.2016.08.060.
[26] I. Staffell and S. Pfenninger, “Using bias-corrected reanalysis to simulate current and future wind power output,” *Energy*, vol. 114, pp. 1224–1239, 2016, doi: 10.1016/j.energy.2016.08.068.

[27] Bundesnetzagentur, *Beendete Ausschreibungen.* [Online]. Available: https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Ausschreibungen/Wind_Onshore/BeendeteAusschreibungen/start.html (accessed: Jun. 26 2023).
[28] Bundesnetzagentur, *Beendete Ausschreibungen.* [Online]. Available: https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Ausschreibungen/Solaranlagen1/BeendeteAusschreibungen/start.html (accessed: Jun. 26 2023).

VII. APPENDIX

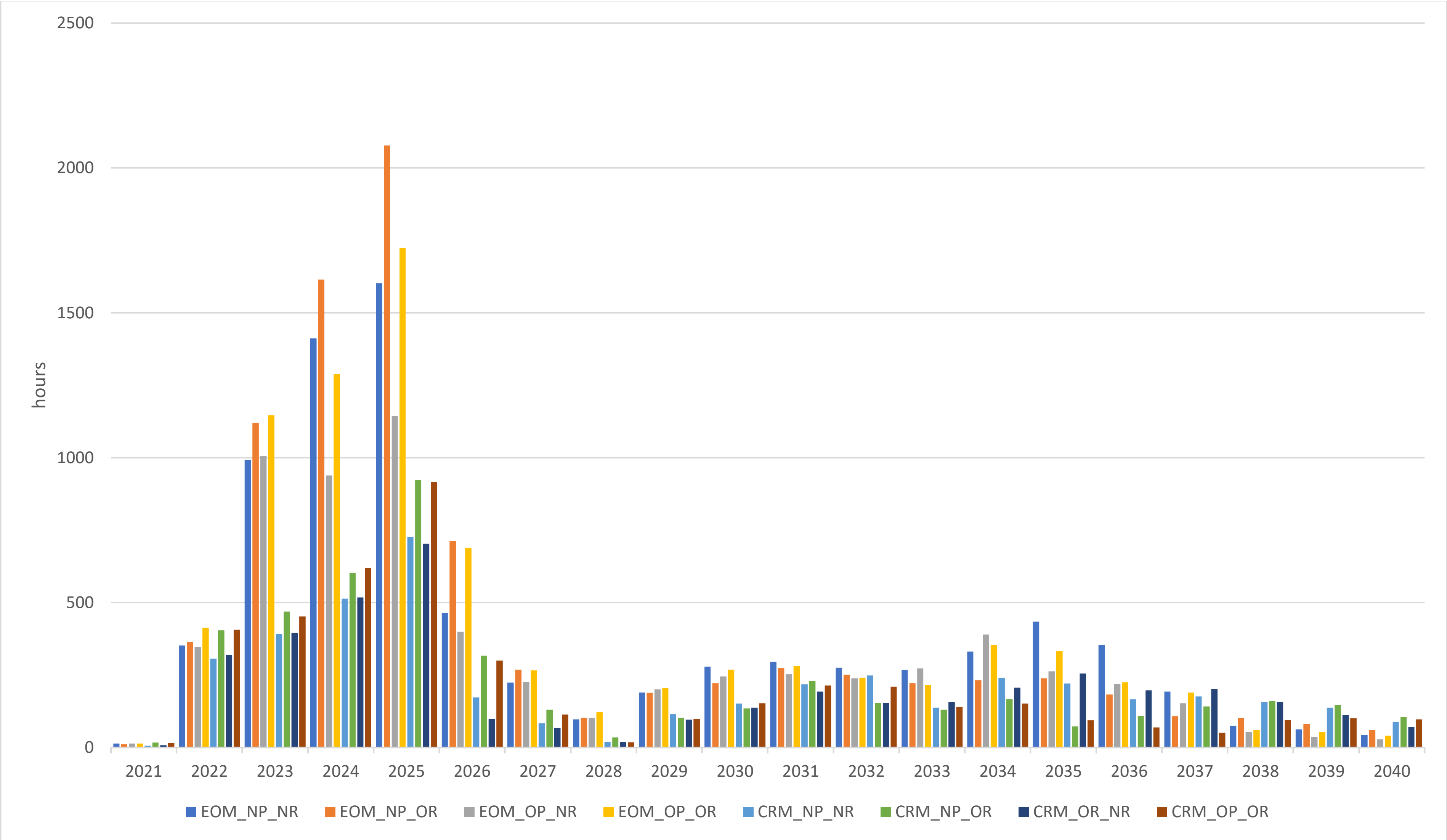

Figure 5: Loss of load expectation per year

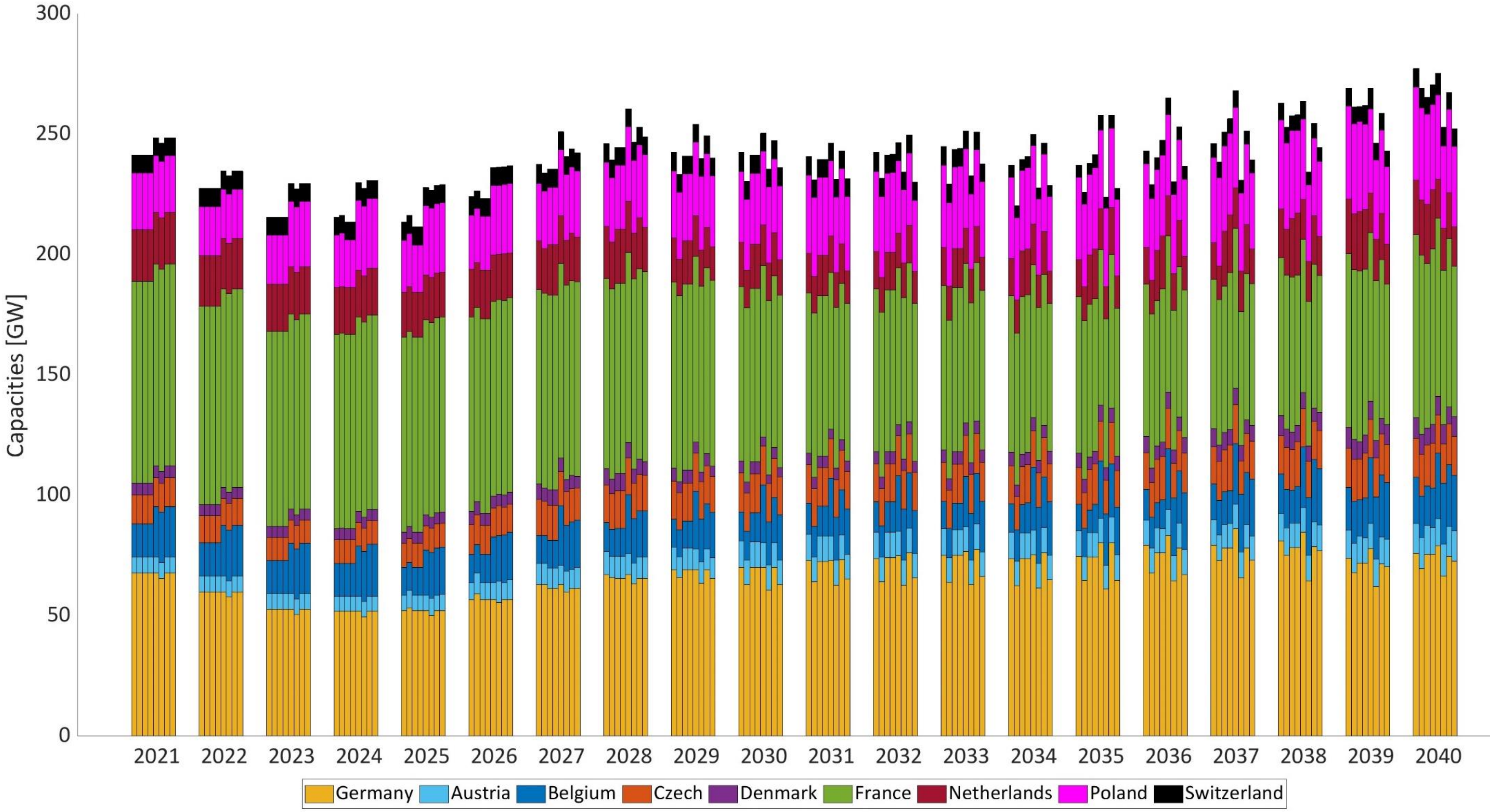

Figure 6: Firm capacities per market area for the different scenarios and years. Scenarios from left to right: EOM_OP_OR, EOM_OP_NR, EOM_NP_OR, EOM_NP_NR, CRM_OP_OR, CRM_OP_NR, CRM_NP_OR, CRM_NP_NR