Discussion Papers
Department of Economics
University of Copenhagen

No. 22-02

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ISSN: 1601-2461 (E)

A coordination failure between EU climate policies exemplified by the North Sea energy island*

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February, 2023

Abstract

We highlight a coordination problem between the EU Emissions Trading System (ETS) and the EU's offshore energy strategy. We exemplify this coordination failure by analyzing carbon leakage effects associated with Denmark's planned North Sea energy island. The island will not start production before 2033, implying a long interval between project announcement and production. Using a dynamic model of the EU ETS, we show that the large time gap between announcement and production likely results in a Green Paradox, where the energy island increases aggregate EU ETS emissions. The mechanism is complicated and works through the Market Stability Reserve. The estimated 2050 leakage rate is 128 percent in our main scenario and not below 100 percent in any alternative scenario. We discuss how to improve the environmental benefits of the energy island and similar large-scale renewable energy projects. This includes revisions to the EU ETS and the role of Power-to-X technologies.

Keywords: Cap-and-trade, EU ETS, Market stability reserve, Overlapping policies, Green Paradox

JEL Classification: E61, H23, Q48, Q54, Q58

*We would like to thank Peter Birch Sørensen, Frederik Silbye, Esben Bak Larsen, Mads Dalum Libergren, August Emil Twile Nielsen, Pernille Birch, Frederik Læssøe Nielsen, Mette Dalsgaard, Mikael Bjørk Andersen, Peter Mogensen, Ulrik Beck, and Jørgen Søndergaard for useful comments, discussions, and suggestions. Additionally, we would like to thank seminar participants at the Danish Environmental Economic Conference 2022 for their valuable comments. Any remaining errors are our own. The article is partly based on chapter 3 in the report "The North Sea Energy Island: Arguments, Auctioning and Climate Impact" (original Danish title: Energiøen i Nordsøen: Argumenterne, udbuddet og betydningen for klimaet) by Kraka Advisory, 2022.

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1 Introduction

The EU strategy on offshore renewable energy implies a massive offshore energy expansion over the coming decades (European Commission, 2023). Aligning with this strategy, Denmark, Germany, the Netherlands, and Belgium have already committed themselves to a monumental offshore expansion through the Esbjerg Declaration of 2022. In particular, the countries plan to substantially increase their offshore capacity between 2030 and 2050.

We highlight a general coordination problem between the Esbjerg Declaration and the EU's offshore ambitions on the one side and the EU Emissions Trading System (ETS) on the other. Specifically, we show that the long time lag between the announcement and the offshore energy production likely results in a Green Paradox, where projects – that are designed to reduce greenhouse gas emissions – end up increasing them.[1] The mechanism is complicated and works through the EU ETS.

To highlight the coordination problem, we investigate the carbon emission impact of a particular large-scale offshore energy project: the North Sea energy island. The Danish parliament recently approved the establishment of two offshore energy hubs. The largest and most innovative being an artificial energy island in the North Sea 80 kilometers from the Danish coastline. The North Sea energy island will have a capacity of up to 10 GW, and it will by far be the most expensive infrastructure project in Danish history (Danish Ministry of Climate, Energy and Utilities, 2021). However, electricity production will not begin until 2033.

The question is then how the energy island affects foreign emissions through the EU ETS. Electricity production is mostly covered by the EU ETS, hence an expansion in renewable electricity production displaces fossil-based production, reducing the demand for emission allowances. In a textbook cap-and-trade system with a fixed quantity of emission allowances, this reduces the allowance price but has no effect on emissions (Goulder, 2013). Following this reasoning, it has been argued that unilateral emission-reducing policies in sectors covered by the EU ETS have no long-run effect on cumulated ETS

[1] Sinn (2008) coined the term "Green Paradox" to describe a situation where climate policies that are designed to reduce emissions end up increasing them. His mechanism goes through the market for fossil fuels, while the mechanism studied here goes through a politically constructed market: the EU ETS.

emissions (e.g., Böhringer et al., 2008). The effect is often referred to as the *waterbed effect*, and it implies that the intra-ETS leakage rate is 100 percent in the long run.

However, the 2018 reform of the EU ETS punctures this waterbed effect (Perino, 2018; Beck and Kruse-Andersen, 2020). The mechanism is closely linked to the *Market Stability Reserve* (MSR), a quantity-based regulation mechanism officially approved in 2015 and amended in 2018. In the following, we explain how the system works and how the amended MSR may puncture the waterbed effect.

Figure 1 provides a simple illustration of the current EU ETS. The EU issues new allowances every year. This quantity is reduced yearly by a linear factor, resulting in a cap on long-run cumulated emissions. The EU allocates the new allowances to firms covered by the EU ETS, via the member states, through auctioning and free allocations. ETS-covered firms face a consumption-saving problem: consume allowances today to allow emissions or save allowances for later use. The total saving of allowances basically equals the *allowance surplus*, that is the number of allowances in circulation.

The MSR absorbs allowances if the allowance surplus is large (above 833 million) and injects allowances back into the market when the allowance surplus is small (below 400 million). This is, in itself, emission cap preserving, i.e. it does not puncture the waterbed effect (Perino and Willner, 2016).

However, the 2018 reform introduced a cap on the number of allowances that can be contained by the MSR. This cap equals the amount of auctioned allowances of the previous year: a quantity that declines over time as fewer allowances are issued. The number of allowances exceeding the MSR cap are permanently cancelled, effectively endogenizing the emission cap (Beck and Kruse-Andersen, 2020).

The mechanism behind the punctured waterbed effect is as follows. A unilateral climate policy that reduces current allowance demand increases the number of allowances in circulation. This leads to more allowances being absorbed by and (potentially) cancelled in the MSR. Thus, demand-reducing policies may reduce both short-run and long-run ETS emissions, implying an intra-ETS leakage rate of less than 100 percent.

Nevertheless, the mechanism can also lead to leakage rates above 100 percent as emphasized by Gerlagh et al. (2021). The problem arises when there is a long time lag

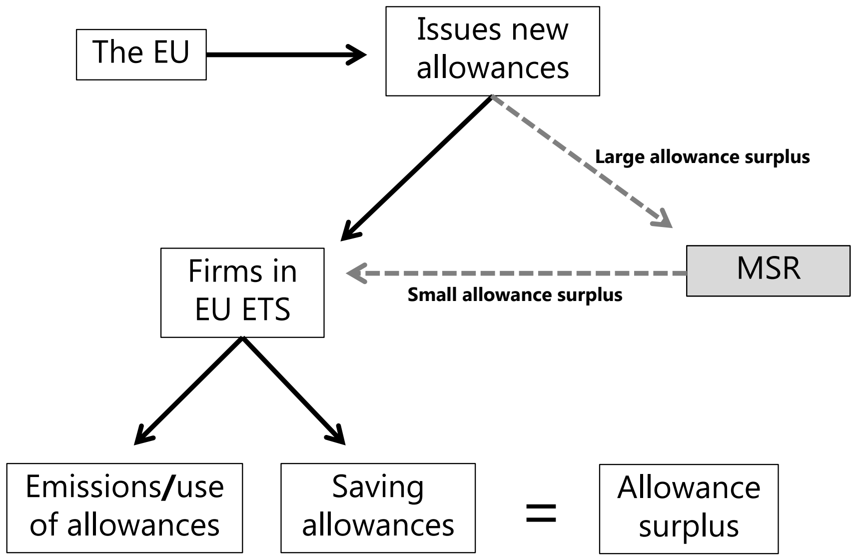

FIGURE 1: Simple illustration of the current EU ETS.

between the announcement of an emission abatement project and its emission abatement. The mechanism works as follows. An emission abatement project is announced at time t_0, resulting in emission abatement from time t_1, see figure 2. This is called the *announcement period*. From time t_1, the project results in emission abatement, and the period from t_1 to t_2 is called the *abatement period*. After time t_2, the allowance surplus never exceeds the threshold for MSR intake. Following Beck and Kruse-Andersen (2020) we call this the *MSR cut-off date*. After this date, the system returns to a textbook cap-and-trade system with 100 percent leakage.

When an emission abatement project is announced at time t_0, the market realizes that the allowance demand is reduced through the abatement period. This reduces the allowance price from time t_1, hence the incentive to save emission allowances through the announcement period is reduced. This leads to a higher emission allowance consumption and a smaller number of allowances in circulation. This in turn leads to fewer allowances being absorbed by and cancelled in the MSR, making more emission allowances available to market participants in the long run. After time t_1, the project may result in allowance cancellations which pulls in the opposite direction.

In short, emissions increase during the announcement period, while emissions decline over the abatement period. The timing of the project announcement, the actual emission abatement, and the MSR cut-off date are therefore crucial for the total leakage effect of the project. Thus, it is an empirical question whether a project results in a leakage rate below or above 100 percent.

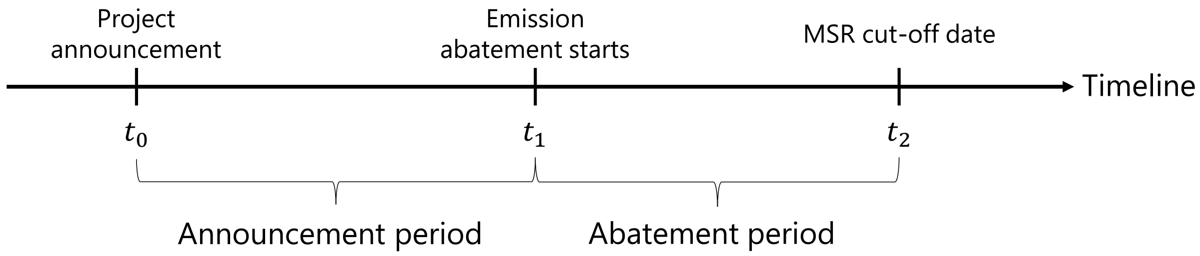

FIGURE 2: Timeline of an emission abatement project.

The North Sea energy island is an example of a large-scale emission abatement project that may result in an unintended negative environmental effect through the EU ETS. The energy island has long been in the making, but the project was concretized in 2020, when the Danish parliament agreed on the location for the island (Danish Ministry of Climate, Energy and Utilities, 2020). Yet, the island is not expected to produce electricity before 2033. Thus, there is a considerable time lag between the announcement and the emission abatement, which is exactly what Gerlagh et al. (2021) warn about.

To evaluate the emission effect of the North Sea energy island, we employ an updated version of the EU ETS model developed by Beck and Kruse-Andersen (2020). Our aim is to provide illustrative simulations of the ETS emission effect of the energy island. We show that the energy island is likely to have a negative climate benefit under the rules following the latest agreement on the EU ETS from December 2022 (Council of the EU, 2022). We also discuss how to improve the environmental impact of the project including changes to EU ETS rules and the potential role of Power-to-X technologies.

Importantly, we find it difficult to shut down the Green Paradox mechanism through changes to EU ETS legislation, while ensuring climate neutrality by 2050 or earlier. The key insight is that the MSR cut-off date is likely to occur several years before the energy island starts production, thereby eliminating the abatement period.

The article is organized as follows. We present the closest related literature and explain how our study contributes in section 1.1. Section 2 explains our method and, in particular, how we estimate the leakage effects of the energy island. Section 3 outlines our main results. Here we also analyze how different EU policies affect leakage associated with the energy island. Finally, section 4 and 5 offer a discussion and some concluding remarks.

1.1 Related literature

Our study contributes to the literature on the EU ETS with a MSR mechanism.[2] Beck and Kruse-Andersen (2020) show how the EU ETS reform from 2018 can puncture the waterbed effect by investigating the impact of temporary allowance demand-reducing policies. Beck et al. (2023, pp. 6-7) show that permanent allowance demand-reducing policies may also puncture the waterbed effect, although the long-run leakage rate is high.

Our study is closest related to Gerlagh et al. (2021), who show that allowance demand-reducing policies with a substantial time lag between announcement and emission abatement may result in leakage rates above 100 percent. We contribute to this research agenda in two dimensions. Firstly, we have a more policy-oriented focus, highlighting a coordination failure between current EU policies exemplified by a particular policy proposal. Secondly, our simulations are based on the most recent agreement on the EU ETS from December 2022 and account for the EU's 2050 target of net zero emissions.

Osorio et al. (2021) analyze how changes to the MSR affect allowance cancellations, and how adjustments to the linear reduction factor for allowance issuances can ensure the EU's 2030 emission target. Our main focus is not to analyze the effect of such EU policies. But we show how the agreement from December 2022 impacts the EU ETS, thereby contributing to this literature.

A closely related study is Tosatto et al. (2022) who investigate the impact of the two Danish offshore energy hubs (including the North Sea energy island) on the European power system and electricity market using a detailed model of the pan-European transmission system. However, they assume a constant EU ETS allowance price and do not consider dynamic emission effects through the EU ETS. We add an analysis of the leakage

[2] These studies include (but are not limited to) Perino and Willner (2017), Perino (2018), Carlén et al. (2019), Quemin and Trotignon (2019), Silbye and Sørensen (2019), and Beck and Kruse-Andersen (2020).

effects of the North Sea energy island as another piece to the puzzle.

Finally, our study relates to the literature on overlapping climate policies, e.g., Jarke and Perino (2017) and Kruse-Andersen and Sørensen (2022). Beck et al. (2023) estimate leakage effects of unilateral economy-wide carbon taxation for a range of EU countries in a global CGE model that incorporates current EU climate policies. They find that EU policies – and the EU ETS in particular – amplify carbon leakage effects substantially. The studies mentioned here take a more macroeconomic approach to the overlapping policy issue, but they do not analyze the Green Paradox mechanism embedded in the EU ETS highlighted in the present study.

2 Methodology

Through our simulations, we distinguish between the direct and the equilibrium emission effect of the energy island. The *direct emission effect* is the effect on EU ETS emissions holding the baseline allowance price path constant. This effect will be the direct emission impact caused by the crowding out of fossil-based electricity production. Basically, this is the emission effect calculated in techno-economic models featuring a constant EU ETS allowance price.

However, as fossil-based electricity production is reduced, so is the demand for emission allowances, resulting in a lower allowance price. This price reduction incentivizes additional allowance consumption – and thereby emissions – over the entire trading system. Thus, the *equilibrium emission effect* takes the full EU ETS mechanism into account and reveals the final environmental impact of the energy island.

We first compute the direct emission effect. We then feed it to our EU ETS model which computes the equilibrium emission effect.

2.1 Direct emission effect

The direct emission effect of the energy island is computed in two steps. First, we compute the change in net electricity exports caused by the energy island. We then compute how much this change in electricity exports crowds out emissions from fossil-based electricity production.

We take Danish electricity demand until 2040 from the Danish Energy Agency (2021a) and extrapolate linearly from there based on a 2050 projection from the Danish Energy Agency (2021b).[3] The Danish power production is also taken from the Danish Energy Agency (2021a) subtracting production from "unknown seas", as this category may overlap with the energy island. The energy island is assumed to produce 3 GW in 2033, increasing by 1 GW per year up to 10 GW in 2040 based on the Danish Finance Act of 2022 (Danish Ministry of Finance, 2021).[4] Finally, net electricity exports are computed as excess supply.

Figure 3 shows net electricity exports in a reference (frozen policy) scenario without the energy island and in a scenario where the energy island is constructed. Danish net electricity exports are negative from 2035 without the energy island. However, if the energy island is constructed, it ensures a positive net electricity export over the next several decades.

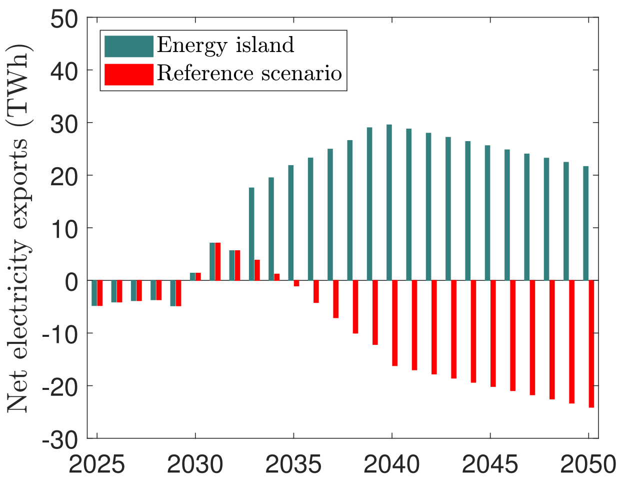

FIGURE 3: Danish net electricity exports.

The Danish Energy Agency (2022a) calculates the marginal foreign emission impact per unit of Danish electricity exports in 2030 using its large-scale techno-economic model

[3]The Danish Energy Agency (2021b) has four scenarios of how Denmark can reach the net-zero target in 2050. We use the carbon absorption scenario from the Danish Energy Agency (2021b), which has the largest electricity demand in 2050, due to the use of direct air capture. We find this scenario more plausible given the expected role of both direct air capture and Power-to-X technologies in 2050.

[4]The agreement states that the energy island should have a capacity of 3 GW but aiming towards 10 GW by 2040.

Ramses. The model features 23 countries, but as it is designed for Danish policy experiments, Danish plants are described in more detail. Importantly, the EU ETS allowance price is exogenous in Ramses, ensuring that we do not double count leakage through the EU ETS.[5]

For offshore wind, the Danish Energy Agency (2022a) finds a marginal effect of 0.21 tonnes of foreign CO_2 reductions per MWh. We use this number to compute our direct emission effect, but our main conclusions are not sensitive to this number.

2.2 EU ETS model

We employ an updated version of the EU ETS model developed by Beck and Kruse-Andersen (2020) to compute EU ETS emission paths. The model features three elements: (i) a representative firm in the EU ETS that takes prices and aggregate quantities as given, (ii) an administrative system ensuring that the EU ETS rules are complied with, and (iii) an exogenous technological development.

The objective of the representative ETS firm is to maximize the net present value of its profits. Essentially, this boils down to a dynamic consumption-saving problem, i.e. the representative firm must decide when to consume and save emission allowances. The representative firm does not consider its own effect on aggregate quantities or the allowance price, as it represents a large number of firms each with a negligible impact on aggregate quantities and prices.

The energy island reduces the total allowance demand from 2033, which affects the representative firm's optimal allowance-saving behavior. This behavioral effect together with the MSR mechanism determined by the administrative system is what drives our results.

We refer to appendix A for more details on the model.

2.2.1 Model calibration

Compared to Beck and Kruse-Andersen (2020), we update all stock variables, and behavioral parameters are recalibrated to match the historical emission trend and the market

[5] See Danish Energy Agency (2022b) for further details on the Ramses model.

situation in 2021 which is also the first year in our simulation (see appendix B for details).

2.2.2 Announcement

We assume that the market learns at the beginning of 2021 that the energy island will be built. However, the market likely anticipated the construction of the island prior to that.[6] This potential shortcoming will only weaken the announcement effect discussed above, and thus, the Green Paradox mechanism will only be strengthened if the announcement is assumed to occur earlier.

2.2.3 Latest changes to the EU ETS and climate neutrality by 2050

The EU ETS system in our model is based on changes to the system as they appear in the latest agreement on the EU ETS from December 2022 (Council of the EU, 2022). As our simulations start in 2021, the implicit assumption is that ETS-covered firms anticipated a similar reform already back then. This seems reasonable given the EU Commission's "Fit for 55" proposal, which contained proposals to tighten the EU ETS (European Commission, 2021).

The latest agreement implies a rebasing of the overall emission cap by 117 million allowances, increases to the linear reduction factor for allowance issuances from 2024 to 2030, a prolonged intake rate of 24 percent for the MSR, and a MSR cap of 400 million allowances. See appendix B for details.

After 2030, we assume that the linear reduction factor returns to its current rate of 2.2 percent. This implies climate neutrality by 2050 according to our main scenario, aligning with the EU's current 2050 target of climate neutrality (European Commission, 2018).[7]

[6] Although the formal approval took place in 2020, the market is likely to have anticipated the island prior to that. A state-owned TSO, Energinet, investigated the possibility of building an artificial island at a specific location in the North Sea already in 2017 (Energinet, 2017). The location was unfit, but the Danish parliament agreed to screen a larger area in the North Sea to map the wind energy potential in 2018 (Danish Ministry of Climate, Energy and Utilities, 2018). Based on this work, a broad majority in the Danish parliament agreed to build the energy island in the North Sea in 2020 (Danish Ministry of Climate, Energy and Utilities, 2020).

[7] The model features considerable emission smoothing over time, implying that there can be several years with very low emission levels before emissions completely cease. We, therefore, define climate neutrality by 2050 as a situation where yearly emissions are less than 0.1 billion tonnes in 2050 and forward. A stronger definition of climate neutrality increases leakage from the energy island.

2.3 Equilibrium effect

The equilibrium emission effect is computed in the following way based on the approach from Beck and Kruse-Andersen (2020). Firstly, we run our EU ETS model in a reference scenario without the energy island. Secondly, we use the allowance price path from the reference scenario to compute the reduction in emission demand compatible with the direct emission effect of the energy island. That is, we adjust the emission function of the representative firm such that given the price path of the reference scenario, the equilibrium emission effect of the energy island equals the direct emission effect. Thirdly, we run our EU ETS model with the adjusted emission function to obtain the equilibrium effect.

2.4 Leakage effect

Let t_0 denote the year where the energy island is announced. In some following year, $T \geq t_0$, the intra-ETS leakage rate is given by:

$$L_T = -\frac{\sum_{t=t_0}^{T}\left(\Delta E_t^{\text{Eq.}} - \Delta E_t^{\text{Direct}}\right)}{\sum_{t=t_0}^{T}\Delta E_t^{\text{Direct}}},$$

where $\Delta E_t^{\text{Eq.}}$ is the absolute equilibrium change in emissions in year t, and $\Delta E_t^{\text{Direct}}$ is the direct emission effect in year t.

An intra-ETS leakage rate of 80 percent means that 80 percent of the potential CO_2 emission displacement from the energy island is offset through the EU ETS mechanism. If the leakage rate is 120 percent, aggregate EU ETS emissions increase by 20 percent of the potential CO_2 emission displacement, causing a negative environmental impact of the island.

3 Results

3.1 Main scenario

Figure 4 shows the EU ETS development from 2021 to 2060. Emissions decrease systematically through the period and become less than 0.1 billion tonnes in 2050, which we consider compatible with carbon neutrality.[8] The allowance surplus starts above the MSR intake threshold, and allowances are transferred to the MSR until 2030. The allowance surplus stays below the MSR intake threshold from 2029, and there is, therefore, no allowance transfers to the MSR from 2030. The stock of allowance in the MSR is dramatically reduced in 2023 when the MSR cap becomes active. The MSR cap is binding through the entire period, implying that allowances transferred to the MSR are systematically cancelled.

Figure 4 reveals an important insight: the MSR cut-off date occurs before the energy island starts electricity production. Hence, there is no abatement period associated with the project, see figure 2. Accordingly, we should expect a leakage rate above 100 percent.

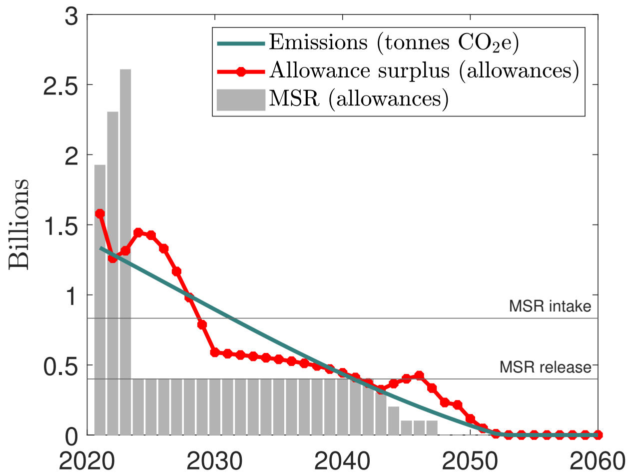

FIGURE 4: EU ETS development, 2021-2060.

Before analyzing the leakage effects, we investigate the underlying cause. Figure 5 shows the emission effect of the energy island in the entire EU ETS. The energy island reduces the demand for emissions after its completion, hence reducing the incentive to save allowances in the 2020s and early 2030s. As shown in figure 5, this leads to a positive emission effect in the beginning. Later, the emission effect turns negative. The negative impact does not occur in primo 2033 when the energy island starts production, as the energy island does not immediately hit its full production capacity. Yet, the positive

[8]Emissions of this magnitude can be offset through negative emission technologies. Note that the Green Paradox mechanism is only strengthened if we tighten the system further to achieve absolutely zero emissions after 2050.

emission effect is clearly affected in 2033, where it starts to decline.

The asymmetry around the first axis shown in figure 5 reflects that the energy island results in a loosening of the effective emission cap. The increase in emissions at the beginning of the period reduces the allowance surplus, which leads to fewer allowances transferred to and cancelled in the MSR. Thus, ETS-covered firms have access to more allowances as a consequence of the energy island. This is also what leads to a long-run leakage rate above 100 percent.

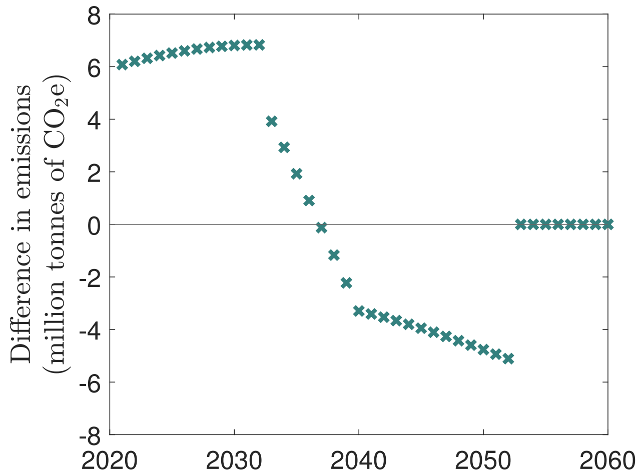

FIGURE 5: EU ETS emission effect of the energy island.

Leakage rates for the period 2035-2050 are shown in figure 6. The leakage rate is around 860 percent in 2035 and drops to 128 percent in 2050. There is no direct emission effect until 2033, and thus, L_T cannot be calculated for this period. The leakage rate is very high in the years following 2033, as the direct emission effect is small compared to the equilibrium effect, as the latter has accumulated over more years. The direct emission effect has partly caught up in 2050, resulting in a leakage rate of 128 percent.

All in all, our main scenario shows that the energy island starts production after the MSR cutoff date, hence the project has no abatement period. As a consequence, the increase in emissions and associated reduction in MSR cancellations during the announcement period dominates, resulting in a 2050 leakage rate above 100 percent.

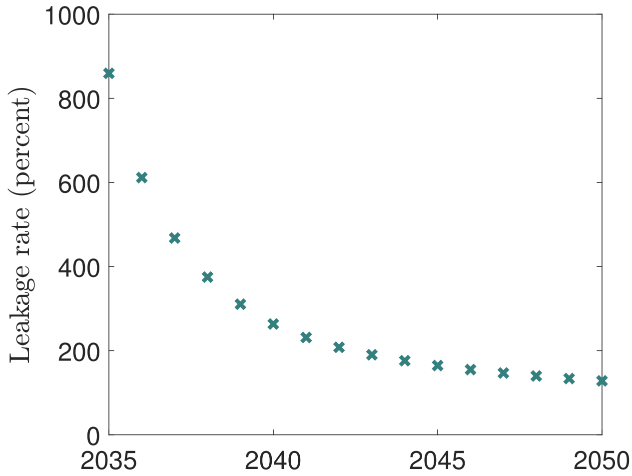

FIGURE 6: Carbon leakage effect of the energy island.

3.2 Effect of new EU policy

A natural question is how the recent agreement to tighten the EU ETS affects our results. In our scenario I.1, we have recalibrated the model to a situation where the EU ETS is not tightened and where this aligns with market expectations. The leakage rate increases notably in both 2035 and 2050, as shown in table 1. The intuition is as follows. Without a tightening of the EU ETS, there are substantially more emission allowances in the system. The allowance surplus, therefore, remains above the MSR intake threshold over the next few decades, implying more years where the energy island results in a lower MSR allowance uptake. This is not outweighed by the emission abatement occurring from 2033, as the energy island starts at a relatively low production level.

TABLE 1: Leakage associated with the North Sea energy island

Scenario	**Leakage rate (percent)**	
	2035	**2050**
Main scenario	860	128
I. Effect of new EU policy		
I.1 Without changes to EU ETS rules	1651	248
I.2 Without changes to MSR rules	1026	153
I.3 High linear reduction factor post 2030	565	130
II. EU policies that may reduce leakage		
II.1 Lower MSR uptake threshold	1242	184
II.2 Increasing MSR uptake threshold	825	123

To test the effect of changing MSR rules, scenario I.2 recalibrates the model to a situation where only the linear reduction factor for allowance issuances is changed in accordance with the recent agreement. As shown in table 1, the leakage effect increases compared to the main scenario. A lower allowance intake rate (12 instead of 24 percent) from 2023 causes the allowance surplus to stay above the MSR intake threshold for more years compared to the main scenario. Hence, the increase in emissions through the announcement period caused by the energy island results in more years with MSR transfers. On the other hand, the intake rate is lower for those years. Yet, the first effect dominates according to our model.

The results from scenario I.1 and scenario I.2 suggest that both changes to MSR rules and the linear reduction factor weakened the Green Paradox mechanism, although they are far from eliminating it.

3.2.1 EU policies and climate neutrality

Scenario I.3 investigates how our assumption on the linear reduction factor post 2030 affects the results. The scenario assumes that the linear reduction factor is permanently set equal to 4.4 percent. This results in climate neutrality (here CO_2e emissions less than 0.1 billion tonnes) in 2043. This is arguably more in line with the emission path toward climate neutrality by 2050 proposed by the European Commission (2020), where the power sector is almost climate neutral by 2040, while industrial emissions have declined significantly.

The long-run leakage effect in scenario I.3 is basically the same as in the main scenario, see table 1. On the one hand, firms react less to the energy island, as it affects allowance demand over fewer years. On the other hand, the allowance surplus is above the MSR intake threshold for longer, as firms save more allowances at the beginning of the period to oppose the additional allowance scarcity caused by the faster decline in allowance issuances. The second effect dominates, resulting in more cancelled allowances within the MSR.

3.3 EU policies that may reduce leakage

In this subsection, we investigate how EU policies can be changed to reduce the leakage effect associated with the energy island. In this case, we do not recalibrate the model as these changes would be unanticipated by the market. Thus, the policy changes will also affect the initial emission level.

Our first approach is to lower the threshold for allowance intake into the MSR. The idea is to increase the number of years where the energy island can abate emissions.

Scenario II.1 shows the effect of lowering the MSR intake threshold from an allowance surplus of 833 to 500 million allowances. At first, the results seem counterintuitive, as the leakage rates increase. Lowering the threshold results in more allowances being allocated to and cancelled in the MSR through the entire lifetime of the system. This reduces allowance availability, increasing the propensity to save allowances at the beginning of the period. The ETS-covered firms, therefore, respond stronger to the energy island.

Scenario II.2 instead increases the MSR uptake threshold to one billion allowances. This results in a 2050 leakage rate of 123 percent – about 5 percentage points below the main scenario. Intuitively, increasing the MSR intake threshold moves the system towards an exogenous emission cap, resulting in a long-run leakage rate approaching 100 percent as in a textbook cap-and-trade system.

Experimenting with different changes to current EU ETS legislation reveals that it is difficult to shut down the Green Paradox mechanism, while preserving the 2050 target of climate neutrality. This is partly because the energy island distorts the intertemporal value of allowances for any given set of rules. But it is also because the tightening of the system needed to reach climate neutrality by 2050 implies that the allowance surplus declines fast thereby shutting down MSR uptake and cancellations. The abatement period of the energy island is therefore either short or non-existing.

To document this claim, we provide several simulation experiments in appendix C including a time-dependent MSR intake threshold and changes to MSR cancellation rules. None of these hypothetical policy changes eliminate the Green Paradox, i.e. the long-run leakage rate associated with the energy island remains above 100 percent.

3.4 Alternative scenarios

Appendix D provides several alternative scenarios to investigate the robustness of our results. In all cases, we find a 2050 leakage rate associated with the energy island of more than 100 percent. Hence, our results seem robust within our modelling framework.

4 Discussion

Our analysis shows that the MSR cut-off date is likely to occur prior to the energy production of the North Sea energy island. Hence, the energy island and similar projects are likely not to have any emission abatement period. This also explains why we find it difficult to eliminate the Green Paradox mechanism and achieve climate neutrality by 2050 through changes to the EU ETS legislation. However, there are ways to weaken the Green Paradox mechanism, which works around the legislative framework of the EU ETS.

One way to counteract the adverse emission effects of the energy island is through Power-to-X technologies. Power from the energy island could, for instance, produce green fuels for international transportation. The electricity would then not enter the ETS-covered electricity market directly, thereby avoiding leakage through the EU ETS. There would still be a leakage effect through the international market for fossil fuels (see Beck et al., 2023, p. 2). However, Power-to-X production is associate with a significant energy loss, which could reduce the direct emission effect of the island. Still, given the potent leakage effect through the EU ETS, this seems like an attractive option. It should also be noted that the leakage effects investigated in this article still applies to Power-to-X products sold to ETS-covered firms.

Another option is to accelerate the construction process to shorten the announcement period. The viability of this option is a question of both technical feasibility and additional construction costs. Alternatively, the project could be reduced in size. This might reduce the economic viability of the project due to economies of scale. However, it could reduce construction time, thereby increasing the environmental benefit. Nevertheless, simulation experiments show that the leakage rate is only marginally affected if the island is completed a few years before 2033 (see scenario IV.3, appendix D).

The government can also purchase (or abstain from auctioning) emission allowances until 2033 to fully or partly offset the allowance demand effect of the island. These allowances should permanently be removed from the market to have the desired effect.[9] Although the negative abatement effect of the energy island can be avoided through this policy, the total cost per unit of emission abated would probably be high, as the two abatement instruments work against each other.

It has also been suggested that new data centers should be placed on the island (North Sea Energy Island, 2022). If these data centers would alternatively have been placed somewhere else in the ETS-covered region, this would have no effect on the leakage rate, as there would be no effect on net allowance demand. However, if these data centers would otherwise be placed outside the scope of the EU ETS, two environmental benefits emerge. Firstly, foreign emissions would be lower, as the foreign non-ETS economy would not have to power the data centers. Secondly, the centers would counteract the increase in Danish electricity exports caused by the energy island, resulting in a weaker ETS demand effect, hence a smaller leakage effect.

5 Concluding remarks

The present study finds that the climate benefit of the North Sea energy island is likely negative. This is a consequence of current EU ETS rules, where an emission abatement project with a long time gap between project announcement and emission abatement may lead to an increase in long-run cumulated emissions. These results point to a more general coordination failure between the EU's offshore strategy and the EU's main emission abatement instrument: the EU ETS.

Our analysis shows that it is difficult to eliminate the adverse emission effect through changes to EU ETS rules. Yet, one natural option is to remove the MSR cancellation mechanism from the system. All emission abatement projects would then be subject to a long-run leakage rate of 100 percent, as the effective emission cap would be exogenous.

[9]They should, however, not be cancelled before the MSR stops absorbing allowances (Beck and Kruse-Andersen, 2020).

Projects like the energy island would then have no effect on long-run cumulated emissions rather than an adverse effect. The politicians would also be completely in control of long-run cumulated emissions and would be able to set an optimal carbon budget. The cost is an amplified leakage effect associated with certain emission abatement projects with a short announcement period. Thus, it appears that there is no silver bullet.

One potential shortcoming of our analysis is the lack of endogenous policy response. When the energy island or a similar project increases short-run emissions and reduces the allowance price, EU policymakers may respond by tightening the EU ETS. Nevertheless, we find such mechanisms speculative and difficult to quantify. We also note that the direction of such effects might be ambiguous given the complexity of EU policymaking.

In our view, national policymakers should be aware of the potential negative climate impact of the North Sea energy island and similar large-scale renewable energy projects. Yet, we are not making a case against the North Sea energy island. The island could still be defended as a commercial and/or large-scale R&D project. However, politicians should be hesitant to use the environmental benefit of the energy island and similar projects as a main selling point to the public given that this benefit is potentially negative. Finally, politicians should consider ways to counter these adverse emission effects – balancing the costs and benefits of doing so.

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A Description of EU ETS model

This appendix provides a short description of our model, which is an updated version of the model developed by Beck and Kruse-Andersen (2020).

A.1 Overview

The model features three elements: (i) a representative firm in the EU ETS that takes prices and aggregate quantities as given, (ii) an administrative system ensuring that the EU ETS rules are complied with, and (iii) an exogenous technological development which erodes the competitiveness of ETS covered firms relative to their renewable competitors.

A.2 The representative firm

Time is discrete and denoted $t \geq 1$. The objective of the representative ETS firm is to maximize the net present value of its profits. Specifically, the representative firm's problem is

$$\max_{e_t \geq 0} \sum_{t=1}^{T} \left(\frac{1}{1+r} \right)^{t-1} f(e_t, A_t) \quad \text{s.t.} \quad B_{t+1} = B_t + y_t - e_t, \quad B_t \geq 0,$$
$$\text{given} \quad B_1 > 0, \quad \{y_t\}_{t=1}^{T}, \quad \text{and} \quad \{A_t\}_{t=1}^{T}.$$

where T is the terminal period, $f(\cdot)$ is current profits, $r > 0$ is the discount rate, e_t is emissions, A_t is the relative technological disadvantage of renewable energy competitors, B_t is the firm's stock of emission allowances at the beginning of period t which equals the allowance surplus in equilibrium, and y_t is allowances allocated to the representative firm. As shown by Beck and Kruse-Andersen (2020), we can leave out an explicit allowance market, as there is only one representative firm demanding allowances. The allowance price is therefore the shadow price of emissions.

The profit function, $f(e_t, A_t)$, increases in e_t for $e_t < \bar{e}_t < \infty$, and decreases for $e_t \geq \bar{e}_t$. Thus, emissions remain finite (equals $\bar{e}_t$) in the absence of a cap-and-trade system. The profit function is also increasing in A_t. We assume that A_t decreases over time, reflecting a higher relative technological level of renewable energy competitors.

Given a positive next-period allowance stock, B_{t+1}, the first-order conditions are given by

$$p_t = \frac{\partial f(e_t, A_t)}{\partial e_t} \equiv f_e^{'}(e_t, A_t) \quad \text{and} \quad p_{t+1} = (1+r)p_t,$$

where p_t is the shadow price of emissions and the price of emission allowances. For $B_{t+1} = 0$, $e_t = B_t + y_t$ and $p_t = f_e^{'}(e_t, A_t)$.

A.3 Administrative system

We refer to Beck and Kruse-Andersen (2020) for a full description of the administrative system before the agreement from December 2022 (Council of the EU, 2022). The agreement implies four changes that are relevant here.

Firstly, the overall emission ceiling is rebased by 117 million allowances over two years: 90 million allowances in 2024 and 27 million allowances in 2026. Note that both changes have permanent effects on allowance issuances.

Secondly, the agreement increases the linear reduction factor for allowance issuances from 2.2 to 4.3 percent (of the average yearly reduction of allowances over the period 2008-2012) from 2024 to 2027. The factor is then increased to 4.4 percent from 2028-2030. In principle, the linear reduction factor continues to be 4.4 percent from 2030 without further revisions to the system. However, we expect further revisions in line with the EU's 2050 target of climate neutrality. We, therefore, set the reduction factor to 2.2 percent from 2031, which results in approximately net zero emissions in 2050 aligning with the EU's long-run ambitions.

Thirdly, the intake of allowances into the MSR (allowance surplus above 833 million) is permanently increased to 24 percent of the allowance surplus of the previous year. Before the agreement, this number was 12 percent from 2024.

Fourthly, the agreement alters the cap over emission allowances that can be contained within the MSR. Before the agreement, the cap over emission allowances in the MSR equaled the auctioning volume of the previous year. This implies a decreasing MSR cap over time, as the number of new allowance issuances – and thereby the auctioning volume

– declines over time. The agreement changes this to a permanent cap of 400 million allowances.

The agreement also places certain maritime activities under the EU ETS. However, this change applies to the allowance demand function. The market knows that more allowances are demanded in the future by expanding the scope of the EU ETS, which affects initial emissions. Thus, the inclusion is implicitly taken into account through the calibration of the allowance demand function.

A.4 Technological development

Renewable technologies become relatively more competitive over time but at a decreasing rate. Thus, A_t evolves according to

$$\begin{aligned} A_{t+1} &= A_t(1-g_t), \quad A_1 > 0, \\ g_{t+1} &= \frac{g_t}{1+\kappa}, \quad g_1 > 0, \quad \kappa \geq 0. \end{aligned}$$

where g_t is the technological growth rate, and the parameter κ reflects how fast the catching-up effect is depleted.

A.5 Specifying the profit function

The specific profit function used in the analysis is

$$f(e_t, A_t) = A_t \left[\gamma \left(e_t + \varphi\right)^{\alpha} - \delta e_t - \omega\right] - p^f e_t, \quad 0 < \alpha < 1, \quad \gamma, \varphi, \delta, \omega, p^f > 0,$$

where $\gamma A_t(e_t + \varphi)^{\alpha}$ is the value of output, $\delta A_t e_t$ is all variable costs except fossil fuel inputs, $A_t\omega$ is a quasi-fixed cost, p^f is the constant fossil fuel price, and $p^f e_t$ is the cost of the fossil fuel input. Profits are zero if the firm chooses not to emit any greenhouse gasses, implying that: $\omega = \gamma\varphi^{\alpha}$. Note that $\varphi > 0$ ensures that the marginal product of the fossil fuel input does not approach infinity for e_t approaching zero. Hence, the firm may cease production within its planning horizon.

A.6 Solution method

We employ the solution method from Beck and Kruse-Andersen (2020, pp. 793-794), although we use a simple algorithm to provide a better initial guess.

B Calibration

The calibration procedure largely follows Beck and Kruse-Andersen (2020), but there are some minor differences.

B.1 Stock variables

The model is calibrated to 2021. The allowance surplus and the stock of allowances in the MSR primo 2021 are taken from European Commission (2021). We note that the allowance surplus primo 2021 equals the allowance surplus ultimo 2020.

B.2 Price and emissions, 2021

The 2021 emission price is calculated as the average auctioning price of EU ETS allowances based on data from the European Energy Exchange. The 2021 emissions are taken from the EEA data viewer.

B.3 Calibrating behavioural parameters

As a point of departure, all parameter values are taken directly from Beck and Kruse-Andersen (2020). Without further adjustments, the model does not hit the correct 2021 emission and price level. The model especially undershoots the 2021 price. To deal with this issue, we set φ to 0.5 instead of one which pushes the inverse emission demand function up (higher price given emission level).

The next step is to calibrate δ, γ, and $\bar{g}$, where $\bar{g}$ is the technological growth rate in 1990. Note that given a value of $\bar{g}$, one can compute the entire path for A_t.

To calibrate the three parameters, we use a two-step procedure. Consider the calibration targets:

- ETS sector emissions in 1990: 2.7 billion tonnes of CO_2.
- ETS sector emissions in 2004: 2.4 billion tonnes of CO_2.
- Market situation in 2021: the allowance price is 54.1 Euros in 2021 if the EU ETS sector emissions are 1.34 billion tonnes of CO_2.

Calibration targets (i) and (ii) ensure that the model matches the declining emission trend of the ETS sector before the introduction of the EU ETS. Target (iii) ensures that the market situation in 2021 is a point on the 2021 inverse emission demand curve (i.e. a possible outcome).

The first step is to choose δ and γ such that (i)-(iii) are satisfied. The second step is to choose $\bar{g}$ such that in equilibrium, the model matches the market situation in 2021. Finding the equilibrium of 2021 requires that we run the entire model. Thus, we set up a minimization problem, where we minimize the squared difference between predicted and actual emissions in 2021 with respect to $\bar{g}$. Each iteration requires that step one (computation of δ and γ) is conducted again, as the technological level enters all relevant equations.

The procedure essentially ensures a perfect match between actual and predicted 2021 emissions, while satisfying calibration targets (i)-(iii).

B.4 Matching the data

Beck and Kruse-Andersen (2020, pp. 808-809) show that this relatively simple model may provide a good fit on historical data. We provide a similar exercise here.

We keep our 2021 calibration but change the first year to 2008. Although the EU ETS launched in 2005, the period 2005-2007 was a test phase, and allowances from this phase could not be used after 2007. Thus, 2008 marks the actual beginning of the system. We set the allowance surplus to zero in 2008. We also remove the MSR from the model, as this mechanism was not agreed upon until 2015, and, therefore, not expected by the market in 2008.

Figure 7 shows actual and predicted emissions from 2008 to 2021. The model provides a good fit on historical data despite being calibrated to 2021. We note that our model overpredicts emissions from 2019. This is because the MSR mechanism is absent in this simulation, while the EU introduced the MSR cap in 2018, resulting in a tighter overall emission cap, which lead to lower emissions. Hence, it is logical – and reassuring – that our model overpredicts emissions toward the end of the period in this particular simulation.

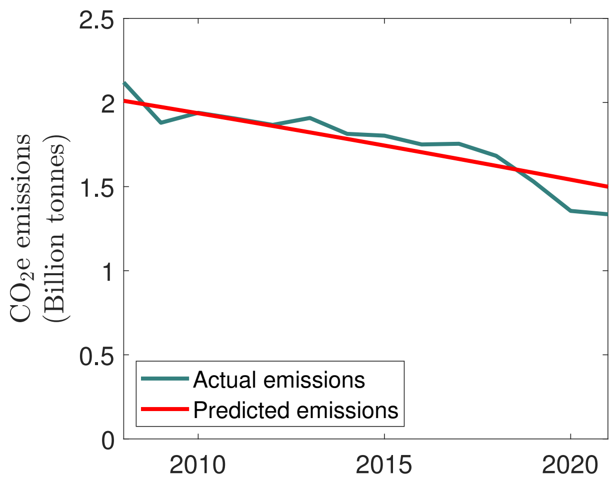

FIGURE 7: Actual and predicted emissions without the MSR, 2008-2021.
Data source: Actual emissions are obtained from the EEA Data Viewer (January 2023).

C Other changes to EU ETS rules

Table 2 provides simulation results for some alternative EU policies. In scenario III.1 we increase the initial MSR intake threshold to 1.2 billion allowances. The threshold then declines linearly to 500 million in 2050. The idea is to reduce MSR intake effects in the announcement period and strengthen them in the abatement period. As shown in table 2, this policy change reduces the leakage rate by only a few percentage points in 2050, and the long-run leakage rate is therefore substantially above 100 percent.

Scenario III.2 investigates how the leakage rate is affected if all allowances entering the MSR are cancelled. The calculations show that this has little effect on the leakage rate. Intuitively, all but 400 million allowances are cancelled in the MSR in the main scenario. Thus, the effect of the policy change is that there are 400 million allowances less available to the market in the 2040s, where these allowances would leave the MSR. This increases allowance scarcity, but the effect is small. The marginal propensity to save increases in the 2020s and 2030s, resulting in a small increase in the leakage rate.

Another idea is to increase the MSR intake rate. Scenario III.3 investigates the effect of an increase in the intake rate from 24 to 40 percent. This has a small but negative effect on the leakage rate. To investigate if the effect is monotonically increasing in the intake rate, Scenario III.4 goes further and increases the rate to 45 percent. In this case, the leakage rate increase above the main scenario.

TABLE 2: Other changes to EU ETS rules

Scenario	**Leakage rate (percent)**	
	2035	**2050**
Main scenario	860	128
III. Other EU policy changes		
III.1 Time-dependent MSR intake threshold	823	123
III.2 MSR cap of zero	878	130
III.3 Increase in MSR intake rate	809	120
III.4 Large increase in MSR intake rate	911	135

D Alternative scenarios

In this appendix, we keep the EU ETS rules fixed, but we change the characteristics of the policy shock.

In our main scenario, we assume that foreign fossil-based firms emit 0.21 mt. CO_2 less per TWh Danish electricity export based on Danish Energy Agency (2022a). In scenario IV.1, we increase this number to 0.30. We get almost the same effect as in the main scenario as shown in table 3. This result indicates that it is the timing and not the size of the shock that matters for the leakage rate.

To investigate this further, scenario IV.2 assumes that the energy island becomes twice as large. That is, we multiply the effect by two in all years. Again, there is no significant difference to the main scenario as shown in table 3.

A key question is what happens if the energy island is build faster than expected. This will weaken the Green Paradox mechanism by reducing the announcement period and increasing the abatement period. In scenario IV.3 we assume that the island is complete in 2030 instead of 2033. The 2035 leakage rate drops significantly compared to the main scenario. This is because the emission difference with and without the energy island is smaller over the period 2030-2032. But the ETS firms' saving reaction is stronger through the 2020s, as they have fewer years to react. Hence, the long-run leakage only declines by two percentage points.

TABLE 3: Alternative scenarios

Scenario	**Leakage rate (percent)**	
	2035	**2050**
Main scenario	860	128
IV. Alternative scenarios		
IV.1 Dirtier foreign electricity production	862	128
IV.2 Double size of energy island	860	128
IV.3 Energy island complete in 2030	367	126
IV.4 Foreign emissions approach net zero	422	115
IV.5 Announcement in 2023	759	120

Scenario IV.4 considers a situation, where electricity production in the foreign economy approaches net zero emissions. In 2033 foreign fossil-based firms emit 0.21 mt. CO_2 less per TWh Danish electricity export. This number declines linearly over time and becomes zero the last year with EU ETS emissions. This reduces the emission reaction by EU ETS firms in the 2030s, as the abatement effect of the energy island is weakened. The leakage rates therefore drop, but they remain above 100 percent.

Finally, we want to investigate how the timing of the announcement affects the leakage rate. Our results are surely robust to an earlier announcement, as this would only amplify the leakage effect of the energy island. Scenario IV.5 investigates how our results change if the announcement is postponed to 2023. The market realizes primo 2023 that the energy island will be constructed. This leaves fewer years for ETS firms to react compared to our main scenario. As shown in table 3, the 2050 leakage rate drops by 8 percentage points compared to the main scenario but remains well above 100 percent.

All in all, these alternative scenarios show that the Green Paradox mechanism is robust to various changes to our main approach.