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EU carbon prices signal high policy credibility and farsighted actors

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Abstract

Carbon prices in the EU emissions trading system (EU ETS) are a key instrument driving Europe's decarbonization. Between 2017 and 2021, they surged tenfold, exceeding 80 €/tCO₂ and reshaping investment decisions across the electricity and industry sectors. What has driven this increase is an open question. While it coincided with two significant reforms tightening 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 more farsighted as the reform signaled policymakers' credible long-term commitment to 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 farsighted. To underline the role of credibility, we test what would happen if a crisis undermines policy credibility such that actors become myopic again, demonstrating that carbon prices could plummet and endanger the energy transition.

Introduction

The EU emissions trading system (EU ETS) is a central pillar of the European Union's decarbonization strategy. It covers the electricity sector, large-scale industrial installations, aviation, and maritime transport, and hence controls above 40% of the EU's total greenhouse gas emissions¹. Over a period with two major reforms of the ETS and notably a substantial tightening of the cap, the carbon market underwent a remarkable transition: Carbon prices increased tenfold within 4 years, with a first rise in 2018 from below 10 €/tCO₂¹ to a plateau at 20-30 €/tCO₂ in 2019-2020, and then a second, even sharper rise, during which prices repeatedly reached almost 100 €/tCO₂ in 2021 and 2022². The question of why prices have risen so steeply is still unanswered though, and a subject of debate among the scientific and policy community.

¹ All carbon prices throughout the paper are nominal prices until 2023, adjusted for inflation using OECD inflation rates for EU27⁷¹. Computed prices after 2023 are in real EUR₂₀₂₃.

35 The literature so far identifies various factors as playing a potential role in carbon price
36 developments in general: (1) regulatory changes (such as the introduction of the Market
37 Stability Reserve (MSR), or changes in the linear reduction factor)³⁻⁶, (2) actors' behavior
38 (foresight horizon, hedging, or participation in trade)⁷⁻¹⁰, and (3) speculation and external
39 financial investors¹¹⁻¹⁴. However, most work focuses on one of those aspects, provides only
40 qualitative assessments, and covers only the period before the recent reforms and price
41 increases.

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

51 In light of that, we hypothesize that the reform could have had another important effect on
52 actors: making them more farsighted. The reason is that through the reform EU policymakers
53 substantially firmed up the credibility of their commitment to the ETS overall. They did this
54 both explicitly, by emphasizing that the "ETS is front and centre to all our efforts"¹⁶, and
55 implicitly, by investing a lot of political capital in the political negotiation. More broadly, a
56 recent empirical study also shows that the EU has currently the world's highest climate policy
57 credibility¹⁷.

58 Such instilled credible commitment is essential to shape firms' expectations about the
59 durability of long-term policies such as the ETS¹⁸, and indeed studies suggest that low policy
60 credibility can be associated with decreased "green" investments¹⁹, and that policy credibility
61 can enhance actors' farsightedness²⁰. The main reason is that low credibility creates high
62 regulatory uncertainty regarding a future softening of the cap or interventions to dampen high
63 carbon prices – a major reason for myopia. Correspondingly, increasing credibility implies that
64 actors become more farsighted.

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

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

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

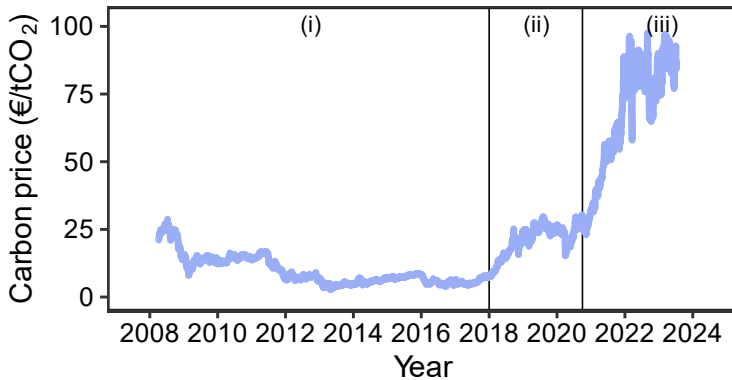
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82 From past to present

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€/tCO₂, (ii) the period of 2018 – 2020, “the
86 first rise” up to a plateau of 20-30€/tCO₂, and (iii) the period since late 2020, “the second rise”,
87 in which prices increased strongly, and are now stabilizing around 70-90€/tCO₂. 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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99 **Fig. 1| Evolution of carbon prices on the EU ETS (2008-2023).**

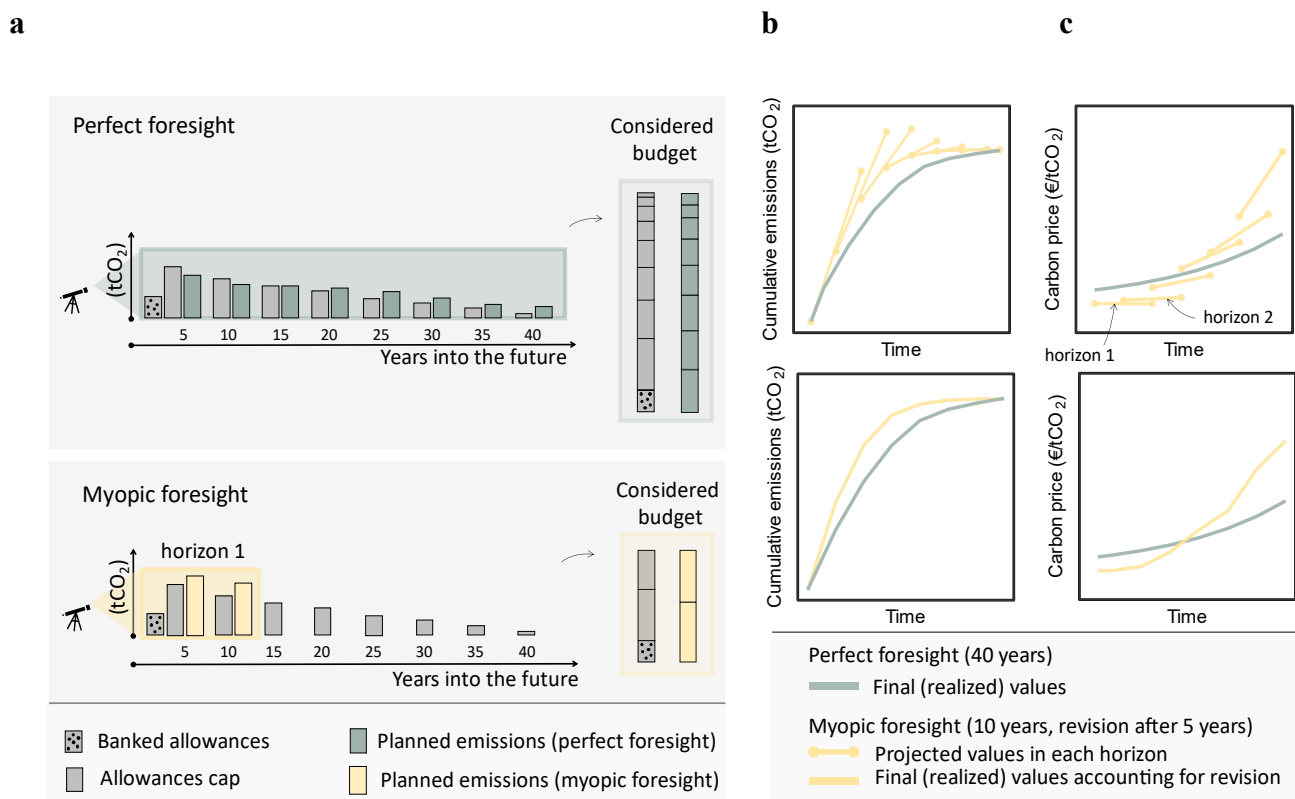
100 Prices correspond to historical EU ETS allowances (EUA) prices on the
101 EEX spot market^{2,22}. The year tick marks the beginning of a year.

102

103 Regarding the first period (i), the common understanding is that prices dropped because of a
104 high surplus of allowances that accumulated since 2008. The financial crisis reduced emissions
105 more than anticipated, leaving compliance actors with a high number of unused allowances,
106 hence limiting incentives to decarbonize²³.

107 Different publications furthermore suggest that the limited foresight of compliance actors
108 contributed to low carbon prices^{5,8-10,24}. To understand the role of foresight, one needs to
109 consider that the EU ETS allows for almost unlimited forward bankability: any certificate not
110 used today can be used in the future. Hence, expected future prices may have a strong influence
111 on today’s prices. In contrast, in a market without bankability, a surplus of certificates over
112 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 years²⁵. 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*).



120

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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 ever². What
 125 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
 127 tightened the cap²⁶. 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,

129 we first give an overview of the most relevant reforms from the past years and then present our
 130 modeling results.

131 The past years were marked by numerous reforms and rapid EU climate policy developments²⁷⁻
 132 ³⁴. While it is challenging to pinpoint one specific regulation with the highest impact on carbon
 133 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
 135 summarized in Table 1.

136

137 **Table 1 | 2015-2022: An intensive period in climate policy. Developments and reforms relevant for the**
 138 **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 ²⁷	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 ²⁸	EU ETS design: 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 ²⁹	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 ³⁰	EU ETS design: 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) ³¹⁻³³	EU ETS design: 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	“MSR reform” ETS/MSR reform for trading period IV (2021-2030) officially adopted ³⁴	EU ETS design: Directive with the ETS/MSR reform officially published.
Dec. 2019	Presentation of the European Green Deal ³⁵	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 ³⁶	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 ³⁷	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 ³⁸	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 ³⁹	EU climate policy: Parliament, Council and Commission agree in trilogue negotiations on the -55% 2030 reduction target, enabling the formal adoption of the Climate Law in June 2021.
July 2021	"Fit for 55" package ^{40,41}	EU ETS design: 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 "Fit for 55" proposal ⁴²	EU ETS design: 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.

139

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

145 Fig. 3 shows our modeling results on the impact of reforms and actors' foresight on carbon
146 prices. First of all, one can see between period (i) and period (ii), when the MSR reform was
147 negotiated and implemented, actors presumably started to look further into the future. When
148 turning to period (i) before 2018, one notices that observed ETS prices are closer to the modeled
149 prices for myopic actors than to the modeled prices for farsighted actors. It seems therefore
150 plausible to assume that market actors behaved at least partially myopically, which is in line
151 with earlier assessments^{9,10}. For periods (ii) and (iii), one observes the opposite: Both, the 2019-
152 2020 observed ETS prices of 20-30 €/tCO₂, and the 2021-2022 ones of 70-90 €/tCO₂, are
153 consistent with the modeled prices for farsighted actors (i.e., perfect foresight trajectories for
154 old "MSR reform" targets, and new "Fit for 55" targets, respectively). We also calculate the
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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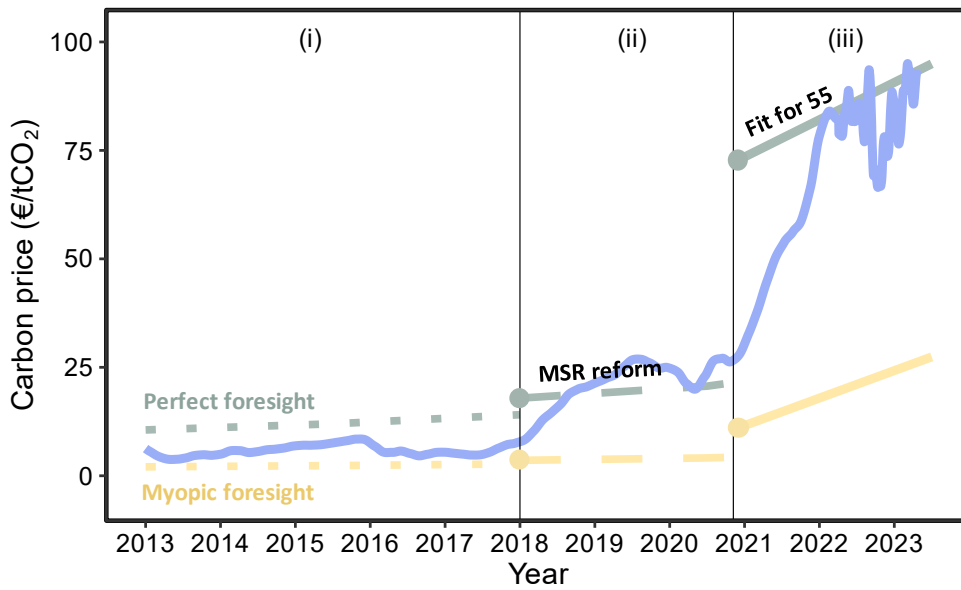
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Model results		Real developments	
EU ETS targets	Foresight	Actual EU ETS prices	
	Myopic	Perfect	
Pre-reforms	---	---	—
MSR reform	—	—	
Fit for 55	—	—	

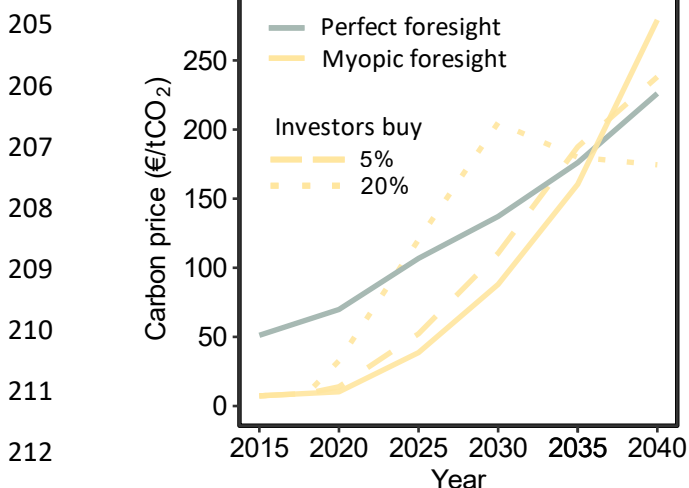
Fig. 3| Impact of reforms and actors’ foresight on carbon prices. Historical carbon prices on the EU ETS, and modeled carbon price trajectories with the assumption of either perfect or myopic foresight, over the three periods (i)-(iii) as defined in Fig. 1. For each period, we show the carbon price trajectories 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^{1,18}. 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”).

188 emphasized the will of EU policymakers to “repair” the ETS (showing “the doctor has not
189 given up on the patient”⁴⁶), which strongly increased its long-term credibility, inspiring market
190 actors to show longer foresight. These findings align with previous assessments, which, on the
191 one hand, demonstrate that the MSR can lead to increased carbon prices^{47,48}, while, on the other
192 hand, argue that the effect of the MSR reform on the emission budget alone is unlikely to fully
193 explain the surge in carbon prices^{8,11}.

194 Secondly, Fig. 3 shows that the “Fit for 55” package sharply increases the stringency of the EU
195 ETS. Optimal carbon prices (i.e., obtained under the assumption of perfect foresight) to reach
196 the new targets are significantly higher than those that were necessary for achieving previous
197 goals. In fact, modeled prices for the “Fit for 55” targets for 2020-2023 are in the order of 70-
198 90€/tCO₂, corresponding well to observed 2021-2023 prices on the EU ETS, thus supporting
199 the hypothesis that actors have transitioned towards a more farsighted perspective. To the best
200 of our knowledge, no other studies have yet assessed whether ETS actors currently show
201 farsighted or myopic behavior.

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

204



212

213 **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.

213

214 Here, we assume external investors temporarily “block” a part of the allowances on the market,
215 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.

218 In reality, it is estimated that external investors currently hold only around 5-10% of allowances
219 futures¹³, consistent with the scenario in which 5% of auctioned allowances are bought by
220 external financial investors. This scenario shows only a small price increase of less than
221 10€/tCO₂ in 2025 compared to the pure myopic scenario (*Fig. 4*). Thus, following our results,
222 a major contribution of external investors to the price rise seems unlikely. What is on the other
223 hand possible, is that they acted as a “catalyzer”, speeding up the process of compliance actors
224 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€/tCO₂, and more recently to 70-90€/tCO₂) are consistent with a first regulatory
227 reform that had limited impact on the cumulative certificate budget but contributed to a switch
228 of actors’ behavior from myopic to farsighted, and a second reform that substantially tightened
229 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.

231 Furthermore, our results provide insights about the present state of the EU ETS. Our modeling
232 indicates that observed 2022 and 2023 prices of around 80€/tCO₂ put the ETS sectors on track
233 to achieving their reduction targets set by the Climate Law, a result in line with earlier
234 findings⁴⁹.

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

242 **A look into the future**

243
244 The previous section has shown that the recent rise in ETS prices doesn’t result from an acute
245 scarcity of allowances - as their surplus is still vast - but can rather be explained by market
246 actors having turned more farsighted. A plausible interpretation is that this was due to the long-
247 term cap becoming considerably more credible. This may suggest that from this point on, ETS
248 prices would only increase. However, what would happen if policy credibility gets shaken
249 again due to a crisis or political backlash? How much would prices plummet and what would
250 it imply for the energy transition? This is what we analyze in the following with a scenario
251 considering a shock – for illustrative purposes - in 2025.

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

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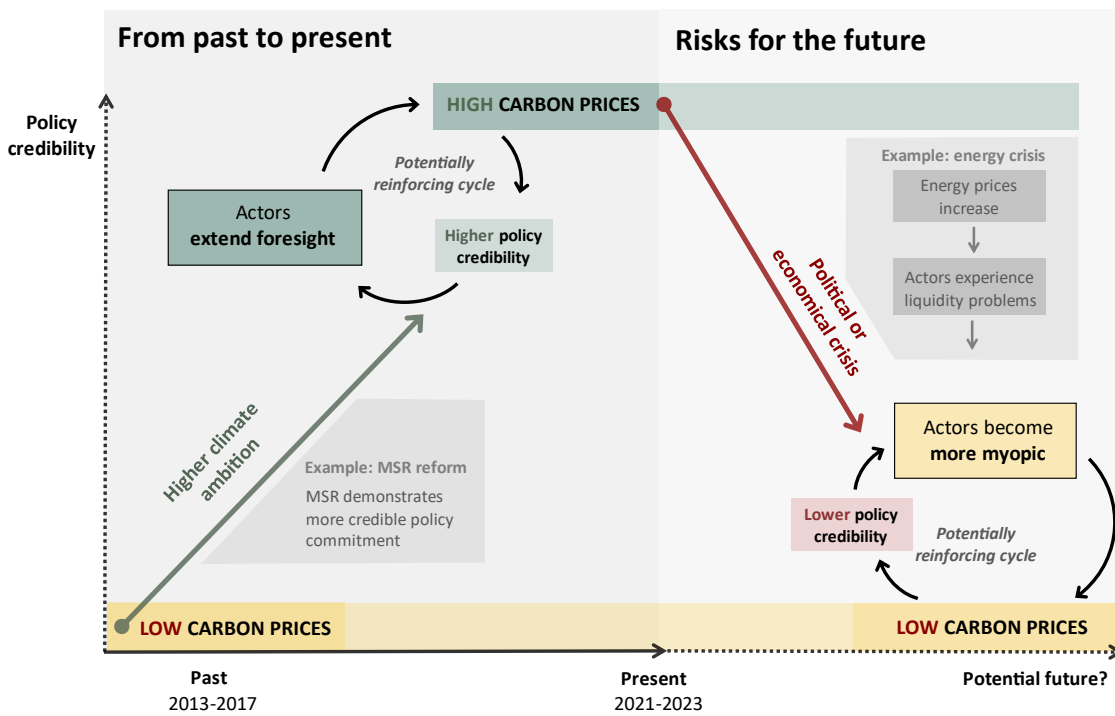


Fig. 5 | Role of actors’ foresight and policy credibility in carbon price formation. A distortion from a high or low prices level can enchain a potentially reinforcing loop leading to a fall, or rise in prices, respectively. Policy credibility plays a major role in how actors react to a distortion. The 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^{41,42}, 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 increase⁵⁰ 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 firms⁵¹⁻⁵³. Under liquidity problems, firms might sell assets not required in the short-term – such as banked CO₂ 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

290 repeatedly proposed to freeze carbon prices at 30€/tCO₂⁵⁴ or even temporarily suspend the EU
291 ETS⁵⁵. If the EU were to give in to such proposals, it would decrease its long-term policy
292 credibility, and hence, following our hypothesis, compliance actors' foresight. Given the
293 trilogue results in late 2022⁴², it appears the EU managed to overcome this critical situation
294 without weakening the ETS and undermining its long-term policy credibility.

295 Nevertheless, the future remains uncertain, with the energy crisis serving as just one recent
296 illustration of potential risks. Political crisis can happen anytime and history has repeatedly
297 shown that all policy reforms face the threat of being undone or weakened over time⁵⁶. This
298 emphasizes the importance of exploring the risks of undermined policy credibility and actors
299 returning to myopia. More specifically, to safeguard against such a turn of events, it is
300 important to quantify what would be lost in terms of price degradation, and how this would
301 slow down the energy transition.

302 Fig. 6 shows the price trajectory of such a “reversal-to-myopia” scenario. It presumes actors
303 were myopic in the past, became farsighted around 2020, and turn fully myopic again in 2025.
304 Prices could then start falling, reaching a level below 30€/tCO₂ in 2025. There is currently no
305 mechanism ensuring prices stay high in the next years.

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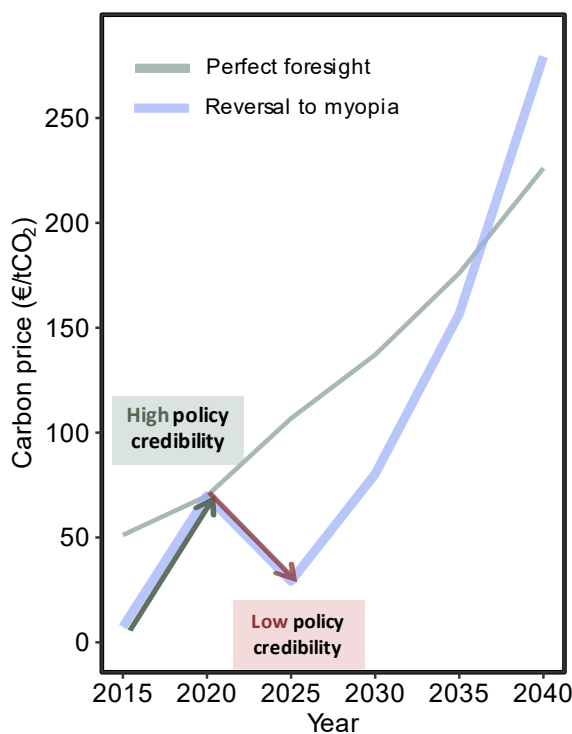


Fig. 6 | Risk of falling EU ETS prices due to undermined policy credibility. Carbon price trajectories assuming perfect foresight and reversal to myopia (i.e., actors are first fully myopic, become farsighted around 2020 and then fall back fully into myopia until 2025). Both trajectories correspond to 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.

319 Assuming such a relapse into myopia really happens and prices fall in the near future below
 320 30 €/tCO₂, what would it mean for the energy transition? The general impacts of myopic
 321 foresight in the energy sector have been studied in previous literature^{57–61}. Nerini et al.⁶² show
 322 using the cross-sectoral capacity expansion model UK Times that myopia might result in
 323 delayed climate action and higher total transformation costs, compared to the pathway set by a
 324 perfect foresight model. On the one hand, emissions abatement gets delayed. On the other hand,
 325 the solutions chosen are focused on the near-term, creating lock-ins, and not the most efficient
 326 ones from a long-term perspective.

327

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

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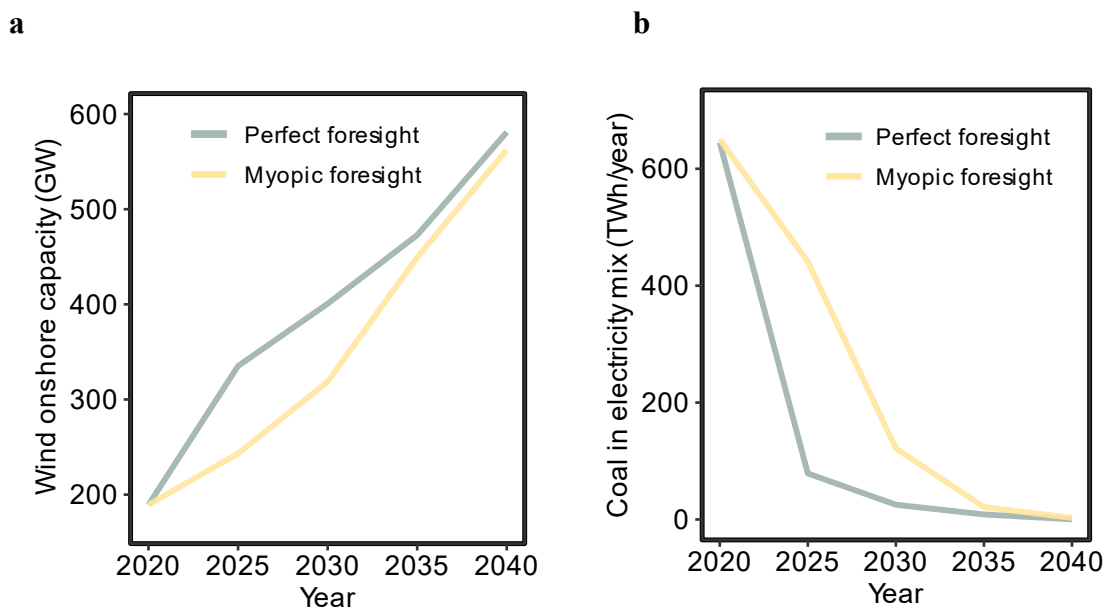


Fig. 7 | Delays in decarbonization due to myopia. **a**, Expansion of wind onshore capacity in the EU under perfect and myopic foresight. **b**, Yearly electricity generation in the EU from black and brown coal under perfect and myopic foresight. Trajectories in both a, and b, correspond to newest targets 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.

344

345 As illustrated in Fig. 7a, our modeling shows that myopia could massively slow down wind
 346 capacity expansion in the next 10 years, with yearly investments reduced by a factor of three,
 347 compared to the cost-optimal (i.e., perfect foresight) trajectory. The missing wind power in
 348 combination with low carbon prices would strongly delay the phase-out of coal (Fig. 7b).

349 These risks are examples of what can happen in the electricity sector. Any delay poses the risk
350 of climate targets becoming out of reach, or being reachable only at very high costs, as feasible
351 roll-out rates can be limited, e.g., due to the availability of skilled workers, or production
352 capacities⁶³. Likewise, the required steeper carbon price in the long-term might increase the
353 likelihood of a political backlash that dismantles the policy⁶⁴. Hence, it is crucial to be aware
354 that carbon prices could principally fall again in the near future, with strong consequences for
355 the energy transition. Exploring potentials of a price floor in the ETS, proposed in the past to
356 address the problem of myopia²⁴, as well as designing complementary policy instruments to
357 shore up the energy transition thus remains critical - despite currently high carbon prices.

358

359

360

361 **Conclusions**

362

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

371 We discuss the hypothesis that policy credibility impacts actors' foresight, and hence carbon
372 prices. Consequently, a glimpse into the future shows that carbon prices could fall again if
373 actors become myopic again (e.g., due to a price shock and reduced policy credibility). A
374 fallback into myopia and low prices can threaten short-term decarbonization efforts. To prevent
375 such a development, additional policy instruments seem advisable to stabilize expectations of
376 agents. As an example, a price floor would limit the drop of carbon prices in the short term
377 when long-term policy credibility is temporarily reduced, and could even keep prices higher
378 without being binding⁶⁵.

379 Overall, we find that observed 2022 and 2023 prices of around 80 €/tCO₂ are in line with EU
380 Climate Law reduction targets and should not be artificially lowered. Compliance actors seem
381 to trust the political commitment and act farsighted – a good sign for the reachability of EU's
382 2030 climate targets of the ETS sectors, if the current energy crisis and related policy reactions
383 do not undermine this mindset.

384

385

386

387

388 **Methodology**

389

390 **The model LIMES-EU**

391 All quantitative results in this work are obtained using the model LIMES-EU (Long-term Investment
392 Model for the Electricity Sector), version 2.38. LIMES-EU is a linear optimization modeling framework
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
395 electricity sector, the energy-intensive industry and district heating are also represented through
396 marginal abatement cost curves. Compared to simple emissions trading models with static exogenous
397 cost abatement curves, using an energy system model such as LIMES-EU allows to assess not only
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)⁶⁶.
401 Hence, one can analyze figures such as the number of allowances in circulation, the intake by the MSR,
402 and resulting carbon prices. By varying the cap and MSR parameters, one can reproduce the state of the
403 EU ETS between different political reforms.

404 A comprehensive description of the LIMES-EU model, including parameters, equations, and
405 assumptions, is provided in the documentation available from the model's website⁶⁷.

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

407

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

409 *Rolling horizon as operationalization of myopia*

410 Originally, LIMES-EU was formulated as a perfect foresight model running in five-year steps from
411 2010 until 2070. For the purpose of this study, to simulate the effect of myopic behavior of decision-
412 makers, we extend the model with the option to use rolling time horizons instead of full intertemporal
413 foresight. Mathematically this means that instead of solving one optimization problem over the whole
414 time period from 2010 until 2070, we solve multiple (consecutive) optimization problems, covering
415 shorter time periods.

416 In our choice to implement a rolling horizon, we follow several other publications from our field: The
417 rolling horizon approach (i.e., short foresight with overlapping time steps) has already been used
418 extensively as a way to represent myopia in the context of energy systems modeling^{57,58,60–62,68–70}.
419 Although principally other approaches would be possible (e.g., by varying the discount rate), we are
420 not aware of any publication in our field representing myopia in a different manner.

421 *Foresight length*

422 All myopic foresight results in this work assume 10-year horizons with an overlap of 5 years between
423 the horizons. Practically it means, actors have foresight of 10 years but can revise their decisions every
424 5 years. As LIMES-EU runs in 5-year time steps, one optimization horizon comprises always two time
425 steps (e.g., [2020, 2025], covering years 2018 - 2027).

426 The literature provides different estimations on planning horizons of manufacturing companies, ranging
427 between 3 and 12 years⁸. Bocklet and Hintermayer⁸, as well as Quemina and Trotignon¹⁰ show that a
428 horizon of around 10 years can best replicate EU ETS developments (these analyses were conducted
429 around the time of the MSR reform). Hence, we also chose a foresight horizon of 10 years. As our
430 model runs in 5-year time steps, 10 years is also the shortest foresight horizon we can meaningfully

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 decarbonization⁶².

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
436 next optimization horizon. It concerns all previous capacity additions and decommissioning (needed to
437 correctly compute current capacities) as well as emissions and banked certificates (needed for the
438 ETS/MSR simulation). For instance, for the optimization horizon [2020, 2025] capacities will be fixed
439 for 2020 and all time steps before 2020. We assume that dispatch decisions can still get revised every
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?*

443 In our study, we use rolling horizons as a tool to represent actors’ myopia due to low trust in the long-
444 term stability of the EU ETS. Hence, our main aim is to depict actors that are myopic with regards to
445 the ETS. Our modeling approach implies that actors don’t consider any information outside of their 10
446 years foresight horizon (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*

455 The MSR, which is originally implemented iteratively as a loop around the main optimization
456 problem⁶⁶, runs in the myopic model version around each time horizon.

457

458

459 **Specific modeling aspects**

460 *Carbon prices*

461 Reported carbon prices (in €/tCO₂) 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 EU27⁷¹. Computed prices after 2023 are in real EUR₂₀₂₃.

467

468 *External investors (financials)*

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

473 To model the impact of external investors, we implement a one-step iteration approach. Hence, we
 474 implicitly assume that both compliance actors and external investors can't react the other group's action.

475 I/ In a first instance, a LIMES-EU run with full myopic foresight without external investors is
 476 conducted.

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

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

$$482 \quad s. t. \quad v_{bought}(t_y) \leq \alpha \cdot p_{auction}(t_y) \quad (2)$$

$$483 \quad \sum_0^{t_y} v_{sold}(t_y) \leq \sum_0^{t_y - 1} v_{bought}(t_y) \quad (3)$$

$$484 \quad v_{sold}(t_y) \leq \gamma \cdot \sum_{t_y \in T} v_{sold}(t_y) \quad (4)$$

492

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

493 Eq. (2) sets a limit on the number of allowances external investors can maximally buy. Herein, α 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 subtraction of allowances transferred into the MSR. In our work, α 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 .

498 Finally, eq. (4) limits the number of allowances that can be sold in a given time step t_y , to prevent all
 499 of them being sold in a single year. Results assume an γ of 0.2, meaning allowances need to be sold
 500 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.

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

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

506 Herein, $p_{investors}$ is the absolute number of allowances bought or sold by external investors. These
 507 influence the level of allowances, as shown in eq. (7). Herein, $v_{tnac}(t)$ is the total number of allowances
 508 in circulation (TNAC) at the end of time step t , $p_{cap}(t)$ the total number of allowances auctioned and
 509 freely allocated, and $v_{emi}(t)$ the total emissions in time step t . Herein, $t \in [2010, 2015, \dots, 2040]$ are
 510 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.

519 As we conduct only one iteration, we implicitly assume that external investors plan all their future
 520 behavior only once and base it on myopic carbon prices. In real world, there is a constant feedback
 521 between prices and investors' buying/selling strategy. Hence, our methodology does not aim to provide
 522 realistic predictions regarding possible behavior of external investors. It is, however, suitable to show
 523 the order of magnitude of the increase in carbon prices, assuming external investors accumulated and
 524 "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 Documentation²¹, the industry and heating sectors are not modeled
 534 explicitly in LIMES-EU but the cost of emission abatement is approximated by marginal abatement
 535 cost curves (MACC). Originally, as they have been designed for runs starting in 2020, both MACCs
 536 assumed a minimum cost of 8€/tCO₂, being a well suited assumption for benchmark modeling, in which
 537 modeled carbon prices always exceed 8€/tCO₂ for relevant ETS scenarios. As in this work certain
 538 counterfactual scenarios yield prices below 8€/tCO₂, we extrapolate the MACC curves to also cover the
 539 price regime of 0-8€/tCO₂ by analyzing the change in industry and heating emissions upon
 540 implementation of the ETS. We thus estimate two additional emissions steps of 45 MtCO₂ in industry
 541 and 15 MtCO₂ in heating that would be emitted additionally compared to historic industry/heating
 542 emissions when ETS prices remain below 5€/tCO₂ and again when they remain below 3€/tCO₂.

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 ⁷² .	> Electricity generation capacities fixed for time step 2015 > TNAC value fixed prior to time step 2015

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 ⁷² and current ²¹ 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 ²¹ 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).

552 For Figures 4, 6, and 7, we exclusively use the “Fit for 55” scenario, representing the current
553 EU ETS state. This simplification serves the purpose of preventing information overload,
554 aligning with the figures' primary objective. These figures are designed to illustrate specific
555 trends or effects rather than striving for an exact replication of historical conditions. In Figure
556 6, we extrapolate our results to 2015.

557 *Modeling assumptions: EU ETS parameters*

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

560 Table Methodology 2 | Parameters used in this study representing the state of the EU ETS between different
561 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	'Backloading', of 900 Mio EUAs between 2014-2016	-	'Rebasing', of 117 Mio EUAs (not specified, assumed in 2024)
MSR			
EUA intake	-	When TNAC > 833 Mio: <ul style="list-style-type: none"> ▪ Intake is 24 % of TNAC until 2023 ▪ Intake is 12 % of TNAC after 2024 	When TNAC > 1096 Mio: <ul style="list-style-type: none"> ▪ Intake is 24 % of TNAC until 2030 ▪ Intake is 12 % of TNAC after 2031 When 1096 > TNAC > 833 Mio: <ul style="list-style-type: none"> ▪ Intake is TNAC – 833 Mio

EUA outtake	-	When TNAC < 400 Mio:	
		<ul style="list-style-type: none"> ▪ 200 Mio until 2023 ▪ 100 Mio after 2024 	
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*

564 All results in this study related to ETS targets from the “Fit for 55” package assume parameters from
565 the Commission’s proposal published in July 2021⁴¹. As this study takes into account real ETS prices
566 until December 2022, it is plausible to assume that until then market actors were basing their decisions
567 on the Commission’s proposal, not being aware yet of the upcoming changes in the final negotiations.

568 The final agreement between the Council, Parliament and Commission was reached in December 2022
569 and includes minor changes related to the linear reduction factor and the operation of the MSR⁴².

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
573 agreement is implemented accordingly to the text of the trilogue agreement^{42,73} 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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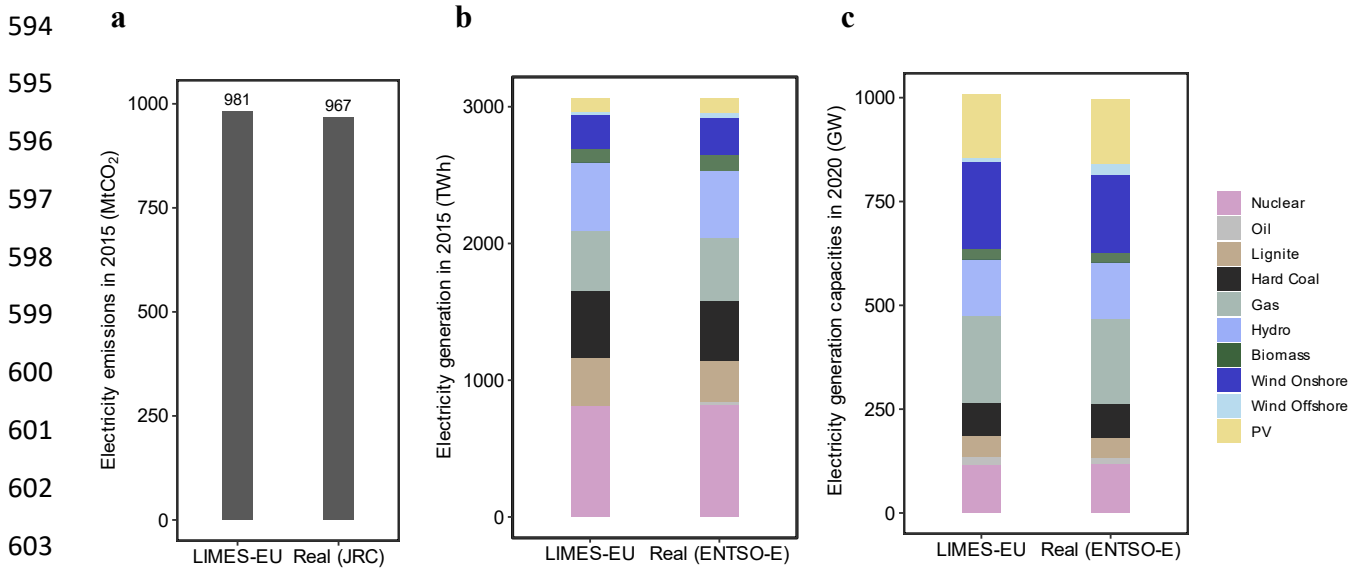
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604 **Fig. Methodology 1 | Comparison of 2015 model results with historical data.** **a**, Emissions from electricity
605 generation in year 2015. Real emissions from the Joint Research Center (JRC) Dataset IDEES⁷⁴. **b**,
606 Electricity dispatch in 2015. Real dispatch from ENTSO-E Power Statistics⁷⁵. **c**, Planned capacities for
607 year 2020. In myopic mode, the model takes this investment decision in time step 2015, hence the
608 2020 generation capacities serve to validate decisions in time step 2015. Real capacities from ENTSO-E
609 Transparency Platform⁷⁶. 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
611 by LIMES-EU amount to 981 MtCO₂, closely aligning with the historical emissions of 967 MtCO₂ as
612 reported by Mantsos et al.⁷⁴ Since emissions from industry, heating, and aviation are also calibrated to
613 match their historical 2015 levels (as described in LIMES-EU documentation²¹), this calibration ensures
614 that our model generates meaningful values for total emissions in the 2015 time step. Also, the model-
615 endogeneous investments in 2015 lead to standing capacities in 2020 that match historic wind and solar
616 capacities in 2020. To this aim, we additionally assume subsidies for electricity generated from solar or
617 wind sources (0,04 €/kWh for solar and 0,015 €/kWh for wind) to represent the various renewable
618 subsidies that were in place in most EU member states. Our model, however, underestimates the
619 capacity additions of offshore wind until 2020, which took place mostly in the UK.

620

621 *Reproducing historical developments in time step 2020*

622 Scenario: perfect foresight, EU ETS post-MSR reform

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

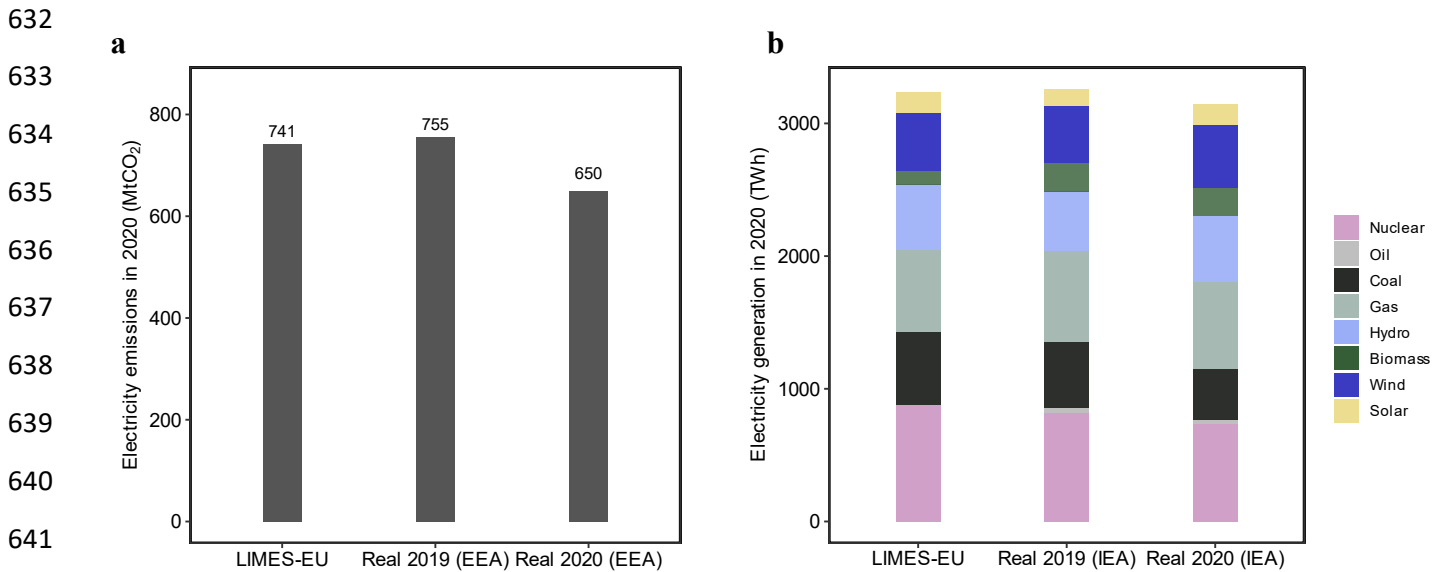
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642 **Fig. Methodology 2 | Validation of historical time step 2020.** **a**, Emissions from electricity generation in
643 year 2020 and 2019. As we are not aware of a data source providing 2019 and 2020 emissions for the
644 electricity sector, we estimate real electricity sector emissions by taking EEA ETS emissions data for
645 “combustion of fuels” and assuming that electricity generation accounted for 79% of this (in 2015,
646 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 dataset⁷⁷. 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.

653 With respect to electricity dispatch, our model estimates lower generation from biomass compared to
654 IEA historical data. This discrepancy may be attributed to several factors, including our reliance on the
655 ENTSO-E dataset for total capacities, while using the IEA dataset for generation values (as ENTSO-E
656 lacks a Statistical Factsheet covering generation for the years 2019 and 2020). Differences in values
657 from different sources can often be substantial. Regarding biomass, variations may be due to, e.g., the
658 way biomass co-firing in coal power plants is accounted for. Nevertheless, despite minor deviations in
659 our 2020 electricity dispatch from historical data, our model still provides a meaningful estimate of
660 emissions. This aspect is critical for validating EU ETS models, as it directly impacts CO₂ prices, the
661 total number of allowances in circulation, and the functioning of the MSR

662

663 *Estimating future developments*

664 While validating future projections is inherently impossible, we observe that LIMES-EU generally
665 aligns with findings in the literature and does not produce results that are far outliers compared to other
666 models. Osorio et al. discuss that LIMES-EU's estimates of MSR cancellations are consistent with other
667 studies⁶⁶. Furthermore, a recent model comparison study led by Henke et al. revealed that LIMES-EU's
668 projections for various EU electricity sector variables from 2020 to 2050, such as final energy demand
669 and the share of renewable energy sources in electricity generation, are in line with the range provided
670 by ten other energy systems and IAM models⁷⁸. In another model comparison study assessing EUA
671 prices until 2030, LIMES-EU's estimate of 140€/tCO₂ falls within the range of 80€ to 160€/tCO₂
672 produced by six different models⁷⁹.

673 **Methodological contribution**

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

685 Data for core model assumptions (investment costs, fuel costs, etc.) are provided in the LIMES-EU
686 documentation (Methods). The dataset containing all results displayed in this paper is publicly available
687 at: [10.5281/zenodo.10363561](https://doi.org/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 been
691 started to make the model available under an open-source license. When this process will be completed,
692 the code will be available for download from the PIK webpage <http://pik-potsdam.de/limes>.

693

694 **Author contributions**

695 R.P. and G.L. suggested the research question. J.S. and R.P. jointly conceived and designed the study
696 in consultation with S.O. and G.L. J.S. extended the model, conducted scenario runs and created
697 visualizations. J.S., R.P., M.P., G.L. and S.O. interpreted the results. J.S. wrote the manuscript with
698 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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707 ClimAte Policy AcceptaBiLity Economic framework), as well as funding from the European Climate
708 and Energy Modelling Forum (ECEMF, H2020 grant agreement No 101022622).

709

710

711 **Extended Data**

712

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 CO₂ prices assuming myopic or perfect**
 716 **foresight.** This table supplements Fig. 3 by providing values of the MAPE error between modeled CO₂ prices and
 717 real historical EUA prices. Highlighted in bold are the runs with the lower MAPE, hence lower error compared to
 718 real historical EUA prices. MAPE is calculated as the average absolute percent difference between two numeric
 719 vectors⁸².

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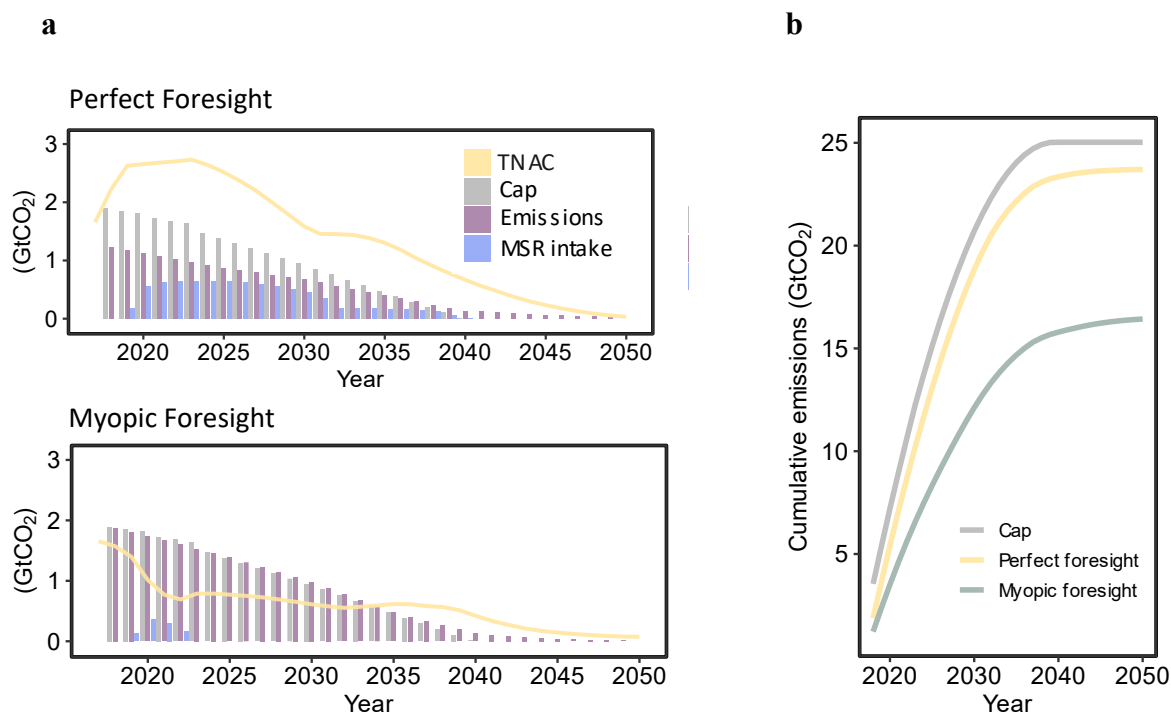
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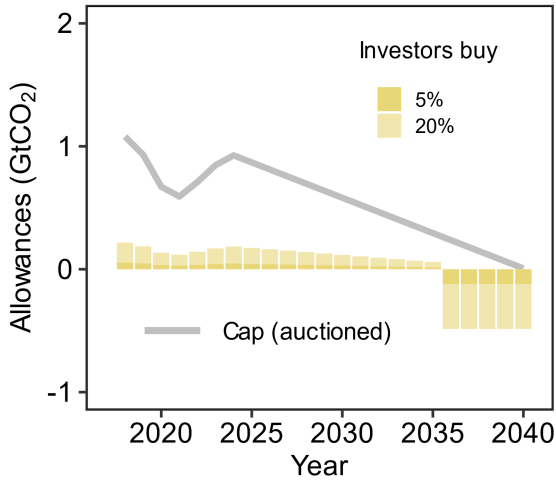
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Extended Data Fig. 1 | Interactions between foresight horizon and MSR. a, Total number of allowances in circulation (TNAC), theoretical cap (allowances to be freely allocated and auctioned before accounting for MSR intake or outtake), total emissions, 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.



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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).

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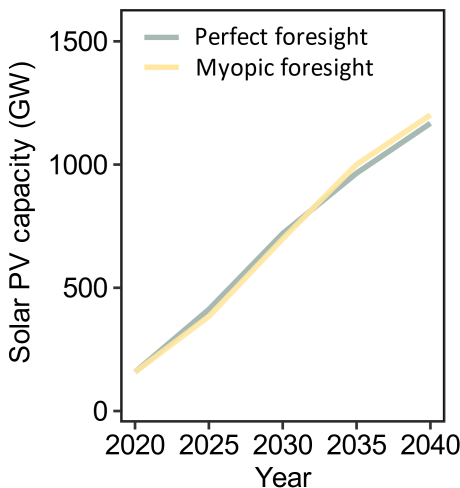
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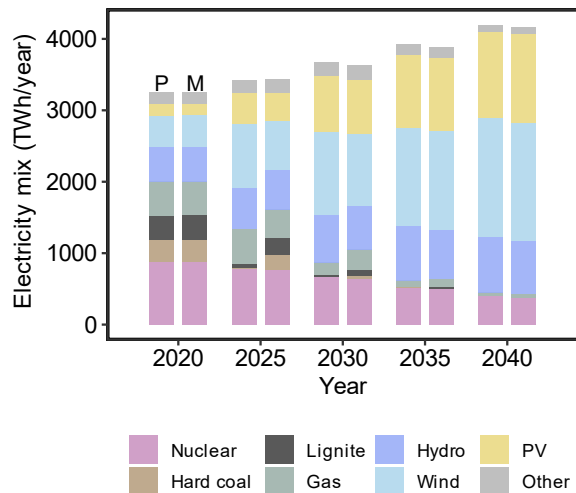


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Extended Data Fig. 3 | Delays in decarbonization due to myopia. All results in this figure complement Fig. 7 and correspond to runs with targets from the "Fit for 55" proposal with an active MSR. **a**, Expansion of solar capacity in the EU under perfect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

753 Extended Data Table 2 | EU ETS caps and MSR parameters: differences between (i) “Fit for 55” initial proposal and
 754 (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 (LRF)	4.2 % (‘Rebasing’, of 117 Mio [not specified, assumed in 2024])	4.3 % from 2024-27 and 4.4 % from 2028 onwards (‘Rebasing’, of 90 Mio in 2024 and 20 Mio in 2026)
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 ~43% of the cap	Path defined and to be phased out by 2034

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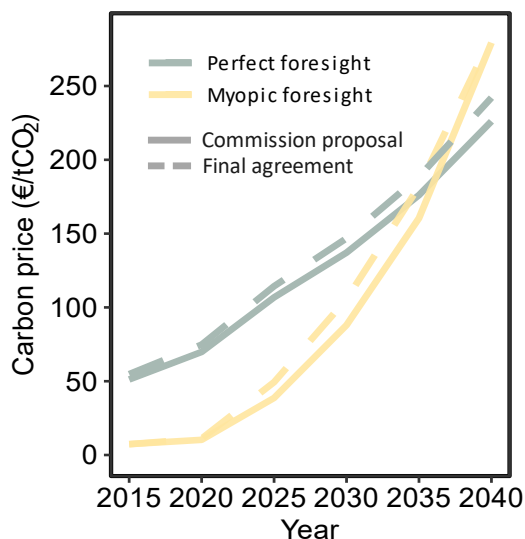
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Extended Data Fig. 4| “Fit for 55” Commission proposal vs. Final agreement. Carbon prices corresponding to targets from the Commission’s proposal (used throughout the whole study) and carbon prices corresponding to targets from the final agreement after trilogues. All scenarios include the MSR.

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