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Persons in Charge	Paul Ekins, Sebastian Osorio
Checked by Action Leader	Albert Ferrari
Verified/Reviewed by	Lea Heinrich, Marie Raude
Approved by Project Director	Simone Borghesi

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ROBERT SCHUMAN CENTRE

Tel. +39 055 4685 703
FSRClimate@eui.eu

Casale, Via Boccaccio 121
50133 Firenze (FI), Italy
www.eui.eu

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Summary of the first International Conference on Ex-Post Evaluation of Emission Trading

by Paul Ekins

Conference: goal and set-up

The purpose of the conference held on Tuesday 20 June was "to identify the latest policy-relevant studies on ex-post assessments of emissions trading", with a special focus on carbon leakage, competitiveness, and distributional effects of the European Union and other major Emissions Trading Systems (ETS). The conference had four sessions:

Keynote lecture: "The distributional impacts of market-based climate policy: State of knowledge and future directions for research"

Session 1: "Competitiveness and Carbon Leakage"

Session 2: " Policy Roundtable - Carbon leakage: (how) can we effectively prevent that risk?"

Session 3: "Social impacts and acceptability of emission trading"

The full Programme, with presenters, is given in Appendix 1. The Abstracts and the Slides of the papers presented in sessions and of the Keynote Lecture are linked in the programme and accessible online on the webpage of the event.

Introduction

Carbon pricing has long been economists favoured tool of carbon emissions reduction. It is increasingly being applied, both as carbon taxes and through Emissions Trading Systems (ETSs). However, carbon prices are still typically low, and well below both mainstream estimates of the Social Cost of Carbon (SCC) and the carbon prices estimated to be required to meet the temperature targets of the Paris Agreement.

Two main barriers to carbon pricing recur increasingly in the relevant literature: fears about negative impacts on the competitiveness of businesses if carbon prices are imposed unilaterally at the national level; and concerns about fairness, especially in relation to low-income households and individuals. Steckel (slide 4) identifies fairness concerns as relating to self, to others, and to trust in government to take these concerns into account, including through the use of the revenues from carbon pricing.

This report of the conference discusses the distributional and social acceptability issues raised first (Keynote lecture and Session 3), and then moves on to the conference discussion about competitiveness (Session 1). Insights from the Policy Roundtable (Session 2) are interpolated as appropriate.

Distribution and Fairness

The distributional issues related to carbon pricing are largely driven by perceptions of 'fairness' – to self, to others and in respect of governmental procedures for its introduction. Most obviously, such issues can be considered between different income groups, e.g. between the richest and poorest groups, what Steckel calls 'vertical distribution', but also looking at 'hardship cases' within different groups ('horizontal distribution'). Governments obviously have the option of changing the first-order distributional effects from the carbon pricing by making transfers within or between groups, perhaps using the revenues from the carbon price, or by using the revenues in different ways. What they do with the revenues, and how they do it, is important not just for the distributional outcome but also for perceptions of procedural fairness.

The headline findings of Steckel's analysis are that carbon pricing is more progressive in poorer countries, when it is applied to transport, and when its wider economic effects are taken into account (slide 9).

Between groups, the key variable that determines whether the first-order effects of carbon pricing are regressive is expenditure on carbon-based energy. In richer countries, such energy expenditure is normally a higher proportion of poor households' expenditure than for rich households, so that the first-order effects are regressive, but this is not true for poor countries. In the data set for Steckel's analysis (that excludes North America and most European countries), carbon pricing is not regressive for the Sub-Saharan African countries except South Africa, for Latin American countries except Peru, and for most Asian countries, including China and the countries of South and South-East Asia (slide 10), although there are regional differences within countries (slide 12), and the effects in individual countries depend crucially on the design of the carbon tax. Policy-relevant studies of carbon pricing need to take regional and local differences into account.

Within groups, there can be huge variation in first-order effects of carbon pricing. For example, while in Vietnam the median effect on the poorest quintile was 2.4%, 5% of that quintile experienced an effect of more than 7% (slide 14) – and it is often different categories across groups (e.g. rural vs urban, or car ownership) that generate the largest political impacts. In Latin American countries, while in the majority of countries energy expenditure was the most important variable in explaining the impacts of carbon pricing, for Costa Rica, Dominican Republic, Guatemala and Mexico, the key explanatory variables were car ownership and cooking fuel (slide 16). Unintended consequences from carbon pricing or subsidy reform can also be important, as when the removal of fossil fuel subsidies for clean cooking fuels causes a resumption of reliance on biomass for cooking, with its negative health and environmental effects (slide 17). However, the first-order, within group, category and side effects vary so much according to the context that generalisations are not helpful and each case needs to be assessed in its own right.

Much the same is true when governments seek to compensate for distributional effects through tax reform or social transfers, when much depends on the existing structure of taxation and the coverage of social transfer schemes. In each case, it is possible to design a system that is progressive overall, but which still misses out non-negligible proportions of the poorest and worst affected households (slide 22). When transfers are used, a targeted transfer will be more beneficial for the majority of low-income households but will exclude certain 'hard-to-reach' poorer households, while a universal transfer, such as a lump-sum per person or household, will be more inclusive (slide 38). That said, where lump sum distribution has been tried, evidence from Canada suggests that people have a pretty inaccurate perception of what sums they are actually receiving, and their perceptions tend to align more with their political orientation than with the reality of the situation (slide 27). Governments which wish to use carbon pricing should put effort into communication about what they are doing, why and how they are using the revenues.

An interesting result on an alternative use of the revenue is that in some cases compensation schemes can be made twice as progressive by using (some of) the revenues to invest in basic infrastructure (e.g. electricity, sanitation, water) for the poor (slide 24). However, the time lags for the investment benefits to become apparent may not help with the immediate acceptability of the carbon pricing measure.

Social acceptability and economic impacts

The theme of perception, and social acceptability more generally, was picked up in Session 3, the papers in which examined the issue from very different angles. Existing research suggests that people evaluate carbon pricing against three criteria: costs to self, fairness and effectiveness. Those who oppose carbon pricing do so because they do not perceive it to be effective, although levels of support can be increased by devoting the revenues to 'green spending', and, perhaps, avoiding the use of the term 'tax' and levying it upstream.

One approach to carbon pricing in climate policy which has so far not won the support of policy makers is a mandatory global policy that applies to all countries. Yet a global survey, reported on by Fabre, finds high levels of support for such policy, whether this entails dividing up the global carbon budget between countries, on the basis of their population, or levying a global tax on millionaires to finance sustainable development in low-income countries. Focusing specifically on the Global Climate Scheme (GCS), an emission trading system in which a basic income is paid to all people out of the proceeds of emission auctions, Fabre finds a modest level of global support, with generally stronger support in European countries than in the USA. This support is broadly replicated for a whole range of other policies that would result in redistribution from richer to poorer countries to enable climate action in those countries. Moreover, further tests suggest that this support is sincere, that it is not the result of social desirability bias and that the GCS would not be unpopular electorally. There is therefore a conundrum that such stated support has not yet translated into actual global policies along these lines. There is as yet no clear explanation as to why this is the case.

Another survey reported by Funke examined differences in perceptions and attitudes in relation to carbon taxes and emissions trading, with the former being hypothesised as more salient to consumers and, perhaps, government, and the latter more relevant to businesses. Relative support for these two instruments varies in different European countries, but overall stands at about 40% for each. Preliminary work correlated the support for each instrument across a wide range of characteristics and perceptions, some of the most significant of which are reported here (slide 10). For example, the possession of a college degree was positively correlated with support for a carbon tax but slightly negatively correlated with emission trading. Concern about climate change was, perhaps unsurprisingly, positively correlated with support for both tax and trading, with tax showing the more positive correlation. There was a positive correlation too between carbon pricing (both tax and trading) and those with a green voting preference, with tax again showing the stronger correlation. Those with liberal voting preferences showed a positive correlation with support for trading but a negative correlation with support for a tax. The belief in a strong role for government in the net-zero transition correlated with support for both tax and trading, with tax again the slightly stronger correlation. While perceptions that the instrument was easy to evade was correlated negatively with support for an ETS as expected, it was surprisingly correlated positively with support for a tax. Support for both instruments was correlated positively with perceptions of trust in government, but only for trading with perceptions of trust in business. Support for both instruments was also positively correlated (trading more than tax) with perceptions of equitable burden sharing, but only support for trading was correlated with perceptions that the instruments increased the government budget. Support for both instruments was strongly correlated (trading more than tax) with perceptions of both their effectiveness in reducing emissions and their positive effects on innovation. On the negative side, support for both instruments was negatively correlated (tax more than trading), with perceptions that they increase the cost of living and had a negative effect on the economy. Perhaps as a result of this, support for both instruments was negatively correlated with those in the lowest income tertile.

Comparing a carbon tax and the EU ETS directly (slide 11), the most significant effects of a shift from a carbon tax to trading were perceived to be increased fairness of both burden sharing and ease of evasion, and lower effectiveness of emission reduction, negative effects on the economy, increases in the cost of living and increases in the government budget.

There are two types of revenues available to governments from the EU ETS: revenues from auctions, 50% of which are intended to be invested in decarbonisation, and funds from the 10c derogation applicable to some countries to help them modernise their electricity sectors. Poland was the largest EU recipient of derogation 10c funds. One presentation (Sobkiewicz and Kobyłka) evaluated the impact of these funds in Poland from 2012-2020, focusing particularly on the impacts of these funds on the level of investment and the development of infrastructure in the context of the energy transition and the achievement of sustainable development objectives.

The evaluation showed that the auction revenues were not invested in ways that brought about significant additional decarbonisation, and there were few investments in infrastructure. The 10c derogation funds financed 378 projects, but 82% of these were focused on coal-fired plants, and only 1% involved investment in renewables. Nor did the derogation funds fulfil the other required objectives of these funds, namely that they should contribute to diversification of the supply mix and should not cause distortion in the power market. These funds were allocated to the coal-fired power sector and resulted in a negligible (1% increase in renewables). Neither funding sources were therefore effective in contributing to the objectives for which they had been established. It may be that the changes to the regulations after 2020 will lead to an improvement in the way these funds are being used.

The EU ETS is of course just one emissions trading system, and in recent years, many other such systems have been established, or are under development. In fact, trading seems to be outpacing carbon taxation as the pricing instrument of choice. At the same time, carbon prices in these systems are becoming both higher and more volatile, and this introduces both uncertainty for businesses in the business cycle and potential risks for the financial system.

A specially constructed model showed that the two main drivers of the ETS price and its associated volatility, in respect of the EU ETS, are 'abatement shocks' (i.e. the trajectory of emission reduction) and 'climate sentiment shocks' as a result of other climate policies (Benmir, slide 25). Optimality in respect of carbon pricing is achieved when the carbon price follows the social cost of carbon (SCC). A comparison between this and the ETS price shows that the SCC is a factor of 10 less volatile than the ETS price (slide 28). A carbon cap rule that adjusts the cap in order to make it as close as possible to the SCC is shown to reduce significantly the volatility in the carbon price from the ETS.

Competitiveness and Carbon Leakage

As noted in the Introduction, fears about the loss of competitiveness and carbon leakage are the second of the two main barriers to the implementation of carbon pricing at the national level, in the absence of a global carbon tax. Despite these continuing concerns, the literature to date is relatively clear: there is no evidence of negative effects from carbon pricing on productivity and employment; there is very little evidence of carbon leakage; and there is some evidence of innovation in terms of directed technological change, which may benefit competitiveness.

Wang's presentation explored these issues in relation to the introduction of the ETS in Beijing. Phase 1 of this ETS ran over 2013-2015 and involved firms with emissions greater than 10 ktCO2. An interesting difference between the introduction of this scheme and that in Europe was that in Europe the criteria for being involved in the scheme were announced well in advance, whereas in China the criteria were only announced immediately before the scheme was introduced, so there was no 'announcement effect' before the scheme's introduction. In Phase 2, from 2016, the threshold for inclusion in the scheme was lowered to 5 ktCO2. By estimating the emissions reduction in affected firms over 2013-2015 they showed that there was significant emissions reduction in industry, but no significant reduction in service sectors, with the reduction among heavy coal users being the largest of all (slide 15). The main abatement mechanism seemed to be fuel-switching away from coal. A further piece of analysis indicated that the way emission allowances were allocated did not significantly affect emissions, except perhaps among smaller and service sector firms, for whom the transaction costs may have been non-trivial.

The presentation by Bremer explored many of the same issues, specifically competitiveness (employment and profits) and technology adoption (investments) in relation to Dutch manufacturing firms (actually coherent' business units' in these firms) involved in the EU ETS, split into three cohorts, with Cohort 1 (the most energy-intensive) involved in the ETS's Phases 1, 2 and 3, Cohort 2 only involved in Phases 2 and 3 and Cohort 3 only involved in Phase 3. The findings of the regressions (slides 17 and 18), which compared the companies in the ETS with matched controls, suggest (using a difference-in-difference [DiD] methodology) that Cohort 1 experienced some initial negative effect on employment in Phase 1, but that this disappeared in Phases 2 and 3, while this effect persisted through the three Phases when using a two-way fixed effects methodology (TWFE) (i.e. methodology matters). Neither method showed significant effects on profits, but DiD did show a lasting negative effect on investment, which was absent in TWFE.

The impacts of the EU ETS on industrial competitiveness were also the focus of Cameron's presentation, with the addition of the associated risk of carbon leakage. The literature on the risk of carbon leakage is divergent. Theoretical studies suggest that the risk is high, ex ante modelling finds that it depends highly on input assumptions, such as elasticities, and ex post evaluations suggest that it is small. It is possible that explanatory factors for this divergence may include the allowance allocation method (e.g. free allocation), the stringency of the policy (with ETS prices being low until quite recently) or the structure (e,g, the degree of monopoly) of the industries concerned. In terms of measuring the risk of carbon leakage, the European Commission's indicators (trade intensity, emission intensity, and qualitative assessment of threshold cases) have been found to overestimate the carbon leakage risk. The focus of this paper is to explore the potential implications of market structure for carbon leakage risk, by using a hypothetical monopolist test for market power (asking whether the profit after a 5% price increase is higher than before the increase), and estimating substitution elasticities for different products (in this case hydraulic cement, clinker, and flat and long steel) over the period 2008-2018. The main results of this estimation (slide 9) suggest that "cement products are more substitutable between countries than steel products; sub-products do not vary substantially in terms of their substitutability"; and that steel is mostly traded in national markets while cement has mostly regional and sometimes global markets. The focus of this paper on substitutability is complementary to a focus elsewhere in the literature on pass-through rates of the value of emission allowances, and an interesting extension of this work would be to link the two concepts.

The focus in this session then shifted in the presentation by Arlinghaus to the way in which climate policy, especially the EU ETS in Europe, affects the financial sector, given the price volatility of EU ETS allowances and the differential exposure of firms, and therefore banks, to the EU ETS. In Phase 3 of the EU ETS the introduction of the Market Stability Reserve and increase in the Linear Reduction Factor (LRF) in the supply of allowances put upward pressure on the EU ETS price. At the same time, the introduction by the European Central Bank of a Negative Interest Rate Policy (NIRP) in 2013-2014 constituted a shock to the financial sector that was felt differentially by banks, with those with the highest deposits/assets ratios the most affected. The result is that the most affected banks had a stronger incentive to increase their lending, and the paper analysed whether they did so differentially between ETS and non-ETS firms. The results of the analysis suggest that banks increased their lending in the short run to ETS more than to non-ETS firms, and reduced the required collateral for these loans, and their estimated probability of default, for these ETS firms. While the reasons for these results are unclear, one hypothesis is that, in line with the Porter hypothesis, the regulation through the ETS caused ETS firms to increase their innovation and investment.

The emphasis on possible carbon leakage from carbon pricing was continued in the presentation by Trinks, except that the analysis in this paper, covering 15 industrial sectors and 32 countries over 2000-2014, used both explicit and implicit carbon prices, with the latter being estimated from other taxes (e.g. fuel duties) or other measures of climate policy, such as standards and regulations. Six dimensions of firm performance (sales revenue, investment, employment, profitability and firm exit) were regressed against these carbon costs, and only employment showed a significant but small reduction, with a USD 50/tCO2 carbon price leading to a 2.5% reduction in employment (slide 7). However, the results show considerable heterogeneity across different types of firms, with the greatest effect on employment being shown in small firms most subject to leakage risk, which also showed the largest increase in productivity, while large and capital-intensive firms in leakage sectors showed the greatest (but still quite small) increase in investment. Both profit and the probability of exit were hardly affected at all for any type of firm. Both the (negative) employment effects and (positive) investment effects were most clearly shown in EU countries. There is thus little evidence in this analysis for adverse economic effects and relocation from carbon pricing, and such small effects are seen as concentrated in small sub-groups in mainly leakage sectors. One possible explanation for this is that carbon costs over the period were relatively low, and they may therefore have larger effects in the future if they increase significantly, although countervailing policy measures, such as the Carbon Border Adjustment Mechanism (CBAM) may be introduced to mitigate this.

CBAM was the explicit topic of the presentation by Wildgrube, which first explored whether CBAM creates a 'level playing field' for the products (iron and steel, aluminium, cement, electricity, hydrogen, ammonia and fertilisers), to which, from 2027, it will apply. In principle, CBAM will equalise carbon costs for the covered products when sold in the EU. However, many other market distortions will remain, including carbon costs in export markets and special financial support in some EU countries for electricity and renewables, while importers may be disadvantaged by CBAM's incidence on imported products, whereas the EU ETS applies to installations. In fact, given the huge differences that exist in markets in different countries, it may be that the focus on the level playing is misleading, and may even stand in the way of industrial transformation which has historically been a characteristic of industrial development. To enable low-carbon transformation in the EU, perhaps the policy focus should be on installing low-carbon infrastructure, developing low-carbon technologies and providing regulatory certainty. Abroad, it may be that the EU should seek to encourage carbon pricing more flexibly than seeking to equalise carbon costs between its own products and imports in its own markets. If the focus is to be on industrial transformation, then clearly research has a crucial role to play in the development of technologies and of scenarios as to how such transformation might take place and what it would look like.

Another exploration of the effects of a border carbon adjustment (BCA) was presented by Pommeret, in the context of a wider piece of work on short-run transition risk from climate policy. Such risk could arise from multiple interacting causes including Keynesian shock (investment), inflation, input substitutions, stranded assets, labour adjustments (with sectoral heterogeneity), technological change, shocks on competitiveness, sufficiency/sobriety (lifestyle change), critical raw materials, social acceptability, and financial contagion. The focus of this paper was on the last of these, modelling how ambitious climate policies such as a carbon tax and BCA might transmit across borders, with and without financial frictions. Scenarios explored the impact of an unexpected carbon tax of USD 80/tCO2 being imposed in the home economy, both with and without financial frictions. Without these frictions, there is carbon leakage and negative economic impacts on the home country's polluting industry, as capital flows abroad and into the green sector at home. Introducing financial frictions exacerbates the negative economic impacts at home, reducing output also in the home non-polluting sector, but also has a negative impact abroad, the carbon tax shock being transmitted through both home and foreign banks, and resulting in a lower capital stock in both the polluting and non-polluting sectors. In this case, there is still carbon leakage, but it is smaller. The imposition of a BCA on foreign polluting goods amplifies all these negative effects, but reduces leakage further. A conclusion of the paper is that it seems important to take account of financial sector linkages when assessing the impact of both carbon taxes and BCAs.

The presentation by Feng concentrated on the practical details involved in the CBAM, specifically on the procedures that might need to be followed by importers of goods in the covered sectors into the EU in order to verify the carbon intensity of their products. For simple products, it might be sufficient simply to calculate the carbon intensity of the power inputs to production. But for complex products, for example from the chemical industry, determining their carbon intensity would involve complex processes of life cycle assessment, involving multiple stakeholders. The complexity means that it is unlikely that a single 'one-size-fits-all' set of guidelines or regulations would be adequate, but at the same time a case-by-case approach may not be manageable. Feng proposed a "coordinated social governance scheme" involving guidelines from the government, a self-regulated assessment by industry, with professional third-party certification, with social reliance on competitors, NGOs or whistle-blowers within the company to expose poor or inadequate practices.

The panel discussion picked up the USA's Inflation Reduction Act (IRA) as an alternative means of accelerating the clean energy transition without disadvantaging (or aiming to promote) national competitiveness. The IRA seeks to stimulate innovation and boost low-carbon industrial transformation by directing federal spending and tax breaks amounting to $500 billion. It was pointed out that issues of cost-effectiveness and cost internalisation are better addressed by carbon pricing rather than subsidies. Perhaps some combination of carbon pricing and innovation support would be the best approach, and would be better still if a single approach could be harmonised across countries. While such harmonisation has been achieved in some health-related sectors, e.g. pharmaceuticals or food standards, it would probably prove more difficult to achieve with carbon abatement.

Conclusion

In respect of the distributional impacts, the key issues discussed seem to be the targeting of compensation schemes, and their communication to ensure that stakeholders, and particularly those most impacted by the schemes, are more aware of them. Notwithstanding evidence of a lack of awareness of carbon pricing and mechanisms for using the revenues therefrom, a global survey suggests widespread majority support for carbon pricing, which leaves the unanswered conundrum why policy makers have so far not succeeded in introducing a global carbon price.

On competitiveness and carbon leakage, two very different approaches to address these issues are being tried in Europe (CBAM) and the USA (IRA). However, in the session devoted to this topic, as elsewhere in the literature, no convincing evidence of carbon leakage as a result of the EU ETS was presented, although one of the models presented did suggest that a carbon tax induced a slight negative effect in output in both the EU and outside it. So it may be that the whole emphasis in CBAM discussions on creating a 'level playing field' is misplaced, and distracts from the main necessary task of stimulating innovation and low-carbon industrial transformation.

Summary of the first Workshop on Ex-Ante Assessment of Emissions Trading

by Sebastian Osorio

Workshop: goal and set-up

The first annual workshop on ex-ante assessment of emissions trading took place on Monday 5 June 2023. It was devoted to the comparison of selected macro-economic models simulating the development of the European Union Emissions Trading Scheme (EU ETS) and other major emissions trading systems. At a time when emissions trading systems increase in number and face similar problems, only a few comparisons of ex-ante models exist. The goal of the project's workshop on the ex-ante assessment of emissions trading was to step up the benefits of knowledge sharing and mutual learning by collecting scientific evidence from different emissions trading systems worldwide.

This document presents the main takeaways and insights from a workshop organised under the framework of the LIFE COASE project – Collaborative Observatory for ASsessment of the EU ETS. The workshop convened experts from five organisations that operate carbon market models – academic institutions as well as carbon market analysts (see Figure 1). The final programme of the workshop can be found in Appendix 2. Contributions from one model (Refinitiv), which was not presented at the workshop, is also included in this document.

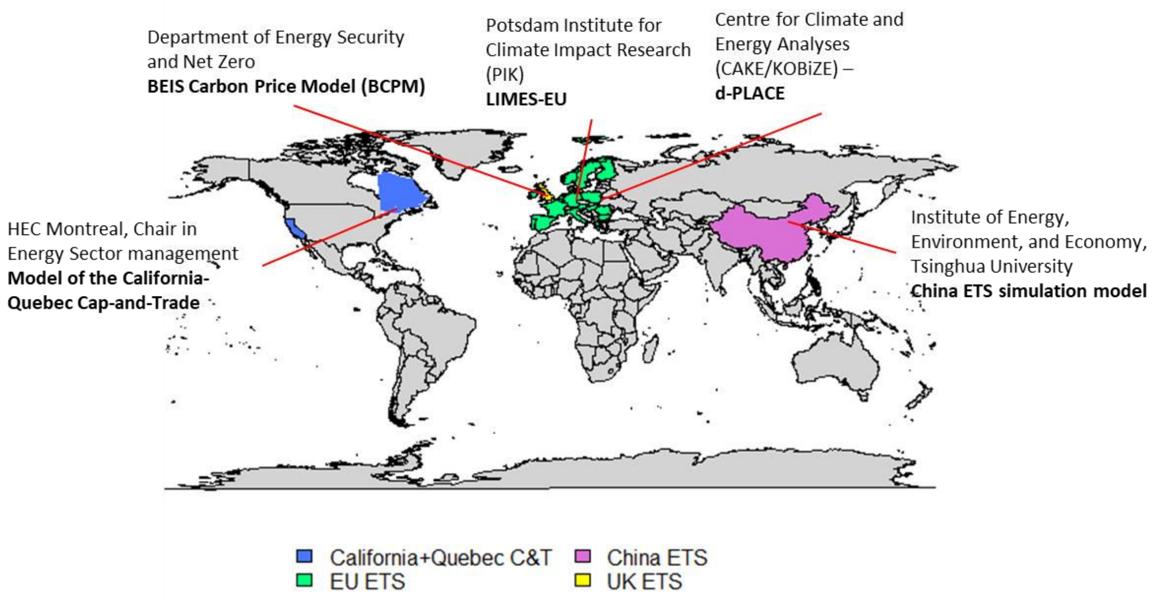

Figure 1. Models presented at the workshop with their corresponding institutions and carbon markets covered.

The workshop's goal was to discuss the types of models, implementation details, and core assumptions employed in the analysis of carbon prices from models around the world. More specifically, the workshop took stock of the diversity of approaches, provided insights on the operation and expected challenges of the respective carbon markets, and identified the main drivers affecting the price dynamics of carbon prices through the end of this decade and beyond. In preparation for the workshop, all participants took part in a survey and provided a short model fact sheet, information about future carbon prices, and an assessment of what they view as the main price drivers in 2030/2050, depending on the model focus. The completed questionnaires can be found in Appendix 3.

The carbon markets

The workshop comprised two sessions. During the first session, the presentations focused on the EU ETS, while during the second session, the presentations focused on non-EU carbon markets, namely, the California+Quebec C&T, China ETS and UK ETS. The five regions' emissions account for 17.4 $GtCO_2$, i.e., 46% of the world's total emissions. The range of emissions covered by each of the carbon markets by its jurisdiction vary between 28 and 74%, while the emissions covered altogether represent 20% of the world's total emissions (European Commission and Joint Research Centre, 2022; ICAP, 2022).

During the first session, the two models LIMES-EU and d-PLACE were presented. Despite the differences in their approach, both LIMES-EU and d-PLACE models have a very clear policy focus, to assess the most recent reforms implemented by the European Commission, in particular those related to the EU Green Deal. The presentation of the d-PLACE model included an analysis of the potential impact of new sectors within the EU ETS, e.g., the option of having an ETS that covers all sectors of the economy. The analysis of the model LIMES-EU focused on the role of the Market Stability Reserve (MSR) in tightening further the EU ETS and the required sharp decrease in emissions, pointing to the particular role of the power sector being almost fully decarbonised by 2030, while the energy-intensive industry would play a more important role after 2030. Both studies emphasised the urgency of exploring alternatives for the EU ETS after 2030 as the models predict that the last allowances would be issued by 2040. This implies that the EU ETS could be jeopardised due to the risk of illiquidity and price distortions. In that sense, the scenarios evaluated with d-PLACE already provide some insights on the effects of expanding the EU ETS by, for instance, merging it with the ETS for buildings and road transport (BRT ETS).

On the non-EU side, the presentations allowed us to address the challenges faced by the -so far-smaller or less mature carbon markets compared to the EU ETS. One issue stands out: the overallocation or excess of allowances in these markets. In the case of California+Quebec, the initial coverage planned during the early stages of the market was used for the allocation of allowances. This initial coverage was however more ambitious than the implemented coverage, leading to overallocation. Another factor reinforcing overallocation in the California+Quebec system is the presence of offsets (up to 4% of emissions in Quebec and 8% in California). The UK ETS, created after Brexit, also faces overallocation due to its too generous cap. This cap was set by taking the UK's share in phase IV of the EU ETS. Besides not being yet in line with UK's net-zero strategy,[1] this cap has recently proven to be excessive as emissions in 2022 (111 $MtCO_2$) were already below the 2030 cap (117 $MtCO_2$). Although it is not possible to assess ex-ante whether the Chinese ETS will also face overallocation, a 'typical' cap-and-trade system (C&T) could lead to abatement at lower costs, compared to the proposed tradable performance standard (TPS). The latter implicitly subsidises output (Fischer, 2001), which compromises cost-effectiveness relative to C&T.

To analyse these dynamics and future challenges, different models have been designed. The models discussed during the workshop have different main features. Their approaches also vary widely, which we show in the next section.

Questionnaire results

The questionnaires unveiled that the main characteristics and features differ across the models (see Table 1). That said, all models except for the California+Quebec model are (single agent) optimisation models, and most of them follow mainly a top-down approach. Although optimisation models following a top-down approach constitute an efficient tool for long-term planning and provide high-level policy assessment, they lack capturing better market dynamics. This can be tackled by complementing such models with bottom-up approaches, but the implications of assuming a single agent still constitute a limitation to analyse markets with such a wide range of heterogenous actors. This has important implications, as the assumption of a perfectly rational central planner is a limitation for markets with very heterogeneous actors.

Linkage to other carbon markets is not yet within the features of the models presented. The only one considering a linkage is LIMES-EU, which assumes that the EU and UK ETS will be linked in the short-term. Until recently, both systems showed a remarkable consistency, which might indicate very similar abatement costs as well as investors hedging behaviour. However, the UKA price has recently dropped significantly. This might hinder a linkage in the short-term, despite the EU and UK agreement for cooperation. In other systems, such as the California+Quebec and Chinese, the experts highlighted potential linkage between existing systems was currently not under consideration.

Depending on the model's main purpose, either perfect or limited foresight is assumed. Assuming complete information for the long-term is a useful but limiting simplification, especially in carbon and energy markets. These face increasingly uncertainty, not only from market dynamics (e.g., fuel prices), but also from regulatory and policy developments. Traditionally, there is a tendency among organisations developing benchmark scenarios (i.e., computing the theoretically optimal prices to drive the energy transition) to assume perfect foresight. However, recently, there has been an increasing interest in capturing market imperfections and investors' behaviour, thus assuming limited foresight. All the optimisation models presented (i.e., all except the California+Quebec model) have at least this feature as an alternative model configuration. The debate about the appropriate time horizon to apply is still ongoing. There is also a discussion on the extent of the impact of an increase in environmental policy stringency on policy credibility and, ultimately, on actors' farsightedness.

Besides addressing the particularities of the different systems (e.g., unlike typical cap and trade systems, the Chinese carbon market relies on tradable performance standards), the models cover different sectors of the economy. In some cases, the sector comprised is not included within the respective carbon market studied. For instance, the d-PLACE model covers all sectors of the economy. It follows a top-down approach based on a CGE model coupled with a detailed energy sector model (MEESA). This allows evaluating the impact of the EU ETS on other sectors of the economy and thus, analysing distributional impacts.

Assessing carbon leakage impacts, e.g., resulting from the implementation of the CBAM in the EU, requires more extensive modelling as regions beyond the scope of the carbon market need to be included. As a result, the required modelling efforts are substantial.

Carbon prices: Convergence within, divergence across

The survey further unveiled a convergence between the EU ETS models towards 2050 and a price divergence across jurisdictions (see Figure 1). European Union Allowance (EUA) prices increase from 84-117 EUR/t in 2025 to 407-526 EUR/t by 2050. The price range increases as a result of the uncertainty regarding abatement costs, EU ETS coverage scope and overlapping policies. The price in non-EU jurisdictions also follows an increasing trend, but at a substantially lower level: from 19-25 EUR/t to 48-84 EUR/t. The UKA prices will increase from 13 to 31 EUR/t between 2021 and 2024.

It is difficult to accurately state the main factor explaining such price differences. Differences might stem from the systems' scope. Although all of them comprise the power sector and at least a substantial part of the industry, non-European systems have a larger scope, as they include buildings and road transport. In addition to that, modellers pointed out a problem of overallocation of allowances, which keeps prices at a low level (e.g., during the EU ETS phase III, prices were below 10 EUR/t from 2013 to 2017). Such overallocation might stem from the larger coverage, which makes it more difficult to estimate an appropriate cap. Another explanation is the lack of maturity of these carbon markets. A special case is the UK ETS, which covers the same sectoral scope as the EU ETS but does not have a market stability mechanism. Despite having the experience of being part of the EU ETS, it seems to be currently going through a transition period after Brexit. The very large cap with respect to current emissions appears to be having an effect on UK allowance prices. This lack of ambition is highlighted by the BCPM model results.

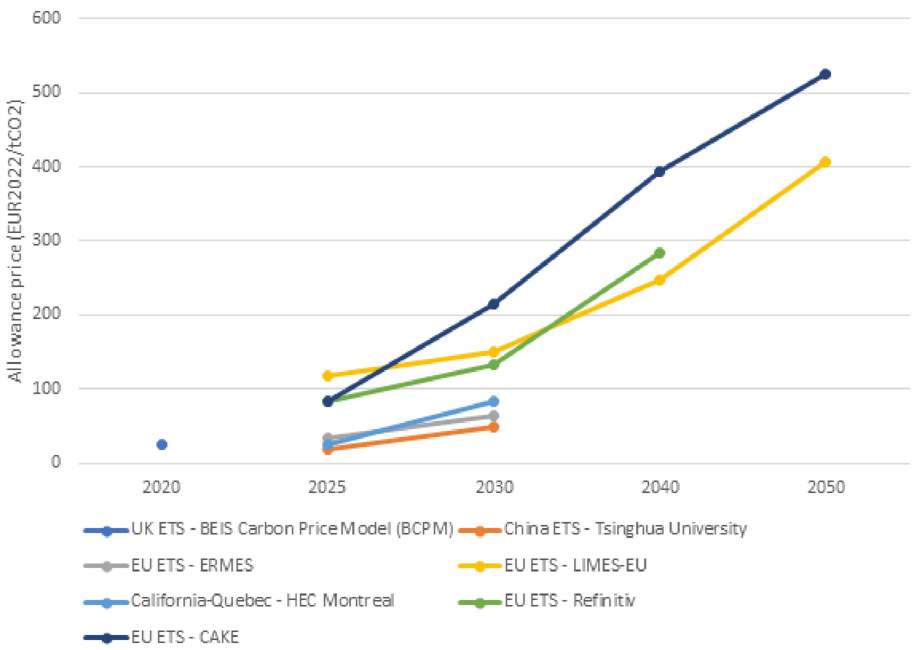

Figure 2. Carbon prices in each model and jurisdiction. [Notes: the BEIS estimation of the UK allowance price is an average of the price between 2021 and 2024]

Main takeaways

The models studied not only showed a wide approach heterogeneity but also highlighted the different carbon market scopes, maturities, and ambitions. On the modelling assumptions, a deep reliance of models on Marginal Abatement Cost Curves (MACCs) is noted. The strong impact of parameters such as the discount rate on model predictions is also underlined. This stresses the need to continue the discussion on ex-ante model comparison. Having these discussion spaces is essential to share experiences and build the robustness of models. With the exception of the model presented by the UK ETS regulator representative, the extent to which these research models can influence policy-decision making is difficult to measure, but closing the loop between the policy process and modelling work is necessary to enhance the predictability of carbon markets and ultimately improve their credibility.

Table 1. Categorisation of models along different features and methodological aspects.

Model name	BEIS Carbon Price Model (BCPM)	China ETS	LIMES-EU	California-Quebec (HEC Montreal)	Refinitiv	d-PLACE model
Institution	Department of Energy Security and Net Zero (formerly BEIS)	Institute of Energy, Environment, and Economy, Tsinghua University	Potsdam Institute for Climate Impact Research (PIK)	HEC Montréal, Chair in Energy Sector management	LSEG	Centre for Climate and Energy Analyses (CAKE/KOBiZE)
Geographical scope	UK	China	EU + UK +NO + CH + aggregated Balkan	California and Québec	EU ETS coverage + UK	EU
Carbon market analysed	UK ETS	China	EU ETS	WCI	EU ETS	EU ETS
Approach	Top-down	Top-down	Bottom-up	Simulation	Bottom-up	Hybrid
Link to other ETS	No	No	UK ETS	No	No	No
Representation of foresight	Between 1 year (i.e. no foresight) to perfect foresight (to 2050)	Limited foresight	Default: Perfect foresight; Optional: limited foresight	--	Limited foresight (3 to 5 years depending on the sector)	Limited foresight
Distributional effects	No	Sectoral and provincial	No	No	No	Yes
Carbon leakage	No	Yes	Within the ETS regions	No	No	Yes
Sectors included (model detail)						
Power sector	BAU emissions projections, plus MACC curves	15 subsectors, with each subsector representing a	Detailed dispatch per technology	Aggregated supply curves	MACC	Detailed per technology (MESSA model)

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		distinct technology used for electricity generation				
Industry	BAU emissions projections, plus MACC curves	CGE account ting for heterogeneity across and within sectors. Heterogenous emission factors are calibrated using plant-data that is later clustered	MACC		MACC	CGE (d-PLACE model)
Buildings						CGE (d-PLACE model)
Road transport						Sectoral model (TR3E model)
Aviation	BAU emissions projections, plus MACC curves		Exogenous (based on historic emissions)		Based on data from RDC aviation	CGE (d-PLACE model)
Maritime			Exogenous (based on historic emissions)			CGE (d-PLACE model)
Forestry						CGE (d-PLACE model)
Waste						CGE (d-PLACE model)
Other sectors						CGE/ agriculture in EPICA model

References

- European Commission, Joint Research Centre, 2022. CO2 emissions of all world countries: JRC/IEA/PBL 2022 report. Publications Office, Luxembourg.
- Fischer, C., 2001. Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards.
- ICAP, I.C.A.P., 2022. Emissions trading worldwide: Status Report 2022. Berlin.

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Tel. +39 055 4685 703
FSRClimate@eui.eu

Casale, Via Boccaccio 121
50133 Firenze (FI), Italy
www.eui.eu

Appendix 1 - Programme of the Conference on Ex-Post Assessment of Emissions Trading

Date: Tuesday 20 June 2023
Chair: Simone Borghesi, FSR Climate and University of Siena

09:30-09:35 **Welcome**

09:35-10:25 **Keynote Lecture "The distributional impacts of market-based climate policy: State of knowledge and future directions for research"**

- Jan Steckel, MCC Berlin [Slides]

10:35-12:55 **Session "Competitiveness and Carbon Leakage"**

- **Huajin Wang** (Renmin University of China) – *Heterogeneous Responses to Carbon Pricing: Firm-level Evidence from Beijing Emissions Trading Scheme* [Abstract] [Slides]
- **Leon Bremer** (Vrije Universiteit Amsterdam) – *Competitiveness and investments under emissions trading* [Abstract] [Slides]
- **Aliénor Cameron** (Université Paris-Nanterre & EconomiX-CNRS) – *Is industrial decarbonisation at odds with competitiveness? An assessment of competition dynamics in two EU heavy industries* [Abstract] [Slides]
- **Johanna Arlinghaus** (MCC Berlin) – *Carbon pricing and credit reallocation* [Abstract] [Slides]

13:45-15:00 **Policy Roundtable "Carbon leakage: (how) can we effectively prevent that risk?"**

- Arjan Trinks, CPB Netherlands Bureau for Economic Policy Analysis [Slides]
- Theresa Wildgrube, Adelphi [Slides]
- Aude Pommeret, Université Savoie Mont Blanc [Slides]
- Wilfred Feng, Dentons [Slides]

15:10-17:30 **Session "Social impacts and acceptability of emission trading"**

- **Adrien Fabre**(CIRED) – *International Attitudes Toward Global Policies* [Abstract] [Slides]
- **Franziska Funke** (PIK Climate/TU Berlin) – *Prices vs. Quantities from a Citizen's Perspective: Does the European Public Perceive Carbon Taxes and ETS differently?* [Abstract] [Slides]
- **Marianna Sobkiewicz & Krzysztof Kobyłka** (WiseEuropa) – *Evaluation of the impact of the EU ETS revenues and derogation under Article 10c on investment and infrastructure in Poland* [Abstract] [Slides]
- **Ghassane Benmir** (London School of Economics) – *Weitzman Meets Taylor: ETS Futures Drivers and Carbon Cap Rules* [Abstract] [Slides]

17:30-17:35 **Conclusions**

Appendix 2 - Programme of the Workshop on Ex-Ante Assessment of Emission Trading

Date: Monday 5 June 2023
Chair: Simone Borghesi, FSR Climate and University of Siena
Moderator: Marie Raude, FSR Climate and Paris Nanterre University

Welcome Coffee

09:20-09:30 **Welcome and introduction**

- **Simone Borghesi**, Director of FSR Climate and Professor at the University of Siena

09:30-11:00 **Modelling the European Union Emission Trading System**

- **Robert Jeszke**, Head of Strategy, Analysis and Auction Unit at the Polish National Centre for Emissions Management (KOBiZE)
- **Sebastian Osorio**, Postdoctoral Researcher at the Potsdam Institute for Climate Impact Research

Coffee Break

11.20 – 12.50 **International perspectives on modelling of emissions trading: the cases of Quebec, China and the United Kingdom**

- **Pierre-Olivier Pineau**, Professor at the Department of Decision Sciences at HEC Montréal
- **Da Zhang**, Associate professor at the Institute of Energy, Environment and Economy at Tsinghua University
- **Chris Ramsay-Collins,** UK Department for Energy Security and Net-Zero

12.50 – 13.10 **Wrap up and conclusions**

- **Sebastian Osorio**, Postdoctoral Researcher at the Potsdam Institute for Climate Impact Research
- **Simone Borghesi**, Director of FSR Climate and Professor at the University of Siena

Standing Lunch

Appendix 3 - Completed questionnaires received for the Workshop on Ex-Ante Assessment of Emission Trading

Responding organisation	Department of Energy Security and Net Zero (formerly BEIS)

Model fact sheet

Model (suite) name	BEIS Carbon Price Model (BCPM)
Website (preferably where model documentation is available)	No website. Full model documentation remains unpublished. Some published information in model and methodology here: • UK Gov's Future of Carbon Pricing Impact Assessment (BEIS, 2019), see 'Annex B – Note on BEIS's models used in this IA', pp. 28 – 32 • Updated Short-term Traded Carbon Values (BEIS, 2019)
Short description	BCPM uses a fundamentals-based approach to project carbon values from 2021 to 2050 in the UK Emissions Trading System. It uses Business As Usual (BAU) emissions projections and UK ETS emissions cap scenarios to project the amount of abatement effort required in the UK traded sector. It then uses externally commissioned marginal abatement cost curves to calculate a value on the necessary effort to achieve these.
Approach Bottom-up, Top-down, Hybrid	Top-down
Geographical coverage	UK only, previously versions of the model covered whole pre-Brexit EU ETS
Sectors covered and modelling detail	(see table below)
Time horizon and temporal granularity	Annualised emissions and carbon price projections out to 2050 (minus length of the foresight period, i.e. if foresight is 5 years then model can project to 2045)

Sectors covered and modelling detail

Sector		Level of modelling detail
Power sector	☒	BAU emissions projections, plus MACC curves
Industry	☒	BAU emissions projections, plus MACC curves
Buildings	☐	
Road transport	☐	
Aviation	☒	BAU emissions projections, plus MACC curves
Maritime	☐	
Forestry	☐	
Waste	☐	
Other sectors		

Philosophy regarding level of detail	Fundamentals-based - Top-down abstract representation of aggregate supply and demand.
Linkage to other ETS? If yes, please briefly elaborate	No
Negative emissions? If yes, which technologies	No – It is possible to model BECCS but this is currently not modelled as negative emissions are not in scope of the UK ETS. The model lacks required input data to model nature-based removals or DACCs.
Offsets and credits included? If yes, please briefly elaborate	No
Representation of foresight	Foresight is incorporated into the BCPM as an aggregation of effort over the relevant foresight period and reading off carbon price need to achieve that effort from the aggregated MAC curve for the given foresight period. This also incorporates an implicit assumption around banking and borrowing into the modelling by allowing participants to bring forward allowances (borrowing) and keep a supply of surplus allowances for compliance in future years (banking).
Representation of non-compliance trading (NCT)	The impact of the carry trade is represented through modelling and factoring in the cost of carry. Other forms of NCT (e.g. speculation, positional trading) are not represented.
Representation of market imperfections	Imperfect foresight is modelled. BCPM also models power sector hedging, taking an exogenous assumption to approximate observed behaviour in the power sector. Otherwise BCPM assumes that all participants act in a rational way and don't face any barriers to investing in cost-effective abatement opportunities.
Potential sectoral expansion	The BCPM is capable of modelling some additional sectors (e.g. land transport) but it currently is not used to analyse these sectors as these are not within scope of the UK ETS.
Analysis of distributional effects	No
Analysis of competitivenes s effects	No

Analysis of carbon leakage	No

Allowances prices in default scenario

Main assumptions Policies, e.g., is carbon neutrality assumed?	• In most recent published scenario (in 2019 UK ETS UK Government response to its consultation) UK ETS cap assumed to be 118 mtCO2e by 2030, which is the current legislated UK ETS cap, based on the UK's notional share of phase IV allowance allocation, had it remained in the EU ETS. This cap is not net zero consistent and compares to recent UK cap consultation which consulted on a cap around 50mtCO2e in 2030.
Result highlights 3-5 points, include a main figure if possible	• Average UKA price over 2021-2024 projected as £15 - £32 in 2019. (~13 – 31 Euros at GBP to EUR exchange rate of £1= 0.877 Euros)

	2025	2030	2040	2050
Allowance price [EUR/t*]				

Please provide base year and type of prices	• Base year: 2021 • Type: real 2019 GBP (£)

**If possible, please express the prices in EUR/t (eventually in USD/t). For the workshop we will harmonise price data to EUR$_{2022}$ using Eurostat inflation rates EU 27* and, if not expressed in EUR, *the European Central Bank's Reference exchange rates (avg. of monthly reported figures).*

Relevant allowance price drivers

Please select the three most important price drivers in 2030 and 2050. For the 2050 prices, please also provide the sensitivity range for the selected most important drivers.

	2030	2050	Range [EUR/t]
Policy parameters (excluding emission cap adjustment) Market stability measures (e.g., price floor/ceiling, market stability reserve [MSR]), Timing of supply (auctions, allocation, supply), Type of supply - allocation vs. auction, Use of revenues	☐	☐	No MSR in the UK ETS; auction reserve max impact = +£22; timing of supply not modelled beyond cap adjustment, allocation type not relevant
Model parameters Year of calibration, discount rate	☐	☐	+/- £5 (based on arbitrary cost of carry range 2% to 10% - standard assumption = 3.25%)
Power sector Renewable targets, Power demand, Fuel prices, Coal/Fossil phase-out policies, Cost of new capacities, Grid costs and constraints, Expansion constraints/bottlenecks	☒	☒	Plus or minus hundreds of £/tonne.

Industry Abatement costs (Cost of substitute fuels, Costs of CO2, Technological learning), Industrial growth/deindustrialisation, Short-term demand response, Carbon contracts for difference	☒	☒	Plus or minus hundreds of £/tonne.
Buildings Abatement costs (Cost of substitute fuels, Costs of CO2), efficiency policies (renovation rates), Short-term demand response, increased pressure of electrification	☐	☐	Not currently modelled in BCPM
Transport Costs of substitute fuels, Short-term demand response, Behavioural trends (Flight shame, regionalisation)	☐	☐	Not currently modelled in BCPM
Behaviour Power sector hedging, Industry hedging/banking, Financial market participants, Speculation (Compliance player and financial player), Investment behaviour (e.g. adoption speed)	☒	☒	Hedging and foresight assumptions change the distribution of carbon abatement effort over time and therefore impact the trajectory of prices – rather than overall scale of prices
External Political signalling, Monetary policy (certificates as inflation hedge), Interest rates slowing down investments, Global climate negotiations (e.g., Article 6), Cost of carbon removals or offsets, Geopolitical risks and opportunities	☐	☐	Not directly modelled.

Please proved a short explanation for your choice of the most important drivers, focussing on the changes between 2030 and 2050.

Varying Projections of power and industry Business as Usual emissions (based on different government policies or projected economic states impacting on the traded sector) leads very wide divergence in projected demand for allowances and therefore carbon prices over the medium to long term. No other factors have anywhere near as substantive an impact on the modelling.

Responding organisation	Institute of Energy, Environment, and Economy, Tsinghua University

Model fact sheet

Model (suite) name	China ETS simulation model
Website (preferably where model documentation is available)	https://conference.nber.org/conf_papers/f178283.pdf
Short description	The China ETS simulation model is a multi-sector dynamic computable general equilibrium (CGE) model. It pays close attention to the special incentives created by China's rate-based emission trading system (ETS) and recognises the pre-existing distortions in the economy. It exploits information from a unique firm-level dataset on emissions, output, and energy use, and recognises the heterogeneity in production methods within sectors. The model can be used to analyse the impacts of China's national ETS by sector and province and in the aggregate for the period 2020-2035. The model also has considerable flexibility to analyse a range of different ETS designs, including allowance allocation methods, a transition to a cap-and-trade system, etc.
Approach Bottom-up, Top-down, Hybrid	Top-down
Geographical coverage	China
Sectors covered and modelling detail	see table below

Sector		Level of modelling detail
Power sector	☒	The model has 15 technological groups in the electricity sectors, and distinguishes renewable electricity (solar, wind, and hydro) and nuclear electricity from fossil-based electricity. Within the group of fossil-based electricity generators, the model recognises heterogeneity across the fossil electricity plants by distinguishing 11 (nine coal-fired and two gas-fired) technology categories.
Industry	☒	Industry is divided into 26 sectors. The cement, aluminum, and iron & steel sectors include subsectors distinguished by technology or emissions-intensity considerations.
Buildings	☒	Belonging to households and services sectors
Road transport	☒	Belonging to Transport and port sector

<table>
<tr><td></td><td>
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<tr><td>Aviation</td><td>☒</td><td>Belonging to Transport and port sector</td></tr>
<tr><td>Maritime</td><td>☒</td><td>Belonging to Transport and port sector</td></tr>
<tr><td>Forestry</td><td>☒</td><td>Belonging to the Agriculture sector</td></tr>
<tr><td>Waste</td><td>☒</td><td>Belonging to the Service sector</td></tr>
<tr><td>Other sectors</td><td></td><td>Services, agriculture</td></tr>
</table>
</td></tr>
<tr><td>Time horizon and temporal granularity</td><td>2020 to 2035, one-year intervals</td></tr>
<tr><td>Philosophy regarding level of detail</td><td>The electricity sector is covered by the current TPS in place. The TPS's coverage will soon expand to include the cement and aluminum sectors and possibly the iron & steel sector. These four sectors account for more than 70% of the total CO_2 emissions in China. Therefore, these four sectors are modeled with more detail and are divided into subsectors based on technical features. In this way, the model is capable of analysing the ETS's impacts on sectors as well as on firms with different technology and efficiency. Also, this feature allows the possibility to analyse the impacts of setting multiple benchmarks for one sector.</td></tr>
<tr><td>Linkage to other ETS?
If yes, please briefly elaborate</td><td>No</td></tr>
<tr><td>Negative emissions?
If yes, which technologies</td><td>No</td></tr>
<tr><td>Offsets and credits included?
If yes, please briefly elaborate</td><td>No</td></tr>
<tr><td>Representation of foresight</td><td>Myopic foresight</td></tr>
<tr><td>Representation of non-compliance trading (NCT)</td><td>Firms are assumed to achieve compliance.</td></tr>
<tr><td>Representation of market imperfections</td><td>The model assumes purely competitive markets, but considers pre-existing distortions in the economy, including administered electricity, pre-existing taxes and subsidies, etc.</td></tr>
<tr><td>Potential sectoral expansion</td><td>The first TPS phase begins in 2020 and covers only the electricity sector. The second phase is assumed to begin in 2023, with the TPS expanding to also cover the iron & steel, aluminum, and cement sector. The third phase begins in 2026, with coverage expanding further to include pulp & paper, other non-metal products, other non-ferrous metals, raw chemicals, and petroleum refining industries.</td></tr>
</table>

Analysis of distributional effects	The model can analyse sectoral and provincial distributional effects.
Analysis of competitiveness effects	The model covers firm-level information in the power, cement, aluminum, and iron & steel sectors, and thus can be used to analyse the impacts on costs for firms with different efficiency.
Analysis of carbon leakage	The model can analyse international carbon leakage caused by China's national ETS.

Allowances prices in default scenario

Main assumptions Policies, e.g., is carbon neutrality assumed?	• **Number of benchmarks**. Four benchmarks apply to the electricity sector: three for coal-fired and one for gas-fired generators. Two benchmarks apply to the iron & steel sector. One benchmark applies to each of all other covered sectors. • **Initial benchmarks.** Initial benchmarks for the electricity sector are set according to the Ministry of Environment and Ecology (MEE) 's released documents. Initial benchmarks for other sectors are set to be 2.5% below their emissions intensity in the year before they are included in the TPS. • **Tightening rates of benchmarks.** The tightening rate for the electricity sector is 0.5 %/year during Phase 1 according to the MEE. We assume the tightening rate for the electricity sector in Phases 2 and 3 is 1.5%, and the rate for other sectors is 2.5%. • We do not consider other new policy interventions during 2020-2035.

Result highlights
3-5 points, include a main figure if possible
	• Policy-induced emissions reductions:
	  o The average annual reduction over the Phase 1,2 and 3 is 184 million tons, 550 million tons and 2.2 billion tons.
	  o Over the entire interval 2020-2035, the cumulative emissions reduction amounts to 24 billion tons, or 12 percent of the cumulative baseline emissions.
	• Aggregate Costs:
	  o The GDP cost in Phase 1 is relatively small (less than 0.01 percent), but costs expand significantly over time, a consequence of increased benchmark stringency and broader sector coverage. The present value of the GDP cost over the period of 2020-2035 is 2.1 trillion RMB, 0.13 percent of the baseline GDP.
	  o The TPS's costs are close to those of an equally stringent C&T system during the first eight years of the program, but rise significantly above the C&T costs in later years.
	• Sector Impacts:
	  o The covered sectors tend to experience the largest reductions in output, reflecting the use of output-reduction as a channel for reducing compliance costs. The reduction in output is highest in the electricity sector. As a result, unit costs of electricity production increase significantly, prompting a significant reduction in electricity demand.

- In all three phases, all of the covered sectors experience increased profits. This reflects the economic rents associated with the value of the free allowances these sectors receive under the TPS.
- In the uncovered sectors, impacts on profits and output reflect changes in demand and production cost.
- For many other uncovered sectors, the TPS raises the costs of production by increasing the prices of their inputs. In Phase 1, this is especially important in the aluminum sector, which is intensive in its use of electricity.
- The shifts toward renewable electricity sources are smaller under the TPS than under C&T.

- Net profit:
  - Under plausible ranges of the parameters determining the benefits and costs, the present value of the TPS's climate and health benefits are in the range of 19-106 trillion RMB over the 2020- 2035 interval. The central estimate is 53 trillion RMB, 25 times the central estimate for the TPS's costs.

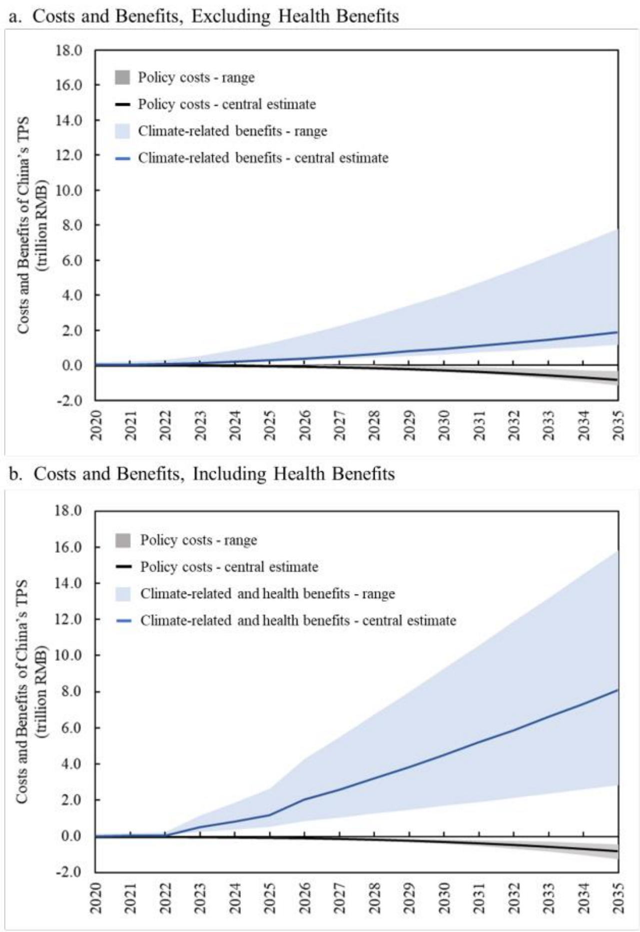


Figure 1. Costs and Benefits of China's TPS

	2025	2030	2040	2050
Allowance price [EUR/t*]	17	43		

Please provide base year and type of prices	• Base year: 2020 • Type: nominal [] real [☒]

**If possible, please express the prices in EUR/t (eventually in USD/t). For the workshop we will harmonise price data to EUR$_{2022}$ using [Eurostat inflation rates EU 27](#)* and, if not expressed in EUR, [the European Central Bank's Reference exchange rates](#) *(avg. of monthly reported figures).*

Relevant allowance price drivers

Please select the three most important price drivers in 2030 and 2050. For the 2050 prices, please also provide the sensitivity range for the selected most important drivers.

	2030	2050	Range [EUR/t]
Policy parameters (excluding emission cap adjustment) Market stability measures (e.g., price floor/ceiling, market stability reserve [MSR]), Timing of supply (auctions, allocation, supply), Type of supply - allocation vs. auction, Use of revenues	☒	☐	14-60
Model parameters Year of calibration, discount rate	☐	☐	
Power sector Renewable targets, Power demand, Fuel prices, Coal/Fossil phase-out policies, Cost of new capacities, Grid costs and constraints, Expansion constraints/bottlenecks	☒	☐	38-51
Industry Abatement costs (Cost of substitute fuels, Costs of CO2, Technological learning), Industrial growth/deindustrialisation, Short-term demand response, Carbon contracts for difference	☒	☐	41-46
Buildings Abatement costs (Cost of substitute fuels, Costs of CO2), efficiency policies (renovation rates), Short-term demand response, increased pressure of electrification	☐	☐	
Transport Costs of substitute fuels, Short-term demand response, Behavioural trends (Flight shame, regionalisation)	☐	☐	
Behaviour Power sector hedging, Industry hedging/banking, Financial market participants, Speculation (Compliance player and financial player), Investment behaviour (e.g. adoption speed)	☐	☐	
External Political signalling, Monetary policy (certificates as inflation hedge), Interest rates slowing down investments, Global climate negotiations (e.g., Article 6), Cost of carbon removals or offsets, Geopolitical risks and opportunities	☐	☐	

Please proved a short explanation for your choice of the most important drivers, focussing on the changes between 2030 and 2050.

- The design of the ETS system has the biggest influence on the allowance price. Using a rate-based system (TPS) can lead to a much higher allowance price than a cap-and-trade that achieves the same amount of emissions reduction. - The marginal abatement cost of the electricity sector and the industrial sector both have a relatively large influence on allowance prices. Lower abatement costs lead to lower allowance prices.

Responding organisation	**Potsdam Institute for Climate Impact Research (PIK)**

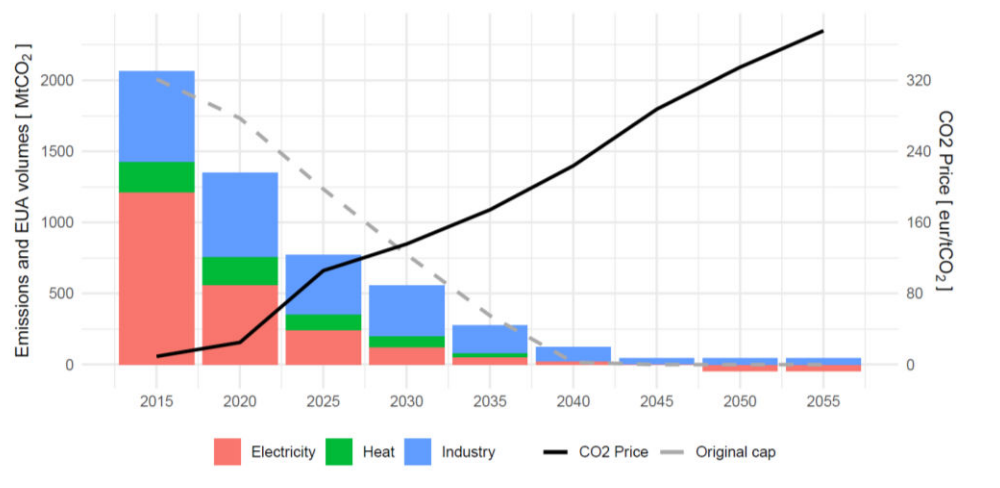
Model fact sheet

<table>
<tr><td>Model (suite) name</td><td colspan="3">Long-term Investment Model for the Electricity Sector in the EU (LIMES-EU)</td></tr>
<tr><td>Website (preferably where model documentation is available)</td><td colspan="3">https://www.pik-potsdam.de/en/institute/departments/transformation-pathways/models/limes</td></tr>
<tr><td>Short description</td><td colspan="3">LIMES-EU is a linear dynamic cost-optimisation model with a focus on the electricity sector. It simultaneously optimises investment and dispatch decisions for generation, storage and transmission technologies. The model covers 32 generation and storage technologies, including different vintages for lignite, hard coal and gas. The energy-intensive industry is also covered and represented by a step-wise linear marginal abatement cost curve for each country.</td></tr>
<tr><td>Approach
Bottom-up, Top-down, Hybrid</td><td colspan="3">Bottom-up</td></tr>
<tr><td>Geographical coverage</td><td colspan="3">EU27 (excluding Cyprus and Malta) + UK + CH + NO + aggregated Balkan</td></tr>
<tr><td rowspan="10">Sectors covered and modelling detail</td><td colspan="2">Sector</td><td>Level of modelling detail</td></tr>
<tr><td>Power sector</td><td>☒</td><td>Dispatch and investments per technology; detailed representation of techno-economic constraints</td></tr>
<tr><td>Industry</td><td>☒</td><td>Marginal abatement cost curve for energy-intensive industry comprised within ETS</td></tr>
<tr><td>Buildings</td><td>☐</td><td></td></tr>
<tr><td>Road transport</td><td>☐</td><td></td></tr>
<tr><td>Aviation</td><td>☒</td><td>Exogenous emissions</td></tr>
<tr><td>Maritime</td><td>☒</td><td>Exogenous emissions</td></tr>
<tr><td>Forestry</td><td>☐</td><td></td></tr>
<tr><td>Waste</td><td>☐</td><td></td></tr>
<tr><td>Other sectors</td><td></td><td></td></tr>
<tr><td>Time horizon and temporal granularity</td><td colspan="3">2010-2070; each year represented by X * 8 time-slices (typically X = 6 days, and thus 48 time-slices)</td></tr>
</table>

Philosophy regarding level of detail	In general, we aim for a suitable trade-off between high detail and model complexity (run time). Solving the model should not take longer than few hours (which requires multiple iterations because of the MSR). With regard to detail, we prioritise including aspects/features according to their expected impact on EUA prices. We believe there is a risk of "over-calibration", especially for long-term analysis, which is the main focus.
Linkage to other ETS? If yes, please briefly elaborate	UK ETS. This link does not exist yet, but we assume a linkage between both markets in the future.
Negative emissions? If yes, which technologies	Yes, from BECCS
Offsets and credits included? If yes, please briefly elaborate	No
Representation of foresight	Default: Perfect foresight (benchmark approach) Optional: limited foresight
Representation of non-compliance trading (NCT)	No
Representation of market imperfections	No
Potential sectoral expansion	Partially. Additional electricity demand from other sectors such as buildings and transport. In the case of building, we are developing a simplified representation of the sector, in order to capture the impact of its decarbonisation (through district heating and heat electrification) on the EU ETS
Analysis of distributional effects	No
Analysis of competitiveness effects	No
Analysis of carbon leakage	Only within the ETS, e.g., across countries due to a unilateral policy such as the german coal phase-out, or across sectors due to higher emission costs in one of them resulting from additional policies such as a carbon price floor

Allowances prices in default scenario

Main assumptions Policies, e.g., is carbon neutrality assumed?	• For investment costs, we assume moderate cost reductions for renewable energy generation technologies, electric batteries and electrolysers, while costs of fossil generation technologies remain constant • For investment and intertemporal trading decisions, we assume perfect foresight and a discount rate of 5% • We consider selected overlapping technology policies on the EU member state level. They influence prices by reducing the demand for allowances. A first group of such policies we consider are mandated coal phase-outs according to Europe Beyond Coal (2022) and RE support measures. We consider the nuclear power phase-out decisions and respective schedules by Germany, Belgium and Switzerland. • By default, we assume the climate policy ambition represented by the recent EU ETS reform. That is, we assume a cap set to reach a reduction of 62% by 2030 with respect to 2005. we adjust this value to an LRF of 4.3% and 4.4% respectively for the years after 2023. Moreover, we deduct the one-off reductions in 2024 and 2026 from the annual caps (rebasing). We additionally extrapolate the LRF and, as a consequence, the cap reaches zero in 2039. • We assume MSR parameters according to the most recent reform, e.g., continued intake of 24% through 2030, adaptive upper threshold to avoid oscillatory effects, and cancellation so that maximum 400 Mt remain in the MSR • In line with the goal of climate neutrality by 2050, we assume that certificate trading is only allowed until that year, and thus net emissions from ETS need to reach zero as of that year. Furthermore, we assume that the scope of the EU ETS as per current regulation will not change.
Result highlights 3-5 points, include a main figure if possible	• Carbon prices reach 130 EUR/t by 2030. In the long term, the CO2 price even rises to over 300 EUR/t after 2050 • Most of the reductions occur already in the current decade; emissions by 2030 are 65% lower than in 2020. • Large parts of the electricity sector are already decarbonised by 2030, and coal is basically phased-out across Europe by then; just 30 TWh of coal generation remains. Industrial emissions also already fall by 36% between 2020 and 2030. • In the short term, the MSR volume reaches a maximum of 2.8 GtCO2 in 2022. In the medium term the MSR volume slightly rebounds due to the high emission reductions and the consequent high TNAC. • Overall cancellation amounts to 7.5 GtCO2, the MSR being active until completely empty by 2048.



	2025	2030	2040	2050
Allowance price [EUR/t*]	98	126	207	341

Please provide base year and type of prices	• Base year: 2015 • Type: nominal [...] real [X]

**If possible, please express the prices in EUR/t (eventually in USD/t). For the workshop we will harmonise price data to EUR*2022* using [Eurostat inflation rates EU 27] and, if not expressed in EUR, [the European Central Bank's Reference exchange rates] (avg. of monthly reported figures).*

Relevant allowance price drivers

Please select the three most important price drivers in 2030 and 2050. For the 2050 prices, please also provide the sensitivity range for the selected most important drivers.

	2030	2050	Range [EUR/t]
Policy parameters (excluding emission cap adjustment) Market stability measures (e.g., price floor/ceiling, market stability reserve [MSR]), Timing of supply (auctions, allocation, supply), Type of supply - allocation vs. auction, Use of revenues	☐	☐	
Model parameters Year of calibration, discount rate	☒	☐	Discount rate +10/-30
Power sector Renewable targets, Power demand, Fuel prices, Coal/Fossil phase-out policies, Cost of new capacities, Grid costs and constraints, Expansion constraints/bottlenecks	☒	☐	Fuel prices +9/-5 No CCS +25 CoC RES +4/-4 No transmission expansion -2
Industry Abatement costs (Cost of substitute fuels, Costs of CO2, Technological learning), Industrial	☐	☐	

growth/deindustrialisation, Short-term demand response, Carbon contracts for difference			
Buildings Abatement costs (Cost of substitute fuels, Costs of CO2), efficiency policies (renovation rates), Short-term demand response, increased pressure of electrification	☐	☐	
Transport Costs of substitute fuels, Short-term demand response, Behavioural trends (Flight shame, regionalisation)	☐	☐	
Behaviour Power sector hedging, Industry hedging/banking, Financial market participants, Speculation (Compliance player and financial player), Investment behaviour (e.g. adoption speed)	☐	☐	
External Political signalling, Monetary policy (certificates as inflation hedge), Interest rates slowing down investments, Global climate negotiations (e.g., Article 6), Cost of carbon removals or offsets, Geopolitical risks and opportunities	☐	☐	

Please proved a short explanation for your choice of the most important drivers, focussing on the changes between 2030 and 2050.

The parameters having the strongest effect on cancellations are discount rates and CCS (un)availability. Since allowance banking is a provision to reduce costs in the future, firms bank less if they discount at a higher rate. Put differently, if firms have a higher discount rate they put a lower weight on the future and thus bank less. A lower bank in turn implies that fewer allowances go into the MSR and therefore also cancellations are lower. CCS availability is relevant due to the unavailability of BECCS rather than fossil-based CCS. Anticipating the lack of negative emissions in the future that help to offset some remaining emissions, decarbonisation increases substantially in the short term. This in turn leads to higher banking and thus to higher cancellations (8.3 GtCO2 compared to 7.7 GtCO2 in the reference scenario) that tighten further the ETS. Another important driver is the fuel price. We only evaluated variations in gas prices and focused on higher gas prices. In the most extreme case we assume a gas price (wo transport costs) 5 times as high as in the reference scenario (e.g., 132 eur/MWh vs. 30 eur/MWh). This impacts severely gas generation, reinforcing the need for coal. As a result, there are more emissions in the shorter term and thus fewer transfers to the MSR. This leads to an overall higher emissions budget, which leads to lower carbon prices.

Responding organisation	HEC Montréal, Chair in Energy Sector management

Model fact sheet

Model (suite) name	Model of the California-Quebec Cap-and-Trade
Website (preferably where model documentation is available)	https://energie.hec.ca/overallocation-ca-qc-carbon-market/
Short description	A simple supply-demand model of emission rights is developed to analyse the stringency of the joint carbon cap in the California (United States) and Québec (Canada) carbon market.
Approach Bottom-up, Top-down, Hybrid	Emission scenarios and economic modelling.
Geographical coverage	California (United States) and Québec (Canada)
Sectors covered and modelling detail	see table below
Time horizon and temporal granularity	Three-year compliance periods until 2030
Philosophy regarding level of detail	Aggregated look at emissions, evolving differently in each scenario. The philosophy is to focus on the usefulness of the cap, not on the actual GHG emission paths.
Linkage to other ETS? If yes, please briefly elaborate	No

Sector		Level of modelling detail
Power sector	☒	No detail – aggregated model
Industry	☒	
Buildings	☒	
Road transport	☒	
Aviation	☐	
Maritime	☐	
Forestry	☐	
Waste	☐	
Other sectors		

Negative emissions? If yes, which technologies	No
Offsets and credits included? If yes, please briefly elaborate	Yes, offsets are included in the analysis to study their impact on the stringency of the cap.
Representation of foresight	No
Representation of non-compliance trading (NCT)	No
Representation of market imperfections	No
Potential sectoral expansion	Yes, more sectoral details could be developed to study different emission levels.
Analysis of distributional effects	No
Analysis of competitiveness effects	No
Analysis of carbon leakage	No

Allowances prices in default scenario

Main assumptions Policies, e.g., is carbon neutrality assumed?	• We assume a price-elasticity for the demand for emission rights, allowing us to built a demand curve for emission rights, and find an equilibirum price with the supply of emission rights.
Result highlights 3-5 points, include a main figure if possible	• In all emission scenarios, the California-Québec carbon cap is useless by 2030, in the sense that it does not provide a constraint limiting emissions to their target level.

	2025	2030	2040	2050
Allowance price [EUR/t*]	$25/t	$85/	n.a.	n.a.

Please provide base year and type of prices	• Base year: 2020 • Type: real

**If possible, please express the prices in EUR/t (eventually in USD/t). For the workshop we will harmonise price data to EUR₂₀₂₂ using Eurostat inflation rates EU 27 and, if not expressed in EUR, the European Central Bank's Reference exchange rates (avg. of monthly reported figures).*

Relevant allowance price drivers

Please select the three most important price drivers in 2030 and 2050. For the 2050 prices, please also provide the sensitivity range for the selected most important drivers.

	2030	2050	Range [EUR/t]
Policy parameters (excluding emission cap adjustment) Market stability measures (e.g., price floor/ceiling, market stability reserve [MSR]), Timing of supply (auctions, allocation, supply), Type of supply - allocation vs. auction, Use of revenues	☒	☐	+/- ...
Model parameters Year of calibration, discount rate	☒	☐	
Power sector Renewable targets, Power demand, Fuel prices, Coal/Fossil phase-out policies, Cost of new capacities, Grid costs and constraints, Expansion constraints/bottlenecks	☐	☐	
Industry Abatement costs (Cost of substitute fuels, Costs of CO2, Technological learning), Industrial growth/deindustrialisation, Short-term demand response, Carbon contracts for difference	☐	☐	
Buildings Abatement costs (Cost of substitute fuels, Costs of CO2), efficiency policies (renovation rates), Short-term demand response, increased pressure of electrification	☐	☐	
Transport Costs of substitute fuels, Short-term demand response, Behavioural trends (Flight shame, regionalisation)	☐	☐	
Behaviour Power sector hedging, Industry hedging/banking, Financial market participants, Speculation (Compliance player and financial player), Investment behaviour (e.g. adoption speed)	☐	☐	
External Political signalling, Monetary policy (certificates as inflation hedge), Interest rates slowing down investments, Global climate negotiations (e.g., Article 6), Cost of carbon removals or offsets, Geopolitical risks and opportunities	☒	☐	

Please proved a short explanation for your choice of the most important drivers, focussing on the changes between 2030 and 2050.

Our model focuses on the 2030 cap and its effectiveness to contain GHG emissions to the target level. The key drivers of the model are the coverage of emissions (closer to 70% than to the

claimed 80%), the abundance of carbon offsets and the speed of emission reductions (induced by complementary measures).

Responding organisation	**Refinitiv**

Model fact sheet

Model (suite) name	Refinitiv EUA price forecasting model
Website (preferably where model documentation is available)	Refinitiv Eikon desktop>> Carbon Europe
Short description	The EUA price forecasting model is a linear optimisation model projecting yearly EU ETS prices to 2030 (2035). It consists of three modules. Module 1 is an econometric model projects future carbon price based on ETS balances forecast. The balances forecasts are based on emissions separately for power and industry (incl. Aviation) sectors and supply forecast for EU ETS including auctioning and free allocation. Market Stability Reserve is modelled in this module too. The second module simulates the interaction between the future EUA price expected by the market and the amount of abatement in the EU ETS. It uses a feedback loop to estimate the impact of abatement on the carbon price and to forecast the future carbon prices and abatement levels, based on in-house marginal abatement cost curves for the power and industry sectors. The third module provides a constraint, which specifies that market participants cannot be short of EUAs for their annual compliance needs. The module simulates the market's reaction to a potential future shortage by calculating companies' abatement assuming they aim to minimise costs. Market participants are assumed to begin to cover shortages by beginning to abate emissions five years in advance. Power sector emissions forecast is based on a least cost dispatch optimisation model, which is then used to calculated power sector's EUA demand profile with assumed three-year ahead forward hedging rates. Industry emissions forecast is based on econometric model and in-house analysis of production and CO2 intensity and assumed four-year ahead forward-looking horizon. The model documentation is available in Refinitiv Eikon.
Approach Bottom-up, Top-down, Hybrid	Bottom-up
Geographical coverage	EU ETS coverage + UK
Sectors covered and modelling detail	

Sector		Level of modelling detail
Power sector	☒	Daily power sector emissions by country to 2030, yearly emissions forecast to 2040

	<table><tr><td>**Industry**</td><td>☒</td><td>Yearly emissions by five sectors by country to 2040</td></tr><tr><td>**Buildings**</td><td>☐</td><td></td></tr><tr><td>**Road transport**</td><td>☐</td><td></td></tr><tr><td>**Aviation**</td><td>☒</td><td>Yearly emissions based on data from RDC aviation</td></tr><tr><td>**Maritime**</td><td>☐</td><td></td></tr><tr><td>**Forestry**</td><td>☐</td><td></td></tr><tr><td>**Waste**</td><td>☐</td><td></td></tr><tr><td>**Other sectors**</td><td></td><td></td></tr></table>
Time horizon and temporal granularity	2008-2040, yearly
Philosophy regarding level of detail	We aim to use the model to represent actual market conditions and project accurately EUA prices. Hence we maintain relatively frequent updates of the model, on a quarterly basis, to make the assumptions up to date and reflecting realities. A complete update of the forecast including emissions and supply will be conducted in stages and take around 5 hours to run. Our model is also built as scenario simulation tool for some of the inputs. It takes half an hour to run scenarios with various MSR parameters.
Linkage to other ETS? If yes, please briefly elaborate	No
Negative emissions? If yes, which technologies	No
Offsets and credits included? If yes, please briefly elaborate	No (apart from 2008-2020 in EU ETS)
Representation of foresight	Default: limited foresight for 3 to 5 years depending on the sector
Representation of non-compliance trading (NCT)	Default: Not represented
Representation of market imperfections	This is captured via the econometric model based on historic balances, most importantly 'perceived balances' considering market participants' behaviour changes and probabilistic approach of uncertainties regarding ETS policies.

Potential sectoral expansion	Will extend to maritime sector
Analysis of distributional effects	No
Analysis of competitiveness effects	No
Analysis of carbon leakage	No

Allowances prices in default scenario

Main assumptions Policies, e.g., is carbon neutrality assumed?	• EU ETS framework as agreed in the Fit for 55 package, finalised in April 2023. • 62% reduction in EU ETS • 4.4% LRF for 2031-2040 • Phase out of free allowances as agreed in CBAM legislation • REPowerEU sales as in final agreement (16.5 Mt in 2023 due to lack of innovation fund sales)
Result highlights 3-5 points, include a main figure if possible	• EU allowance price will set a gradual upward trajectory due to ambitious reduction target for 2030 and market participants' anticipation of tighter balances in the coming years • Fuel-switching price will remain an important anchor for allowance price until 2025, but it will be replaced by industry abatement costs after that • The inclusion of martime sector and the phase-out of free allowances will support allowance prices

	2025	2030	2040	2050
Allowance price [EUR/t*]	87	150	405	...

Please provide base year and type of prices	• Base year: 2022 • Type: nominal [X] real [...]

**If possible, please express the prices in EUR/t (eventually in USD/t). For the workshop we will harmonise price data to EUR$_{2022}$ using Eurostat inflation rates EU 27* and, if not expressed in EUR, *the European Central Bank's Reference exchange rates (avg. of monthly reported figures).*

Relevant allowance price drivers

Please select the three most important price drivers in 2030 and 2050. For the 2050 prices, please also provide the sensitivity range for the selected most important drivers.

	2030	2050	Range [EUR/t]
Policy parameters (excluding emission cap adjustment) Market stability measures (e.g., price floor/ceiling, market stability reserve [MSR]), Timing of supply (auctions, allocation, supply), Type of supply - allocation vs. auction, Use of revenues	☒	☒	+/- 30
Model parameters Year of calibration, discount rate	☒	☒	+/- 20
Power sector Renewable targets, Power demand, Fuel prices, Coal/Fossil phase-out policies, Cost of new capacities, Grid costs and constraints, Expansion constraints/bottlenecks	☒	☐	+/- 15
Industry Abatement costs (Cost of substitute fuels, Costs of CO2, Technological learning), Industrial growth/deindustrialisation, Short-term demand response, Carbon contracts for difference	☒	☒	+/- 30
Buildings Abatement costs (Cost of substitute fuels, Costs of CO2), efficiency policies (renovation rates), Short-term demand response, increased pressure of electrification	☐	☒	+/- 10
Transport Costs of substitute fuels, Short-term demand response, Behavioural trends (Flight shame, regionalisation)	☐	☒	+/- 10
Behaviour Power sector hedging, Industry hedging/banking, Financial market participants, Speculation (Compliance player and financial player), Investment behaviour (e.g. adoption speed)	☒	☒	+/- 20
External Political signalling, Monetary policy (certificates as inflation hedge), Interest rates slowing down investments, Global climate negotiations (e.g., Article 6), Cost of carbon removals or offsets, Geopolitical risks and opportunities	☐	☒	+/- 10

Please provide a short explanation for your choice of the most important drivers, focussing on the changes between 2030 and 2050.

Power sector will remain the most active market participant type in next years and their hedging will still play important rule in EUA market prices. In addition, volatilities in financial markets via inflation hedging or geopolitical risks will also affect carbon market prices to some extent. The market stability reserve will function to help to absorb demand-side shocks, such as the demand destruction or faster decline in power sector emissions. After 2025, the declining cap will lead to rather tight balances and industry abatements costs will be price setter. Hence the abatement measures' adoption speed will be important. The abatement technology and their costs for industrial sectors (including old and the transport and buildings sectors) will be more and more important as price-setter in the EU ETS. Industrial participants' hedging behavior will also become more important.

Against this backdrop of tight balances going forward, supply-side factors such as MSR parameters and auctioning timing etc. will also be more important price drivers. The market will also look further ahead, focusing on the EU 2040 target which will then determine EU ETS rules post-2030. The post-2030 setup including the LRF, use of offset/removals, article 6 etc. will affect the EU ETS balances and market participants' anticipation of market tightness.

Responding organisation	Centre for Climate and Energy Analyses (CAKE/KOBiZE)

Model fact sheet

Model (suite) name	d-PLACE - Computable General Equilibrium model (CGE), MEESA - energy model, TR3E - transport model and EPICA - agriculture model
Website (preferably where model documentation is available)	https://climatecake.ios.edu.pl/analytical-tools/?lang=en
Short description	**d-PLACE model (CGE)** – The proposed dynamic computable general equilibrium model (CGE) which is the core of a comprehensive and consistent analytical toolkit, is accompanied by a package of sectoral partial equilibrium models. The construction of a dynamic macroeconomic model will, on the one hand, allow changes in the economic conditions to be reflected in successive periods of a forecast– enabling a more accurate assessment of the effects of implemented policies and measures – and, on the other hand, it will make it possible to link a macroeconomic model to sectoral models, contributing to improving the quality and reliability of analyses made using an integrated model-based toolkit. More details will be provided in model documentation. **Energy sector model MEESA (Model for European Energy System Analysis)** – Power and heat generation, as areas responsible for a substantial part of the emissions of greenhouse gases and other air pollutants, are a very important part of the economy from the point of the climate and environmental protection issues. Therefore, in order toensure a reliable assessment of the climate-related and environmental effects of the policies pursued, it is crucial to adequately precisely model the energy sector. In the CGE model, the energy sector is addressed in a simplified manner – through nested functions of production in which energy can be substituted for by a combination of capital and labour and at a lower level, by fuel substitution. At this level of generality, it is impossible to map in sufficient detail the operation of the energy sector. In consequence, it is necessary to create a tool which would enable more detailed analyses of the energy sector, taking into account its specificity, and, as a target, to link it to the CGE model. To this end, the creation of an optimisation model is planned. It will cover the supply and demand sides of the energy sector, enabling detailed analyses of the effects of the climate and energy policies pursued. From the point of view of the supply side, the model will address the issues of power security and sufficiency, its transmission and storage, the operation of unstable renewable sources, conventional and nuclear generators, cross-border electricity exchange, district heating generation (including cogeneration), the capabilities and directions of fuel imports.

	Transport sector model TR3E (Transport European Economic Model) – Road transport is now one of the major sources of the emissions of greenhouse gases and dust pollutants, including oxides of nitrogen. Its role is particularly important as these pollutants have a large impact on the air quality in cities, as a result of which they affect a substantial part of their population. At present, the government and territorial administration do not have tools which would ensure a reliable assessment of the strategies implemented in the area of transport, in a manner consistent with other sectors of the economy. The demand for transport activity depends on the condition of the economy; therefore, naturally, the results of a macroeconomic model can consist aninput to the transport model. In turn, activities carried out in the transport sector will affect the rate of economic growth and the optimum solutions, e.g. in the energy sector. Similarly, the electricity generation mix will affect the costs and emission factors of solutions applied in transport. Therefore, a correct assessment of the future changes in transport and the choice of the optimum directions of actions in this area require both precise modelling of the transport sector itselfand linkages between its operation and other areas. For this reason, as a target, the transport model will be integrated with the other models, to produce a joint calculation package which would integrate policies created in different areas, enabling a joint assessment of the emissions-related and environmental effects of the actions taken. **Agriculture sector model EPICA (Evaluation of Policy Impacts – Climate and Agriculture)** – Agriculture is one of the sectors which generate significant level of greenhouse gas emissions. They are related to livestock breeding (methane emissions) and plant cultivation, including the use of fertilisers. Moreover, the sequestration capacity offered by forest complexes, biomass production for energy generation purposes, the use of agricultural waste for energy generation purposes and the production of biofuels are important from the point of view of the national GHG emission balance. It is important to consider these elements not only in order to balance greenhouse gas emissions at the national level. In addition, it is important for assessing the potential for the future energy production from renewable sources. Therefore, the agriculture sector will be affected not only by agricultural policies, but also by elements of climate and other policies pursued in the areas of energy and transport. As a target, the agriculture model will be linked to the general equilibrium model and the other sectoral models, enabling an assessment of the costs and effects of national and European policies on the agriculture sector in the context of Poland's economy as a whole
Approach Bottom-up, Top-down, Hybrid	Hybrid
Geographical coverage	Models focus on European Union

Sectors covered and modelling detail	(see table below)

Sector		**Level of modelling detail**
Power sector	☒	Sectoral model (MESSA model)
Industry	☒	CGE (d-PLACE model)
Buildings	☒	CGE (d-PLACE model)
Road transport	☒	Sectoral model (TR3E model)
Aviation	☒	CGE (d-PLACE model)
Maritime	☒	CGE (d-PLACE model)
Forestry	☒	CGE (d-PLACE model)
Waste	☒	CGE (d-PLACE model)
Other sectors		CGE/ agriculture in EPICA model

Time horizon and temporal granularity	Time horizon: 2050 Temporal granularity: ➔ 5 years (d-PLACE, MESSA*), ➔ and 1 years (EPICA, TR3E). * For each calculation year, the MEESA model takes into account seasons (winter, summer), types of days (low, medium and high demand or different RES productivity) and time of day (in 2 hour daily periods).
Philosophy regarding level of detail	The models ware created to examine the impact of energy and climate policy on the EU economy and therefore their main features have been designed to meet such specific needs. Level of detail depends on the model.
Linkage to other ETS? If yes, please briefly elaborate	NO
Negative emissions? If yes, which technologies	YES
Offsets and credits included? If yes, please briefly elaborate	NO
Representation of foresight	Not perfect foresight
Representation of non-compliance trading (NCT)	NO
Representation of market imperfections	NO

Potential sectoral expansion	Models cover all sectors of the economy with different level of detail. There is potential to expand details for a given sector.
Analysis of distributional effects	YES
Analysis of competitiveness effects	YES
Analysis of carbon leakage	YES

Allowances prices in default scenario

Main assumptions Policies, e.g., is carbon neutrality assumed?	• calculation result (endogenous parameter)
Result highlights 3-5 points, include a main figure if possible	• energy demand, household consumption, GDP, sectoral emissions, marginal emission reduction costs

	2025	2030	2040	2050
Allowance price [EUR/t*]	70	180	330	440

Please provide base year and type of prices	• Base year: 2014 – dPLACE; 2020- EPICA, TR3E, MEESA • Type: nominal [X] real [...]

**If possible, please express the prices in EUR/t (eventually in USD/t). For the workshop we will harmonise price data to EUR*$_{2022}$ *using Eurostat inflation rates EU 27* and, if not expressed in EUR, *the European Central Bank's Reference exchange rates (avg. of monthly reported figures).*

Relevant allowance price drivers

Please select the three most important price drivers in 2030 and 2050. For the 2050 prices, please also provide the sensitivity range for the selected most important drivers.

	2030	2050	Range [EUR/t]
Policy parameters (excluding emission cap adjustment) Market stability measures (e.g., price floor/ceiling, market stability reserve [MSR]), Timing of supply (auctions, allocation, supply), Type of supply - allocation vs. auction, Use of revenues	☒	☒	+/- ...
Model parameters Year of calibration, discount rate	☐	☐	

Power sector Renewable targets, Power demand, Fuel prices, Coal/Fossil phase-out policies, Cost of new capacities, Grid costs and constraints, Expansion constraints/bottlenecks	☒	☒	
Industry Abatement costs (Cost of substitute fuels, Costs of CO2, Technological learning), Industrial growth/deindustrialisation, Short-term demand response, Carbon contracts for difference	☒	☒	
Buildings Abatement costs (Cost of substitute fuels, Costs of CO2), efficiency policies (renovation rates), Short-term demand response, increased pressure of electrification	☐	☐	
Transport Costs of substitute fuels, Short-term demand response, Behavioural trends (Flight shame, regionalisation)	☐	☐	
Behaviour Power sector hedging, Industry hedging/banking, Financial market participants, Speculation (Compliance player and financial player), Investment behaviour (e.g. adoption speed)	☐	☐	
External Political signalling, Monetary policy (certificates as inflation hedge), Interest rates slowing down investments, Global climate negotiations (e.g., Article 6), Cost of carbon removals or offsets, Geopolitical risks and opportunities	☐	☐	

Please proved a short explanation for your choice of the most important drivers, focussing on the changes between 2030 and 2050.

In our models, emission prices are primarily determined by: GHG reduction targets, resource constraints (e.g. RES potential, CO2 storage for CCS technologies), elasticity of substitution.