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## Preprint

# EU carbon prices signal high policy credibility and farsighted actors

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# EU carbon prices signal high policy credibility and farsighted actors

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## 8

## 9

## 10 Abstract

Carbon prices in the EU emissions trading system (EU ETS) are a key instrument driving 11 Europe's decarbonization. Between 2017 and 2021, they surged tenfold, exceeding 80€/tCO<sub>2</sub> 12 and reshaping investment decisions across the electricity and industry sectors. What has driven 13 this increase is an open question. While it coincided with two significant reforms tightening 14 15 the cap ("MSR reform" and "Fit for 55"), we argue that a reduced supply of allowances alone cannot fully explain the price rise. A further crucial aspect is that actors must have become 16 more farsighted as the reform signaled policymakers' credible long-term commitment to 17 18 climate targets. This is consistent with model results that show historic prices can be better explained with myopic actors, while explaining prices after the reforms requires actors to be 19 farsighted. To underline the role of credibility, we test what would happen if a crisis 20 21 undermines policy credibility such that actors become myopic again, demonstrating that carbon prices could plummet and endanger the energy transition. 22

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# 24 Introduction

The EU emissions trading system (EU ETS) is a central pillar of the European Union's 25 decarbonization strategy. It covers the electricity sector, large-scale industrial installations, 26 aviation, and maritime transport, and hence controls above 40% of the EU's total greenhouse 27 gas emissions<sup>1</sup>. Over a period with two major reforms of the ETS and notably a substantial 28 tightening of the cap, the carbon market underwent a remarkable transition: Carbon prices 29 increased tenfold within 4 years, with a first rise in 2018 from below  $10 \notin tCO_2^{-1}$  to a plateau at 30 20-30 €/tCO<sub>2</sub> in 2019-2020, and then a second, even sharper rise, during which prices 31 repeatedly reached almost 100€/tCO<sub>2</sub> in 2021 and 2022<sup>2</sup>. The question of why prices have 32 risen so steeply is still unanswered though, and a subject of debate among the scientific and 33 policy community. 34

<sup>&</sup>lt;sup>1</sup> All carbon prices throughout the paper are nominal prices until 2023, adjusted for inflation using OECD inflation rates for  $EU27^{71}$ . Computed prices after 2023 are in real  $EUR_{2023}$ .

The literature so far identifies various factors as playing a potential role in carbon price developments in general: (1) regulatory changes (such as the introduction of the Market Stability Reserve (MSR), or changes in the linear reduction factor)<sup>3–6</sup>, (2) actors' behavior (foresight horizon, hedging, or participation in trade)<sup>7–10</sup>, and (3) speculation and external financial investors<sup>11–14</sup>. However, most work focuses on one of those aspects, provides only qualitative assessments, and covers only the period before the recent reforms and price increases.

42 With a view on understanding what has driven prices in the recent period, the following puzzle arises. It is economically straightforward that a tightening of the long-term cap should increase 43 current and expected prices. However, past research suggests that market participants in the 44 ETS are myopic<sup>10,15</sup>. While myopia can always have an impact on energy sector investments, 45 it is especially relevant when the power sector is covered by an intertemporal emissions trading 46 system with a cap that strongly tightens over time, so that future certificate scarcities can 47 influence current investments. If most market actors were myopic, a long-term tightening of 48 the cap should thus only have modest effects on current prices, much lower than the observed 49 increase after the reforms. 50

In light of that, we hypothesize that the reform could have had another important effect on actors: making them more farsighted. The reason is that through the reform EU policymakers substantially firmed up the credibility of their commitment to the ETS overall. They did this both explicitly, by emphasizing that the "ETS is front and centre to all our efforts"<sup>16</sup>, and implicitly, by investing a lot of political capital in the political negotiation. More broadly, a recent empirical study also shows that the EU has currently the world's highest climate policy credibility<sup>17</sup>.

Such instilled credible commitment is essential to shape firms' expectations about the durability of long-term policies such as the  $ETS^{18}$ , and indeed studies suggest that low policy credibility can be associated with decreased "green" investments<sup>19</sup>, and that policy credibility can enhance actors' farsightedness<sup>20</sup>. The main reason is that low credibility creates high regulatory uncertainty regarding a future softening of the cap or interventions to dampen high carbon prices – a major reason for myopia. Correspondingly, increasing credibility implies that actors become more farsighted.

To the best of our knowledge, no study has yet assessed whether myopia remains a prevalent influence within the current EU ETS. Equally, there has been no investigation into whether any shifts in the foresight horizon have occurred and their potential impact on the recent surge in

68 carbon prices.

In this work, we provide a model-based analysis of the EU ETS with a specific emphasis on 69 the influence of actors' foresight horizon. The contribution of our work is threefold. We first 70 analyze the past: bringing together the impact of political reforms, the foresight of compliance 71 actors, and the role of external investors, we show which mix of those mechanisms could 72 explain the observed strong rise in carbon prices. We discuss the present: by computing 73 marginal carbon prices necessary to drive the decarbonization of the electricity and industry 74 sectors in line with the new EU's 2030 goals as set in the "Fit for 55" package, we assess 75 whether current ETS prices correspond to the optimal market-efficient carbon price trajectory. 76 77 We turn to the future: having understood the mechanisms that could plausibly have led to the 78 observed increase in carbon prices, we explore in how far this positive development is

vulnerable and potentially could be reversed. We close with policy recommendations on howto secure the energy transition in light of our results.

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# 82 From past to present

83 When analyzing past carbon prices (*see Fig. 1*), one can broadly break down the timeline into 84 three periods with distinct price regimes: (i) the period of 2008 - 2017, in which prices first 85 dropped and then stabilized at a low level below  $10 \notin/tCO_2$ , (ii) the period of 2018 - 2020, "the 86 first rise" up to a plateau of  $20-30 \notin/tCO_2$ , and (iii) the period since late 2020, "the second rise", 87 in which prices increased strongly, and are now stabilizing around  $70-90 \notin/tCO_2$ . What might 88 have been the main mechanisms driving these three regimes, and, in particular, what role could 89 actors' foresight have played?





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Regarding the first period (i), the common understanding is that prices dropped because of a
 high surplus of allowances that accumulated since 2008. The financial crisis reduced emissions
 more than anticipated, leaving compliance actors with a high number of unused allowances,
 hence limiting incentives to decarbonize<sup>23</sup>.

Different publications furthermore suggest that the limited foresight of compliance actors contributed to low carbon prices<sup>5,8–10,24</sup>. To understand the role of foresight, one needs to consider that the EU ETS allows for almost unlimited forward bankability: any certificate not used today can be used in the future. Hence, expected future prices may have a strong influence on today's prices. In contrast, in a market without bankability, a surplus of certificates over emissions would mean the certificate price in that year is zero, as the unused certificates

113 become worthless at the end of the year.

114 Now, many firms might not consider the long-term future (inherently, or due to regulatory 115 uncertainty and lack of policy credibility) but rely on short-term planning horizons of e.g., 5-116 10 years<sup>25</sup>. If allowances scarcity occurs outside their planning horizon, they will not anticipate 117 it and hence don't have incentives to bank certificates for the future nor decrease emissions in 118 the short-term. Consequently, the carbon price will stay lower and decarbonization will be 119 slower than if actors were farsighted (*see Fig. 2*).



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**Fig. 2| Stylized emissions and carbon price trajectory with short-term (myopic) and long-term (perfect) foresight.** Simple cap and trade system without the Market Stability Reserve, for illustrative purposes. **a**, Example of a planning horizon at the beginning of the transformation. With a myopic foresight of 10 years, there is no (or very weak) incentive to reduce planned emissions. With a perfect foresight, future scarcity is anticipated and planned emissions get reduced already in the near-term. **b**, Cumulative emissions over the whole transformation period. Myopic foresight leads to delayed decarbonization. **c**, Carbon prices over the whole transformation period. Myopic foresight leads to very low carbon prices in the near-term. Short lines correspond to the specific horizons: every 5 years a new foresight horizon of 10 years starts.

- 122 Thus, for many years the EU ETS failed in establishing a carbon price that would drive deep
- 123 decarbonization. In period (i) actors presumably acted myopically, a behavior leading to low
- 124 carbon prices. However, just a few years later, EU ETS prices are stronger than ever<sup>2</sup>. What
- happened since 2017? Which mechanisms drove the rise in carbon prices observed in periods
- 126 (ii) and (iii)? A plausible explanation would be that prices simply increased because reforms
- tightened the  $cap^{26}$ . Here we present a more comprehensive explanation: the reforms had the
- 128 "side-effect" that market actors also became less myopic, which drove prices up. Therefore,

- we first give an overview of the most relevant reforms from the past years and then present ourmodeling results.
- 131 The past years were marked by numerous reforms and rapid EU climate policy developments<sup>27–</sup>

<sup>34</sup>. While it is challenging to pinpoint one specific regulation with the highest impact on carbon

- prices, we can, generally, speak about an intensive period in climate policy since 2015 with
- 134 two crucial ETS reform periods: the "MSR reform" and the "Fit for 55" package, as
- summarized in Table 1.
- 136

## 137 Table 1 | 2015-2022: An intensive period in climate policy. Developments and reforms relevant for the

**EU ETS.** General climate policy milestones highlighted in gray, legal ETS milestones highlighted in blue.

Date	Event	Impact on climate policy / the EU ETS	
Dec. 2015	Adoption of the Paris Agreement <sup>27</sup>	Global climate policy: "Goal to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels".	
Oct. 2015	Decision on the establishment of an MSR <sup>28</sup>	<b>EU ETS design</b> : New mechanism with pre-defined rules addressing the high surplus of allowances. Depending on the total number of allowances in circulation (TNAC), allowances get placed in the reserve or released from the reserve. However, as all certificates are to be released in the long term, this reform implies NO tightening of the intertemporal emission cap and thus had little impact on market prices.	
Oct. 2016	Ratification of the Paris Agreement <sup>29</sup>	EU climate policy: All parties (including the EU) having adopted the Paris Agreement are required to submit an NDC till 2020, outlining their post-2020 climate actions.	
Feb. 2017	"MSR reform" Proposal of ETS/MSR reform for trading period IV (2021-2030) - strengthening the MSR and tightening ETS targets <sup>30</sup>	<b>EU ETS design</b> : Parliament and Council formulate their ETS/MSR reform proposals. Council proposes automatic cancellation of certificates in the MSR above a threshold.	
Nov. 2017	"MSR reform" Final agreement on ETS/MSR reform for trading period IV (2021- 2030) <sup>31-33</sup>	<b>EU ETS design:</b> After six trilogues, Commission, Parliament and Council reach an agreement on the ETS/MSR reform. Tightening of the cap: Linear Reduction Factor of allowances (in percentage points of 2005 cap) increases from 1.74 to 2.2. Strengthening of the MSR: higher intake and certificate cancellations from 2024 on.	
March 2018	<b>"MSR reform"</b> ETS/MSR reform for trading period IV (2021- 2030) officially adopted <sup>34</sup>	<b>EU ETS design:</b> Directive with the ETS/MSR reform officially published.	
Dec. 2019	Presentation of the European Green Deal <sup>35</sup>	EU climate policy: EU Commission presents EU's new climate action strategy including the goal of climate neutrality in 2050 and an emissions reduction of 50-55% till 2030, compared to 1990 levels.	
March 2020	Proposal for a European Climate Law <sup>36</sup>	EU climate policy: EU Commission presents legislative proposal of a law setting the objective for the EU to become climate neutral by 2050.	

Sept. 2020	Proposal to set an EU- wide 55% emissions reduction target for 2030 <sup>37</sup>	EU climate policy: EU Commission amends the Climate Law proposal by introducing the updated 2030 climate target of a net reduction of at least 55% of EU's greenhouse gas (GHG) emissions compared to 1990 levels.	
Dec. 2020	The Council agrees on the 55% reduction target for 2030 <sup>38</sup>	EU climate policy: The Council of the EU reaches an agreement on an approach on the climate law proposal, including an agreement to the updated 2030 climate target of a net reduction of at least 55% of EU's greenhouse gas (GHG) emissions compared to 1990 levels.	
April 2021	Final agreement on Climate Law <sup>39</sup>	EU climate policy: Parliament, Council and Commission agree in trilogue negatiations on the -55% 2030 reduction target, enabling the formal adoption of the Climate Law in June 2021.	
July 2021	"Fit for 55" package <sup>40,41</sup>	<b>EU ETS design:</b> EU Commission publishes package of legislative proposals to meet the 2030 emissions reduction target of 55%. For the EU ETS it includes: steeper annual emission reductions, strengthening of the MSR, gradual removal of free allowances for the aviation sector, and the inclusion of the maritime sector into the current EU ETS.	
Dec. 2022	Agreement on EU ETS " <b>Fit for 55</b> " proposal <sup>42</sup>	<b>EU ETS design:</b> Parliament, Council and Commission reach final agreement during trilogue negotiations on the EU ETS "Fit for 55" proposal. Ambitions are kept high: all main elements from the initial proposal remain; the emissions cap gets slightly more tightened compared to the initial proposal.	

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Our modeling findings are divided into two segments. We first present results supporting our hypothesis that actors have extended their foresight, which strongly impacted historical carbon prices. Hereafter, we turn to the role of external financial investors, who have been gaining attention throughout literature and media<sup>12–14,43–45</sup>, to delimit their possible impact on the carbon price surge.

Fig. 3 shows our modeling results on the impact of reforms and actors' foresight on carbon 145 prices. First of all, one can see between period (i) and period (ii), when the MSR reform was 146 negotiated and implemented, actors presumably started to look further into the future. When 147 turning to period (i) before 2018, one notices that observed ETS prices are closer to the modeled 148 prices for myopic actors than to the modeled prices for farsighted actors. It seems therefore 149 plausible to assume that market actors behaved at least partially myopically, which is in line 150 with earlier assessments<sup>9,10</sup>. For periods (ii) and (iii), one observes the opposite: Both, the 2019-151 2020 observed ETS prices of 20-30 €/tCO<sub>2</sub>, and the 2021-2022 ones of 70-90 €/tCO<sub>2</sub>, are 152 consistent with the modeled prices for farsighted actors (i.e., perfect foresight trajectories for 153 old "MSR reform" targets, and new "Fit for 55" targets, respectively). We also calculate the 154 155 Mean Average Percentage Error (MAPE) between the modeled and historical prices (see 156 *Extended Data Table 1*), which confirms the visual conclusions drawn from Fig. 3.

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**Fig. 3** Impact of reforms and actors' foresight on carbon prices. Historical carbon prices on the EU ETS, and modeled carbon price trajectories with the assumption of either perfect or myopic foresight, over the three periods (i)-(iii) as defined in Fig. 1. For each period, we show the carbon price trajectories required to reach the target that was valid during that period. Thus, jumps in same-coloured trajectories between one period and the next show the effect that the change in the ETS targets and MSR parameters has under unchanged actor foresight. Myopic foresight corresponds to a rolling foresight horizon of 10 years (*see Methodology* for underlying model assumptions). Historical prices are historical allowances (EUA) prices on the EEX spot market<sup>1,18</sup>. The mean average percentage error between modeled and historical prices is available in Extended Data Table 1. The interaction between the foresight horizon and the MSR is shown in Extended Data Figure 1. Prices are nominal until 2023 and real EUR2023 from 2023 on (*see Methodology "Carbon prices"*).

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Hence, regarding the "first rise" at the beginning of period (ii), a hypothesis following our results is that prices increased due to a gradual switch from actors' short- to long-term foresight, which might have been triggered, among other things, by the MSR reform tightening the cap and strengthening the MSR. While our results indicate that the direct effect of the reform – the tighter emissions budget – cannot explain the substantial increase in prices under the assumption of continued myopia, the reform might have had a strong indirect impact: the negotiations and ultimate implementation of the reform over 2017 and 2018 (*see Table 1*) emphasized the will of EU policymakers to "repair" the ETS (showing "the doctor has not given up on the patient"<sup>46</sup>), which strongly increased its long-term credibility, inspiring market actors to show longer foresight. These findings align with previous assessments, which, on the one hand, demonstrate that the MSR can lead to increased carbon prices<sup>47,48</sup>, while, on the other hand, argue that the effect of the MSR reform on the emission budget alone is unlikely to fully explain the surge in carbon prices<sup>8,11</sup>.

Secondly, Fig. 3 shows that the "Fit for 55" package sharply increases the stringency of the EU 194 ETS. Optimal carbon prices (i.e., obtained under the assumption of perfect foresight) to reach 195 the new targets are significantly higher than those that were necessary for achieving previous 196 goals. In fact, modeled prices for the "Fit for 55" targets for 2020-2023 are in the order of 70-197 90€/tCO<sub>2</sub>, corresponding well to observed 2021-2023 prices on the EU ETS, thus supporting 198 the hypothesis that actors have transitioned towards a more farsighted perspective. To the best 199 of our knowledge, no other studies have yet assessed whether ETS actors currently show 200 farsighted or myopic behavior. 201

Fig. 4 discusses the final point of this section: could an influx of long-term investors explain the strong rise of carbon prices if other actors had remained myopic?





**Fig. 4**| **Impact of external financial investors on carbon prices.** Carbon price trajectories assuming perfect foresight, myopic foresight, and myopic foresight with external investors buying 5% or 20% of yearly auctioned allowances and reselling them once carbon prices reach the theoretical value from the perfect foresight path. If external investors had started buying 5% or 20% of auctioned allowances from 2018 onwards, they would own, respectively, around 10% or 40% of today's (as of 2022) total number of allowances in circulation. All trajectories correspond to newest targets from the "Fit for 55" proposal with an active MSR. Exact assumptions on the number and timing of allowances bought and sold by external investors is available in Extended Data Fig. 2.

- Here, we assume external investors temporarily "block" a part of the allowances on the market,
- which then cannot be used by compliance actors to cover their emissions during the period (*see*
- 216 *Methodology*). This influences the price trajectory: when external investors buy, prices go up,
- 217 when they sell, prices can go down.

In reality, it is estimated that external investors currently hold only around 5-10% of allowances futures<sup>13</sup>, consistent with the scenario in which 5% of auctioned allowances are bought by external financial investors. This scenario shows only a small price increase of less than  $10 \notin /tCO_2$  in 2025 compared to the pure myopic scenario (*Fig. 4*). Thus, following our results, a major contribution of external investors to the price rise seems unlikely. What is on the other hand possible, is that they acted as a "catalyzer", speeding up the process of compliance actors switching to longer foresight and anticipating the consequences of the "Fit for 55" package.

225 To summarize, we provide a possible explanation of the past: we show that the two price rises

226 (first to  $20-30 \notin/tCO_2$ , and more recently to  $70-90 \notin/tCO_2$ ) are consistent with a first regulatory

reform that had limited impact on the cumulative certificate budget but contributed to a switch

- of actors' behavior from myopic to farsighted, and a second reform that substantially tightened
- the emission cap. While external investors may have accelerated the transition, it seems
- 230 improbable that prices are artificially high solely due to their activity.

Furthermore, our results provide insights about the present state of the EU ETS. Our modeling

- indicates that observed 2022 and 2023 prices of around  $80 \notin /tCO_2$  put the ETS sectors on track
- to achieving their reduction targets set by the Climate Law, a result in line with earlier for  $\frac{1}{2}$
- 234 findings<sup>49</sup>.

Our findings suggest that actors became farsighted, which is consistent with the initially formulated hypothesis that the ETS reform heightened policy credibility. Overall, there are thus reasons for careful optimism: trust in the EU ETS revived, policy credibility seems high, actors are therefore farsighted and current prices are in line with EU's goals. However, the question arises: Are these changes principally reversible? In particular, could credibility plummet again, implying that actors return to myopic behavior? If yes - why? And what would it mean for carbon prices and the energy transition?

# A look into the future

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The previous section has shown that the recent rise in ETS prices doesn't result from an acute 244 scarcity of allowances - as their surplus is still vast - but can rather be explained by market 245 actors having turned more farsighted. A plausible interpretation is that this was due to the long-246 term cap becoming considerably more credible. This may suggest that from this point on, ETS 247 prices would only increase. However, what would happen if policy credibility gets shaken 248 again due to a crisis or political backlash? How much would prices plummet and what would 249 it imply for the energy transition? This is what we analyze in the following with a scenario 250 considering a shock – for illustrative purposes - in 2025. 251

- 252 Before turning to numerical results, to underpin our motivation for analyzing a shock scenario,
- we develop a conceptual model on how policy credibility, actors' foresight, and carbon prices influence each other (*see Figure 5*).



Fig. 5| Role of actors' foresight and policy credibility in carbon price formation. A distortion from a high or low prices level can enchain a potentially reinforcing loop leading to a fall, or rise in prices, respectively. Policy credibility plays a major role in how actors react to a distortion. The theoretical hypothesis is complemented by two examples: the introduction of the MSR as an example of increased commitment to climate targets, and the current energy crisis, as an example of a potential shock. Following studies highlighting the importance of climate policy credibility for an acting private sector<sup>41,42</sup>, we assume actors' foresight depends on policy credibility.

The left side schematically represents the events from 2017-2021. It starts from a state with low policy credibility due to the huge certificate surplus, myopic market actors and ensuing low carbon prices. Then, the MSR reform and the higher ambition in the "Fit for 55" package substantially strengthened the policy credibility and set in motion a reinforcing cycle: actors extend their foresight horizon, which in turn increases carbon prices, which i) may increase the policy credibility and ii) attracts non-compliance actors to the market with at least partially more long-term investment strategies.

The right side shows a path, how the current situation could unravel again: a price shock or a crisis and the ensuing political reactions could potentially reduce policy credibility and trigger a relapse into myopic behavior, and hence lower prices. The recent energy crisis serves as an illustrative example: the tenfold increase<sup>50</sup> of European gas prices in 2022 put pressure on the EU ETS from several directions.

First of all, rising energy prices created strong liquidity problems for many firms<sup>51–53</sup>. Under liquidity problems, firms might sell assets not required in the short-term – such as banked  $CO_2$ certificates, which could decrease prices and scare away external investors. Secondly, the rising energy prices directly created pressure to weaken climate policies. As an example, Poland repeatedly proposed to freeze carbon prices at  $30 \notin /tCO_2^{54}$  or even temporarily suspend the EU ETS<sup>55</sup>. If the EU were to give in to such proposals, it would decrease its long-term policy credibility, and hence, following our hypothesis, compliance actors' foresight. Given the trilogue results in late  $2022^{42}$ , it appears the EU managed to overcome this critical situation without weakening the ETS and undermining its long-term policy credibility.

Nevertheless, the future remains uncertain, with the energy crisis serving as just one recent illustration of potential risks. Political crisis can happen anytime and history has repeatedly shown that all policy reforms face the threat of being undone or weakened over time<sup>56</sup>. This emphasizes the importance of exploring the risks of undermined policy credibility and actors returning to myopia. More specifically, to safeguard against such a turn of events, it is important to quantify what would be lost in terms of price degradation, and how this would slow down the energy transition.

Fig. 6 shows the price trajectory of such a "reversal-to-myopia" scenario. It presumes actors
were myopic in the past, became farsighted around 2020, and turn fully myopic again in 2025.
Prices could then start falling, reaching a level below 30€/tCO<sub>2</sub> in 2025. There is currently no

305 mechanism ensuring prices stay high in the next years.



**Fig. 6** | **Risk of falling EU ETS prices due to undermined policy credibility.** Carbon price trajectories assuming perfect foresight and reversal to myopia (i.e., actors are first fully myopic, become farsighted around 2020 and then fall back fully into myopia until 2025). Both trajectories correspond to newest targets from the "Fit for 55" proposal with an active MSR. The carbon price trajectories are complemented by the hypothesis that actors' foresight strongly depends on policy credibility.

Assuming such a relapse into myopia really happens and prices fall in the near future below 319  $30 \notin /tCO_2$ , what would it mean for the energy transition? The general impacts of myopic 320 foresight in the energy sector have been studied in previous literature<sup>57–61</sup>. Nerini et al.<sup>62</sup> show 321 using the cross-sectoral capacity expansion model UK Times that myopia might result in 322 delayed climate action and higher total transformation costs, compared to the pathway set by a 323 perfect foresight model. On the one hand, emissions abatement gets delayed. On the other hand, 324 325 the solutions chosen are focused on the near-term, creating lock-ins, and not the most efficient ones from a long-term perspective. 326

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To illustrate the delayed action, we focus on the electricity sector. The major problem we identify under the relapse to myopia is that, as seen in Fig. 7, delayed investments into wind capacity in turn delay the phase-out of coal power generation.



**Fig. 7** | **Delays in decarbonization due to myopia. a**, Expansion of wind onshore capacity in the EU under perfect and myopic foresight. **b**, Yearly electricity generation in the EU from black and brown coal under perfect and myopic foresight. Trajectories in both a, and b, correspond to newest targets from the "Fit for 55" proposal with an active MSR. Note that in this figure (both a and b) the 2020 year is fixed to match real 2020 values. Additional data (solar capacity expansion and total electricity mix) on perfect and myopic foresight scenarios can be found in Extended Data Fig. 3.

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As illustrated in Fig. 7a, our modeling shows that myopia could massively slow down wind

capacity expansion in the next 10 years, with yearly investments reduced by a factor of three,compared to the cost-optimal (i.e., perfect foresight) trajectory. The missing wind power in

combination with low carbon prices would strongly delay the phase-out of coal (Fig. 7b).

These risks are examples of what can happen in the electricity sector. Any delay poses the risk 349 of climate targets becoming out of reach, or being reachable only at very high costs, as feasible 350 roll-out rates can be limited, e.g., due to the availability of skilled workers, or production 351 capacities<sup>63</sup>. Likewise, the required steeper carbon price in the long-term might increase the 352 likelihood of a political backlash that dismantles the policy<sup>64</sup>. Hence, it is crucial to be aware 353 that carbon prices could principally fall again in the near future, with strong consequences for 354 the energy transition. Exploring potentials of a price floor in the ETS, proposed in the past to 355 address the problem of myopia<sup>24</sup>, as well as designing complementary policy instruments to 356 shore up the energy transition thus remains critical - despite currently high carbon prices. 357

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## 361 **Conclusions**

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363 This work proposes a quantitative explanation behind the observed rise in carbon prices on the EU ETS since 2017. We extend the LIMES-EU model to simulate different foresight horizons 364 of compliance actors and to depict the role of external investors. We show that the combination 365 of stricter EU ETS policies and changed behavior of compliance actors from myopic to 366 farsighted can explain the rapid increase in carbon prices over the past years, underpinning 367 with a quantitative analysis earlier scholarly work emphasizing the role of myopia<sup>7,10,25</sup>. Our 368 results indicate that external investors probably only played a minor role, by, e.g., accelerating 369 the price rise. 370

We discuss the hypothesis that policy credibility impacts actors' foresight, and hence carbon 371 prices. Consequently, a glimpse into the future shows that carbon prices could fall again if 372 actors become myopic again (e.g., due to a price shock and reduced policy credibility). A 373 fallback into myopia and low prices can threaten short-term decarbonization efforts. To prevent 374 such a development, additional policy instruments seem advisable to stabilize expectations of 375 agents. As an example, a price floor would limit the drop of carbon prices in the short term 376 when long-term policy credibility is temporarily reduced, and could even keep prices higher 377 without being binding<sup>65</sup>. 378

Overall, we find that observed 2022 and 2023 prices of around 80 €/tCO<sub>2</sub> are in line with EU
Climate Law reduction targets and should not be artificially lowered. Compliance actors seem
to trust the political commitment and act farsighted – a good sign for the reachability of EU's
2030 climate targets of the ETS sectors, if the current energy crisis and related policy reactions
do not undermine this mindset.

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#### Methodology 388

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#### 390 The model LIMES-EU

All quantitative results in this work are obtained using the model LIMES-EU (Long-term Investment 391 Model for the Electricity Sector), version 2.38. LIMES-EU is a linear optimization modeling framework 392 393 that simultaneously determines cost-minimizing investment, and dispatch decisions for generation, 394 storage and transmission technologies in the European electricity sector. Although its clear focus is the electricity sector, the energy-intensive industry and district heating are also represented through 395 396 marginal abatement cost curves. Compared to simple emissions trading models with static exogenous cost abatement curves, using an energy system model such as LIMES-EU allows to assess not only 397 398 market developments (e.g., prices or allowances in circulation) but also the investment dynamics and 399 path dependencies within the electricity sector.

400 LIMES-EU allows to fully simulate the EU ETS including the Market Stability Reserve (MSR)<sup>66</sup>. Hence, one can analyze figures such as the number of allowances in circulation, the intake by the MSR, 401 and resulting carbon prices. By varying the cap and MSR parameters, one can reproduce the state of the 402 EU ETS between different political reforms. 403

A comprehensive description of the LIMES-EU model, including parameters, equations, and 404 405 assumptions, is provided in the documentation available from the model's website<sup>67</sup>.

- 406 All changes to LIMES version 2.38 made for the purposes of this study are described below.
- 407

#### A myopic version of LIMES-EU 408

409 Rolling horizon as operationalization of myopia

410 Originally, LIMES-EU was formulated as a perfect foresight model running in five-year steps from 2010 until 2070. For the purpose of this study, to simulate the effect of myopic behavior of decision-411

412 makers, we extend the model with the option to use rolling time horizons instead of full intertemporal

foresight. Mathematically this means that instead of solving one optimization problem over the whole 413

time period from 2010 until 2070, we solve multiple (consecutive) optimization problems, covering 414 shorter time periods.

415

416 In our choice to implement a rolling horizon, we follow several other publications from our field: The rolling horizon approach (i.e., short foresight with overlapping time steps) has already been used 417 extensively as a way to represent myopia in the context of energy systems modeling<sup>57,58,60-62,68-70</sup>. 418 Although principally other approaches would be possible (e.g., by varying the discount rate), we are 419

- not aware of any publication in our field representing myopia in a different manner. 420
- 421 Foresight length

422 All myopic foresight results in this work assume 10-year horizons with an overlap of 5 years between

- the horizons. Practically it means, actors have foresight of 10 years but can revise their decisions every 423
- 5 years. As LIMES-EU runs in 5-year time steps, one optimization horizon comprises always two time 424
- steps (e.g., [2020, 2025], covering years 2018 2027). 425
- The literature provides different estimations on planning horizons of manufacturing companies, ranging 426
- between 3 and 12 years<sup>8</sup>. Bocklet and Hintermayer<sup>8</sup>, as well as Quemin and Trotignon<sup>10</sup> show that a 427
- horizon of around 10 years can best replicate EU ETS developments (these analyses were conducted 428
- around the time of the MSR reform). Hence, we also chose a foresight horizon of 10 years. As our 429
- model runs in 5-year time steps, 10 years is also the shortest foresight horizon we can meaningfully 430

- 431 implement (i.e., which allows for an overlap) in LIMES-EU. Varying the length of the foresight horizon
- 432 impacts the results but not the general trends: the shorter the foresight, the lower the near-term carbon
- 433 prices and higher the delays in decarbonization<sup>62</sup>.

434 When running in myopic foresight, the model solves consecutively several individual optimization 435 problems. Still, some variable values computed in one optimization horizon need to be "fed" into the next optimization horizon. It concerns all previous capacity additions and decommissioning (needed to 436 437 correctly compute current capacities) as well as emissions and banked certificates (needed for the ETS/MSR simulation). For instance, for the optimization horizon [2020, 2025] capacities will be fixed 438 for 2020 and all time steps before 2020. We assume that dispatch decisions can still get revised every 439 440 time step (5 years), so e.g., for the optimization horizon [2020, 2025], emissions and banked certificates 441 values get fixed only for all time steps before 2020, but not 2020 itself.

442 *What do actors neglect and what do they still consider?* 

In our study, we use rolling horizons as a tool to represent actors' myopia due to low trust in the long-term stability of the EU ETS. Hence, our main aim is to depict actors that are myopic with regards to the ETS. Our modeling approach implies that actors don't consider any information outside of their 10 years foresight horizon (i.e., the future ETS cap and the future demand for certificates).

years foresignt norizon (i.e., the future ETS cap and the future demand for certificates).

447 Nonetheless, as ETS actors are mostly large power system or manufacturing companies and salvage 448 values ("book values") are traditionally part of companies balance sheets, we still assume that they 449 consider the future value of assets (capacities) also beyond the foresight horizon. Therefore, a salvage 450 value for the capacity stock remaining at the end the optimization horizon is subtracted from the cost 451 function. In the myopic version, the salvage value is considered in each time horizon. This means that 452 when we run a diagnostic scenario where we turn off the ETS and keep technology prices constant over

- 453 time, the results of the myopic mode exactly reproduce the results of the perfect foresight mode.
- 454 *MSR simulation*
- The MSR, which is originally implemented iteratively as a loop around the main optimization problem<sup>66</sup>, runs in the myopic model version around each time horizon.
- 457

458

## 459 Specific modeling aspects

460 *Carbon prices* 

461 Reported carbon prices (in €/tCO<sub>2</sub>) represent the marginal abatement costs in a given year, which are 462 equal to the dual value (shadow price) associated with the banking constraint in LIMES-EU. 463 Transaction costs are neglected. Reported historic carbon prices are nominal, so given in EUR of the 464 year in which they occurred. LIMES runs in real EUR2010, but all reported prices from LIMES until 465 2023 in this paper were converted to nominal prices until 2023, adjusted for inflation using OECD 466 inflation rates for EU27<sup>71</sup>. Computed prices after 2023 are in real *EUR2023*.

467

468 *External investors (financials)* 

To depict external investors in our model, we assume that the impact on carbon prices of
buying/holding/selling EUA futures can be approximated by the assumption, external investors
buy/hold/sell physical allowances. As we are interested in long-term price developments, we focus on
external investors holding long open position on EUA futures.

- To model the impact of external investors, we implement a one-step iteration approach. Hence, we implicitly assume that both compliance actors and external investors can't react the other group's action.
- I/ In a first instance, a LIMES-EU run with full myopic foresight without external investors isconducted.
- 477

478 II/ The resulting carbon price trajectory  $p_{price,CO_2}(t_y)$  serves as input to the optimization problem from 479 the external investors' perspective:

480

481 
$$\max_{v_{bought}, v_{sold}} \sum_{t_y \in T} (v_{sold}(t_y) \cdot p_{price, CO_2}(t_y) - v_{bought}(t_y) \cdot p_{price, CO_2}(t_y)) \times e^{-i(t_y - t_{y_0})}$$
(1)

482

s.t. 
$$v_{bought}(t_y) \le \alpha \cdot p_{auction}(t_y)$$
 (2)

$$\sum_{0}^{t_y} v_{sold}(t_y) \le \sum_{0}^{t_y-1} v_{bought}(t_y)$$
(3)

 $\nu_{sold}(t_y) \le \gamma \cdot \sum_{t_y \in T} \nu_{sold}(t_y)$ (4)

Eq. (1) is the profit function: external investors want to maximize their profit by buying allowances and selling them at a later time step  $t_y$ . Herein,  $t_y \in [2018, ..., 2040]$  are yearly time steps. *T* is the set containing all yearly steps part of the optimization. Further,  $v_{bought}(t_y)$  and  $v_{sold}(t_y)$  stand for the number of allowances bought and sold in time step  $t_y$ . The profit gets discounted by discount rate *i*. We assume i = 5%, same as in the core model assumptions of LIMES-EU. Finally,  $p_{price, CO_2}(t_y)$ corresponds to the carbon price from a myopic run, which grows at a higher rate than the discount rate of 5%.

- 493 Eq. (2) sets a limit on the number of allowances external investors can maximally buy. Herein,  $\alpha$  is the 494 share of auctioned allowances  $p_{auction}(t_y)$ . We assume  $p_{auction}$  to be the final number of allowances 495 auctioned, after substraction of allowances transferred into the MSR. In our work,  $\alpha$  is varied between 496 5 and 20%. Eq. (3) ensures the number of allowances sold is below the number of allowances external 497 investors bought prior to time step  $t_y$ .
- Finally, eq. (4) limits the number of allowances that can be sold in a given time step  $t_y$ , to prevent all of them being sold in a single year. Results assume an  $\gamma$  of 0.2, meaning allowances need to be sold over minimum five years.

501 III/ Having solved the optimization problem from the perspective of external investors, one can now
502 conduct a new LIMES-EU run with full myopic foresight and additional input on the number of
503 allowances "blocked" by external investors.

504 
$$p_{investors}(t) = v_{bought}(t) - v_{sold}(t)$$
 (6)

505 
$$v_{tnac}(t) - v_{tnac}(t-1) = p_{cap}(t) - p_{investors}(t) - v_{emi}(t)$$
 (7)

Herein,  $p_{investors}$  is the absolute number of allowances bought or sold by external investors. These influence the level of allowances, as shown in eq. (7). Herein,  $v_{tnac}(t)$  is the total number of allowances in circulation (TNAC) at the end of time step t,  $p_{cap}(t)$  the total number of allowances auctioned and freely allocated, and  $v_{emi}(t)$  the total emissions in time step t. Herein,  $t \in [2010, 2015, ..., 2040]$  are are five year time steps.

511 To capture the unpredictability of external investors on the price formation, we assume compliance 512 actors can't see the realization of  $p_{investors}(t)$  before time step t. Hence, even though they have a 513 foresight of 10 years regarding all other model inputs, they only have a foresight of one LIMES-EU 514 time step (5 years) when it comes to  $p_{investors}(t)$ .

515 It is important to note that the way our approach is implemented, external investors behave as farsighted 516 actors and have incentives to enter the market, only if compliance actors are myopic (carbon prices 517 initially lower than under the perfect foresight scenario). Hence, all results showing the impact of 518 external investors presume myopic foresight from compliance actors.

As we conduct only one iteration, we implicitly assume that external investors plan all their future behavior only once and base it on myopic carbon prices. In real world, there is a constant feedback between prices and investors' buying/selling strategy. Hence, our methodology does not aim to provide realistic predictions regarding possible behavior of external investors. It is, however, suitable to show the order of magnitude of the increase in carbon prices, assuming external investors accumulated and "block" a certain number of certificates.

- 525
- 526 *Future ("Reversal to myopia")*

527 In the "Reversal to myopia" scenario from Fig. 5b, similar to the full myopic version, several 528 consecutive optimization problems with 10 years foresight horizons are solved, with the exception that 529 the horizon [2020, 2025] gets replaced by [2020, ..., 2070] to simulate perfect foresight in time step 530 2020. Afterwards, from time step 2025 on, actors have again only myopic foresight.

531

## 532 *MACC curves representing industry and heating sectors*

533 As described in the LIMES-EU Documentation<sup>21</sup>, the industry and heating sectors are not modeled explicitly in LIMES-EU but the cost of emission abatement is approximated by marginal abatement 534 cost curves (MACC). Originally, as they have been designed for runs starting in 2020, both MACCs 535 assumed a minimum cost of 8€/tCO<sub>2</sub>, being a well suited assumption for benchmark modeling, in which 536 modeled carbon prices always exceed 8€/tCO<sub>2</sub> for relevant ETS scenarios. As in this work certain 537 counterfactual scenarios yield prices below 8€/tCO<sub>2</sub>, we extrapolate the MACC curves to also cover the 538 539 price regime of  $0-8 \notin tCO_2$  by analyzing the change in industry and heating emissions upon 540 implementation of the ETS. We thus estimate two additional emissions steps of 45 MtCO<sub>2</sub> in industry 541 and 15 MtCO<sub>2</sub> in heating that would be emitted additionally compared to historic industry/heating emissions when ETS prices remain below 5€/tCO<sub>2</sub> and again when they remain below 3€/tCO<sub>2</sub>. 542

543

## 544 Scenarios

- 545 *Modeling assumptions: calibration, policy targets, technology costs*
- 546 The table below summarizes key assumptions behind our study's main scenario types.

## 547 Table Methodology 1 | Modeling assumptions across different scenarios.

Scenario	Figure(s)	ETS state	ETS modeling running from	Technology costs	Calibration
1.	3	Pre-reforms	Time step 2015 (= real year 2013)	Future capex costs of solar and wind generation technologies based on LIMES-EU documentation from year 2014 <sup>72</sup> .	<ul> <li>&gt; Electricity generation capacities fixed for time step 2015</li> <li>&gt; TNAC value fixed prior to time step 2015</li> </ul>

2.	3	MSR reform	Time step 2020 (= real year 2018)	Future capex costs of solar and wind generation technologies based on the average of 2014 <sup>72</sup> and current <sup>21</sup> LIMES-EU documentation.	> Electricity generation capacities fixed for time steps 2015 and 2020
3.	3, 4, 7	"Fit for 55" proposal	Time step 2020 (= real year 2018)	Future capex costs of solar and wind generation technologies based on current <sup>21</sup> LIMES-EU documentation.	> TNAC value fixed prior to time step 2020

548 In Figure 3, we align scenarios with historical conditions as closely as possible, adjusting 549 variables like ETS modeling start year and technology cost assumptions. Due to the five-year 550 time steps in our model, complete historical replication and path dependency coverage may be 551 limited (e.g., "Fit for 55" scenario starts in 2018).

For Figures 4, 6, and 7, we exclusively use the "Fit for 55" scenario, representing the current EU ETS state. This simplification serves the purpose of preventing information overload, aligning with the figures' primary objective. These figures are designed to illustrate specific trends or effects rather than striving for an exact replication of historical conditions. In Figure 6, we extrapolate our results to 2015.

557 *Modeling assumptions: EU ETS parameters* 

The table below summarizes the relevant parameters used in this study defining the emissions cap andMSR functionality for the ETS state between different reforms.

Table Methodology 2 | Parameters used in this study representing the state of the EU ETS between different
 reforms.

Parameter	Pre-reforms	MSR reform	"Fit for 55" proposal			
	Emissions & Cap					
Linear reduction factor ( <i>LRF</i> )	1.74 %	2.2 % (from trading phase 4 on starting in 2021)	4.2 %			
Additional measures	<i>'Backloading'</i> , of 900 Mio EUAs between 2014- 2016	-	'Rebasing', of 117 Mio EUAs (not specified, assumed in 2024)			
		MSR				
EUA intake	-	<ul> <li>When TNAC &gt; 833 Mio:</li> <li>Intake is 24 % of TNAC until 2023</li> <li>Intake is 12 % of TNAC after 2024</li> </ul>	<ul> <li>When TNAC &gt; 1096 Mio:</li> <li>Intake is 24 % of TNAC until 2030</li> <li>Intake is 12 % of TNAC after 2031</li> <li>When 1096 &gt; TNAC &gt; 833 Mio:</li> <li>Intake is TNAC - 833 Mio</li> </ul>			

		When TNAC < 400 Mio:		
EUA outtake	-	<ul> <li>200 Mio until 2023</li> </ul>		
		<ul> <li>100 Mio after 2024</li> </ul>		
Cancellation mechanism	-	Only after 2023: Cancellation defined as the difference between MSR level and the EUA volume auctioned the previous year.	Only after 2023: Cancellation defined as the difference between MSR level and 400 Mio.	

562

## 563 "Fit for 55": Commission's proposal vs. final agreement

All results in this study related to ETS targets from the "Fit for 55" package assume parameters from the Commission's proposal published in July 2021<sup>41</sup>. As this study takes into account real ETS prices until December 2022, it is plausible to assume that until then market actors were basing their decisions on the Commission's proposal, not being aware yet of the upcoming changes in the final negotiations.

The final agreement between the Council, Parliament and Commission was reached in December 2022 and includes minor changes related to the linear reduction factor and the operation of the MSR<sup>42</sup>.

570 For completeness reasons, we provide a comparison of modeled carbon prices according to the emission

571 cap from the Commission's proposal (used in this study) and according to the emission cap from the

572 final ETS "Fit for 55" agreement in Extended Data Fig. 4. The emissions cap corresponding to the final

- agreement is implemented accordingly to the text of the trilogue agreement<sup>42,73</sup> and can be found in
- 574 Extended Data Table 2.
- 575

## 576 Model validation

577 General modeling choices, e.g., the clustering approach and the representative days choice, are 578 described in the LIMES-EU model documentation. Here, we present additional validation points for the 579 scenarios presented in this study. First, we show that our model can approximate historical 580 developments in 2015 and 2020. Then, we provide references demonstrating that our future estimates 581 for the EU ETS align with other literature.

- 582 *Reproducing historical developments in time step 2015*
- 583 Scenario: myopic foresight, EU ETS pre-MSR reform

584 The capacity spin-up of LIMES EU is fixed so that it matches the 2015 historical mix of installed 585 generation capacities in EU ETS countries. Figure Methodology 1 illustrates that based on this standing 586 capacity, the model-calculated dispatch then reasonable matches the historic power generation dispatch 587 in EU ETS countries.

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**Fig. Methodology 1| Comparison of 2015 model results with historical data. a,** Emissions from electricity generation in year 2015. Real emissions from the Joint Research Center (JRC) Dataset IDEES<sup>74</sup>. **b,** Electricity dispatch in 2015. Real dispatch from ENTSO-E Power Statistics<sup>75</sup>. **c,** Planned capacities for year 2020. In myopic mode, the model takes this investment decision in time step 2015, hence the 2020 generation capacities serve to validate decisions in time step 2015. Real capacities from ENTSO-E Transparency Platform<sup>76</sup>. All results for EU ETS countries (EU28 and Norway).

610 The total modeled emissions from electricity generation in the year 2015 for EU ETS countries covered by LIMES-EU amount to 981 MtCO2, closely aligning with the historical emissions of 967 MtCO2 as 611 612 reported by Mantsos et al.<sup>74</sup> Since emissions from industry, heating, and aviation are also calibrated to match their historical 2015 levels (as described in LIMES-EU documentation<sup>21</sup>), this calibration ensures 613 that our model generates meaningful values for total emissions in the 2015 time step. Also, the model-614 615 endogeneous investments in 2015 lead to standing capacities in 2020 that match historic wind and solar capacities in 2020. To this aim, we additionally assume subsidies for electricity generated from solar or 616 wind sources (0,04  $\in$ /kWh for solar and 0,015  $\in$ /kWh for wind) to represent the various renewable 617 618 subsidies that were in place in most EU member states. Our model, however, underestimates the capacity additions of offshore wind until 2020, which took place mostly in the UK. 619

620

- 621 Reproducing historical developments in time step 2020
- 622 Scenario: perfect foresight, EU ETS post-MSR reform

To validate the 2020 model results, we first fix capacity spin-up so that our model matches the installed
generation capacities for both 2015 and 2020 in EU ETS countries. In Figure Methodology 2, we show
that this calibration enables our model to approximate EU-wide dispatch and total emissions from the

- 626 electricity sector in 2020.
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Fig. Methodology 2 | Validation of historical time step 2020. a, Emissions from electricity generation in year 2020 and 2019. As we are not aware of a data source providing 2019 and 2020 emissions for the electricity sector, we estimate real electricity sector emissions by taking EEA ETS emissions data for "combustion of fuels" and assuming that electricity generation accounted for 79% of this (in 2015, emissions from electricity generation reported by the JRC constituted 79% of emissions from 647 "combustion of fuels" reported by the EEA). b, Electricity dispatch in 2020. Real dispatch from IEA 648 dataset<sup>77</sup>. All results for EU ETS countries (EU28 and Norway).

649 It's important to note that our model operates in five-year steps, with time step 2020 representing the 650 actual years 2018-2022. However, due to the exceptional circumstances of the COVID pandemic, the 651 year 2020 deviates from the typical trends of 2018-2022. Hence, to validate time step 2020, we provide 652 real values for the years 2019 and 2020.

With respect to electricity dispatch, our model estimates lower generation from biomass compared to 653 IEA historical data. This discrepancy may be attributed to several factors, including our reliance on the 654 ENTSO-E dataset for total capacities, while using the IEA dataset for generation values (as ENTSO-E 655 lacks a Statistical Factsheet covering generation for the years 2019 and 2020). Differences in values 656 from different sources can often be substantial. Regarding biomass, variations may be due to, e.g., the 657 way biomass co-firing in coal power plants is accounted for. Nevertheless, despite minor deviations in 658 our 2020 electricity dispatch from historical data, our model still provides a meaningful estimate of 659 emissions. This aspect is critical for validating EU ETS models, as it directly impacts CO<sub>2</sub> prices, the 660 661 total number of allowances in circulation, and the functioning of the MSR

662

## 663 *Estimating future developments*

While validating future projections is inherently impossible, we observe that LIMES-EU generally 664 aligns with findings in the literature and does not produce results that are far outliers compared to other 665 models. Osorio et al. discuss that LIMES-EU's estimates of MSR cancellations are consistent with other 666 studies<sup>66</sup>. Furthermore, a recent model comparison study led by Henke et al. revealed that LIMES-EU's 667 projections for various EU electricity sector variables from 2020 to 2050, such as final energy demand 668 and the share of renewable energy sources in electricity generation, are in line with the range provided 669 by ten other energy systems and IAM models<sup>78</sup>. In another model comparison study assessing EUA 670 prices until 2030, LIMES-EU's estimate of 140€/tCO<sub>2</sub> falls within the range of 80€ to 160€/tCO<sub>2</sub> 671

672 produced by six different models<sup>79</sup>.

## 673 Methodological contribution

While the primary focus of this work lies in providing insights for the ongoing debates surrounding the 674 EU ETS, we also make a notable methodological contribution. There have been other studies using EU 675 ETS models that explicitly simulate the electricity sector<sup>48,80,81</sup>, and there have been energy systems 676 analyses using myopic energy system models<sup>57,58,60-62,68-70</sup>. Also Nerini et al.<sup>62</sup> pioneered the idea to 677 678 compare myopic and perfect foresight modes of a capacity expansion model to formulate more robust policies. Our study extends their approach and is, to the best of our knowledge, the first study to employ 679 both types of foresight to evaluate ex post a concrete policy reform in order to test if the change in the 680 681 observable variable - in our case, the EU ETS price - can better be reproduced in the myopic or perfect

682 foresight mode.

683

# 684 Data availability

Data for core model assumptions (investment costs, fuel costs, etc.) are provided in the LIMES-EU
 documentation (Methods). The dataset containing all results displayed in this paper is publicly available
 at: 10.5281/zenodo.10363561.

688

# 689 **Code availability**

690 The LIMES-EU model code is available upon request from the authors. Moreover, a process has been691 started to make the model available under an open-source license. When this process will be completed,

the code will be available for download from the PIK webpage <u>http://pik-potsdam.de/limes</u>.

693

# 694 Author contributions

R.P. and G.L. suggested the research question. J.S. and R.P. jointly conceived and designed the study
in consultation with S.O. and G.L. J.S. extended the model, conducted scenario runs and created
visualizations. J.S., R.P., M.P., G.L. and S.O. interpreted the results. J.S. wrote the manuscript with
contributions from R.P., M.P., S.O. and G.L.

699

# 700 Competing interests

701 The authors declare no competing interests.

702

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709

## 711 Extended Data

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### 713

Period	(i) Jan 2013 – Dec 2018	(ii) Jan 2018 – Sept 2020	(iii) Oct 2020 – July 2023
Modeled EU ETS	Pre-reforms	MSR reform	Fit for 55 reform
Myopic Foresight 0.58		0.8	0.8
Perfect Foresight	1.15	0.25	0.38

714

715 Extended Data Table 1| Mean absolute percentage error (MAPE) of modeled CO<sub>2</sub> prices assuming myopic or perfect

foresight. This table supplements Fig. 3 by providing values of the MAPE error between modeled CO2 prices and
 real historical EUA prices. Highlighted in bold are the runs with the lower MAPE, hence lower error compared to
 real historical EUA prices. MAPE is calculated as the average absolute percent difference between two numeric
 vectors<sup>82</sup>.





**Extended Data Fig. 1** Interactions between foresight horizon and MSR. a, Total number of allowances in circulation (TNAC), theoretical cap (allowances to be freely allocated and auctioned before accounting for MSR intake or outtake), total emissions, allowances taken in by the MSR for both perfect and myopic foresight. b, Cumulative emissions over transformation period for perfect and myopic foresight. The difference between cumulative theoretical cap and cumulative emissions corresponds to total number of allowances cancelled by the MSR. All results in this figure complement Fig. 3 and correspond to runs with newest targets from the "Fit for 55" proposal with an active MSR.





**Extended Data Fig. 2| Optimization problem from external financial investors' perspective.** Investors optimize their profit till 2040 by buying up to 5% or 20% of yearly's auctioned allowances and reselling them later. Obtained buying and selling strategy corresponds to assumption on external investors from Fig. 4. Before entered to the LIMES-EU model, all values are transformed to 5-year time steps. Cap trajectory corresponds to allowances auctioned, assuming an MSR intake deducted from cap in years 2019-2023, as seen in Extended Data Fig.1 (myopic foresight).



Extended Data Fig. 3| Delays in decarbonization due to myopia. All results in this figure complement Fig. 7 and correspond to runs with targets from the "Fit for 55" proposal with an active MSR. a, Expansion of solar capacity in the EU under perfect and myopic foresight. b, Total electricity mix. P: perfect foresight, M: myopic foresight.

Extended Data Table 2 | EU ETS caps and MSR parameters: differences between (i) "Fit for 55" initial proposal and
 (ii) final agreement.

Parameter	(i) Commission's proposal "Fit for 55"	(ii) Final agreement "Fit for 55"		
Emissions & Cap				
Target 2030 with respect to 2005	-61 %	-62 %		
Linear reduction factor ( <i>LRF</i> )	4.2 % (' <i>Rebasing</i> ', of 117 Mio [not specified, assumed in 2024])	<ul> <li>4.3 % from 2024-27 and</li> <li>4.4 % from 2028 onwards</li> <li>(<i>'Rebasing'</i>, of 90 Mio in 2024 and 20 Mio in 2026)</li> </ul>		
MSR				
Cancellation mechanism	Only after 2023: Cancellation defined as the difference between MSR level and the EUA volume auctioned the previous year	Only after 2023: Cancellation defined as the difference between MSR level and 400 Mio		
Free certificates	No specified but intended to remain at $\sim$ 43% of the cap	Path defined and to be phased out by 2034		





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