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"Green" steel investments in the EU: Pie in the sky?☆

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ABSTRACT

The steel industry accounts for approximately 7%–8% of global carbon dioxide emissions. To address this, several initiatives aim to establish carbon-neutral steel production by replacing coal with hydrogen derived from fossil-free electricity. These projects, however, depend on substantial state subsidies, raising questions about their economic viability, especially under comprehensive carbon policies, such as those outlined in the EU's Fit-for-55 package. Our analysis employs a cost–benefit framework grounded in general equilibrium theory, which explicitly considers the direct and indirect effects of policies on primary and secondary markets, as well as broader economic interdependencies. By integrating the EU Emissions Trading System (ETS) and Carbon Border Adjustment Mechanisms (CBAMs) into this framework, we provide a rigorous evaluation of the social desirability of hydrogen-based steel production. Our findings, based on a case study of a large-scale plant in northern Sweden, indicate significant social losses, with potentially far-reaching implications for similar projects across the EU. We might see a da capo of the 1970s European steel crisis.

1. Introduction

The steel industry accounts for approximately 7%–8% of global carbon dioxide (CO_2) emissions. Steel production typically involves removing oxygen and other impurities from iron ore to produce iron, which is then combined with carbon, recycled steel, and small amounts of other elements to make steel. In recent years, significant efforts have emerged to produce fossil-free — or "green" — steel, which aims to replace coal with hydrogen produced using renewable or fossil-free electricity. While these initiatives offer substantial environmental benefits, they often rely heavily on state subsidies. This raises questions about their economic viability, particularly when assessed within the framework of comprehensive climate policies such as the EU's Fit-for-55 package (see Table 1).

Vogl et al. (2020) evaluate EU policies to commercialize low-emission steel technologies, arguing that a combination of carbon contracts for difference (CCFD) and demand-side market-creation policies offers the best way forward. A CCFD stabilizes revenue for green steel producers by covering the gap between actual carbon market prices and a predefined strike price, mitigating financial risks and incentivizing investment. Demand-side policies may include public procurement, green labeling standards, and consumer subsidies. These mechanisms align with the broader objectives of the Fit-for-55 package and are frequently proposed as tools to facilitate green steel production. Kim et al. (2022) comprehensively review various sociotechnical systems, technological innovations, and policy options for decarbonizing the iron and steel industry. They identify several barriers to decarbonizing the

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Table 1
Symbols and their meanings.

Symbol	Meaning
α	Proportion of production sold within the EU
x_1^s	Production quantity sold within the EU
x_2^F	Imported steel
p_d	Internal EU price of steel
p_w	World market price of steel
t	Tariff per unit of emissions on imported steel
p_p	Price of permits under the EU Emissions Trading System (ETS)
θ_1	Emissions conversion factor for green steel production
θ_2	Emissions conversion factor for imported steel
r	Social discount rate
NPV	Net Present Value of the project
Δp_d	Change in domestic price of steel
Δx_d	Change in domestic demand for steel

EU's basic materials sector, such as limited availability of green and affordable electricity. Low electricity prices are important for the profitability of green steel, a factor we emphasize in our analysis. They also emphasize the importance of reliable carbon pricing mechanisms, which are an integral part of the Fit-for-55 package.

This package represents a cornerstone of EU climate policy, designed to achieve a 55% reduction in greenhouse gas emissions by 2030 compared to 1990 levels. The package introduces a mix of market-based mechanisms, stringent emissions targets, and complementary regulations, all of which significantly alter the economic calculus for green investments. Building on the theory outlined in Johansson and Kriström (2016), we develop a general equilibrium cost–benefit rule to disentangle the benefits and costs of introducing a green steel firm into the economy, considering key elements of the Fit-for-55 package. We model the impact of the new steel mill as a shift between two equilibria. By employing general equilibrium theory, our framework significantly simplifies the analysis, requiring only key information without accounting for effects in every market. This rule can be viewed as a non-parametric approximation of the first-order general equilibrium impacts. Our analysis extends Johansson and Kriström (2022)'s societal cost–benefit analysis (CBA) of a green steel plant under construction in northern Sweden by including key components of Fit-for-55, i.e. (i) updated EU Emissions Trading System (ETS) prices, (ii) accounting for the shift from grandfathering to auctioning permits, and (iii) including the CBAMs.

The structure of the paper is as follows. Section 2 provides an overview of the background to our study. In Section 3, we derive the general equilibrium cost–benefit rule (CBA), outlining its key components. Section 4 then discusses these components in detail. We present the results of the analysis in Section 5, followed by a concluding discussion in Section 6. In the discussion, we highlight pros and cons of government subsidies for green steel investments. Finally, in an Appendix, we provide robustness checks of our main result.

Our findings indicate that green steel investments in the EU can result in significant social losses. As of March 2025, for example, the Swedish steel mill project on which we base our application may already be in financial trouble (Dagens Industri, 2025), and Northvolt, a battery maker in northern Sweden that has also received substantial "green" subsidies, has filed for bankruptcy. The important fact, however, is that there is (as far as we can tell) no publicly available ex ante cost–benefit analysis of either investment (except Johansson and Kriström, 2022). The economic effects on the (rather small) Swedish municipalities that support these investments could be significantly negative. Furthermore, extensive subsidies in the EU could risk creating a second European steel crisis, similar to the one triggered by large subsidies in the 1970s.

2. Background

This study evaluates a steel plant currently under development in the small northern Swedish city of Boden, home to approximately 16,000 inhabitants (28,000 in the municipality). The company, initially named H2 Green Steel (https://www.h2greensteel.com/), rebranded in 2024 as Stegra (https://www.stegra.com/).

Although the term "fossil-free steel" is often used to describe the process, it is somewhat simplified in this context. The process employed by Stegra reduces greenhouse gas emissions by 95%, resulting in annual emissions of 550,000 tons of CO_2 at full operational capacity by 2030. To put this in perspective, only six Swedish companies emitted more CO_2 than this in 2021, and most of these companies have set targets for achieving climate neutrality.

Stegra's process relies on an electrolyzer powered by fossil-free electricity. Electrolysis splits water into hydrogen and oxygen using electricity, and the resulting hydrogen is used to reduce iron pellets into sponge iron, which can then be processed into steel. This green steel production method contrasts with conventional steelmaking, where coke is used as the reducing agent. At full capacity, Stegra plans to produce 5 million tons of steel annually, requiring approximately 20 terawatt-hours (TWh) of electricity—about ten times the energy consumption of Sweden's largest current electricity consumers, such as aluminum plants and mechanical pulp mills. The plant is also expected to employ around 2000 people.

The project is part of a broader green transformation occurring in Norrbotten County, where Boden is located, and in neighboring Västerbotten County. Electricity consumption in Norrbotten is projected to rise from 8 TWh today to over 100 TWh by 2050

Table 2
A sample of green steel projects in Europe 2024.

Country	Key investments in green steel	Technology	Status	Notes
Austria	*H2FUTURE*: Hydrogen electrolysis project by Voestalpine in Linz. (Voestalpine) *SuSteel*: Hydrogen plasma smelting in Leoben. (SuSteelProject)	Hydrogen Electrolysis, Hydrogen Plasma Smelting	Demonstration, Pilot Plant	–
Finland	*SSAB Raahe*: Fossil-free steel production using hydrogen. (SSABRaahe)	HYBRIT	Planned Industrial-Scale Implementation	HYBRIT = Swedish hydrogen-based Direct Reduced Iron (DRI)
France	*Dunkerque CCS*: Carbon capture project at ArcelorMittal Dunkirk. (ArcelorMittal) *Ascoval Plant*: Electric arc furnace in Saint-Saulve. (GFGAlliance)	CCS, EAF	Pilot Plant (CCS), Operational (EAF)	CCS = Carbon Capture and Storage, EAF = Electric Arc Furnace
Germany	*SALCOS*: Salzgitter's hydrogen-based steelmaking initiative. (SALCOS) *Thyssenkrupp Steel*: Shifting focus to DRI with hydrogen. (ThyssenkruppSteel)	DRI	Phased Industrial-Scale Transformation	–
Italy	*Energiron*: Hydrogen DRI technology by Tenova and Danieli. (Energiron) *Arvedi*: Electric arc furnace upgrades in Cremona. (ArvediGroup)	DRI, EAF	In Progress (Energiron), Operational (Arvedi)	–
Netherlands	*Tata Steel IJmuiden*: Hydrogen-based steelmaking and CCS. (TataSteelEurope)	Hydrogen-Based, CCS	Feasibility Study	–
Norway	*Mo Industrial Park*: Hydrogen-based steelmaking in Mo i Rana. (MoIndustrialPark)	Hydrogen-Based	Planned	–
Poland	*Dąbrowa Górnicza*: Hydrogen integration by ArcelorMittal. (ArcelorMittalPoland)	Hydrogen-Based	Under Development	–
Spain	*ArcelorMittal Sestao*: Zero-carbon emissions plant in Sestao. (ArcelorMittalSestao) *H2 Green Steel*: Hydrogen-based steel plant in Puertollano. (Iberdrola)	Hydrogen-Based	Under Construction	–
Sweden	*HYBRIT*: Fossil-free steel initiative by SSAB, LKAB, and Vattenfall. (HYBRITProject) *Stegra*: Large-scale hydrogen-based plant in Boden. (Stegra)	HYBRIT, Hydrogen-Based	Pilot Plant, Under Construction	–

(Skogsberg, 2022), driven by similar green industrial projects.[1] Across the two counties, approximately 10,000 green sector jobs are expected to be created, with the population projected to grow by 100,000 inhabitants (according to Skogsberg (2022, p. 8) and Dagens Nyheter (2024)), up from the current 525,000. However, it remains unclear where the additional TWh of electricity required in Norrbotten will come from, given that Sweden's total annual electricity consumption is around 140 TWh.

A financial analysis of Stegra is not publicly available. Consequently, this evaluation relies on other data sources, effectively treating the analysis as a hypothetical plant with characteristics similar to those of Stegra.

A brief summary of competing green steel projects. The Stegra effort is not without its competitors. A few examples of contemporary projects in Europe are given in Table 2. The table is mainly based on EUROFER (2024) and supplemented with information from company websites and the report by Hasanbeigi et al. (2024).

The current situation is dynamic, with some projects postponed, others started, and in some cases, it is difficult to determine the ongoing status. For instance, Hybrit has been postponed, ThyssenKrupp has refocused one of its projects, and a Norwegian company called Blastr appears to be planning a major factory in Finland. At any rate, competition from outside the EU is also intensifying, though a comprehensive picture is hard to pin down.

For example, according to Reuters (2025), plans are underway to build a green steel plant on the east coast of Thailand, with CBAMs providing an opportunity for such investments. There are also projects in Japan, but production might take place in Australia or Brazil, where high-grade iron ore is accessible and electricity is cheaper than in Japan. China, South Korea, the US, and Canada (along with other countries) seem to be starting similar projects. In the US, NextEra Energy, the country's most valuable power

[1] It should be noted that LKAB, a major Swedish mining company, has postponed its own green steel project indefinitely. That project, known as Hybrit, was expected to use about 70 TWh.

company, has seen the potential to invest more than EUR 18 billion (USD 20 billion) in green hydrogen following the passage of the 2022 Inflation Reduction Act (IRA), which provided significant tax credits for such projects (Wall Street Journal, 2024).

The IRA initially allocated significant funding to support green hydrogen projects, carbon capture initiatives, and investments in renewable energy technologies. However, under President Trump's administration, the IRA has seen substantial adjustments, particularly regarding climate-related grants and tax incentives. For instance, in early 2025, EPA Administrator Lee Zeldin terminated $20 billion in climate grants originally allocated for green energy projects under the IRA (Guillén and Colman, 2025). This decision directly impacts the funding available for clean energy projects, including those supporting green steel technologies reliant on hydrogen production. Despite this, the House of Representatives has argued for maintaining subsidies and incentives aimed at fostering green steel production and renewable energy investments (Reuters, 2025). However, uncertainty remains about the future of subsidies for green steel in the U.S. (MarketWatch, 2025), which may hinder Stegra's ability to secure future funding.

Regardless of developments in the U.S., it is evident from Burchardt et al. (2023, 2) that investment decisions in hydrogen are still pending, as optimistic cost projections have not materialized. As mentioned, the Hybrit project — arguably the largest hydrogen-based project among those discussed — has been postponed.

Before we turn to our theoretical model, we first observe that the Fit-for-55 package has fundamentally altered the economic landscape for steel production in the EU. The package seeks to update EU climate, energy, and transport legislation, with a key component being the reform of the EU Emissions Trading System (ETS). This reform includes a gradual shift from the free allocation of permits (grandfathering) to auctioning, which will significantly impact conventional steel producers who currently rely on free permits to stay competitive against non-EU producers not subject to carbon pricing. Additionally, the CBAM will impose tariffs on foreign steel producers based on permit prices unless they supply green steel. These policy changes create a markedly different economic environment compared to when green steel projects such as Stegra were first assessed (Johansson and Kriström, 2022). We now turn to our theoretical model, in which we derive cost–benefit rules within a general equilibrium framework, catering for key ingredients in the Fit-for-55 package.

3. General equilibrium cost-benefit rule

Assuming a competitive economy, we analyze the transition from one general equilibrium to another as the Stegra perturbs the economy. We account for all secondary (and higher-order) market effects induced by the project. The rule shows how to delineate costs and benefits in the empirical analysis that follows below.

Stegra sells α percent of its production, x_1^s, within the EU at price p_d, and the remaining proportion, $1-\alpha$, outside the EU at the world market price p_w. Due to the EU Emissions Trading System (EU ETS) and tariffs on conventional steel imports, the internal EU price p_d may exceed the world market price p_w (all prices are expressed in the domestic currency using the exchange rate). Within the EU market, Stegra displaces conventional "domestic" steel, denoted x_2^s, as well as imported steel, x_2^F, which is subject to a tariff t per unit of emissions. Let p_p denote the price of permits. We assume the tariff is set as $t = p_p \cdot \theta_2$, where θ_2 is the emissions conversion factor for imported steel. Stegra itself causes emissions of θ_1 per unit of output, with $\theta_1 < \theta_2$, reflecting the lower emissions associated with green steel production.

The indirect utility function V of the representative consumer is defined as:

$$V = V(p_d, \mathbf{p}, m, \mathbf{E}) \tag{1}$$

where $\mathbf{p}$ represents the vector of consumer prices, m denotes lump-sum income, and $\mathbf{E}$ represents total emissions of greenhouse gases. One of the consumer price is taken to be the numeraire and set to one.

The lump-sum income m is given by:

$$m = \sum \pi^i + p_p \cdot \bar{y} + t \cdot x_2^F \tag{2}$$

Thus, income consists of the sum of firm profits, π^i, revenue from selling a fixed number of permits $\bar{y}$, and tariff revenue from imported steel.

The profit functions for Stegra (π^1) and the domestic conventional steel producer (π^2) are defined as:

$$\pi^1 = \left[\alpha p_d + (1-\alpha)p_w\right] x_1^s - C^1(\cdot) - p_p \cdot \theta_1 \cdot x_1^s \tag{3}$$

$$\pi^2 = p_d \cdot x_2^s - C^2(\cdot) - p_p \cdot \theta_2 \cdot x_2^s \tag{4}$$

where $C^1(\cdot)$ and $C^2(\cdot)$ are the cost functions excluding the cost of acquiring emissions permits.

Under competitive market clearing, any impact of the project on prices satisfies the condition $(x_j^s - x_j^d)\,dp_j = 0$ for each domestic market x_j. Therefore, we can omit other markets and focus on the steel market. Observe that there will be changes in quantities in (potentially) all markets, as the economy adjusts to the new equilibrium. Moreover, we assume that the current account remains balanced under a flexible exchange rate.

To capture the impact of Stegra on the economy, we differentiate the indirect utility function V and divide by marginal utility of income (V_m), i.e. converting from units of utility to the numeraire unit:

$$\begin{aligned}\frac{dV}{V_m} &= \left[\alpha p_d + (1-\alpha)p_w - C^1_{x_1}(\cdot) - p_p \cdot \theta_1\right] dx_1^s \\ &\quad + \left[p_d - C^2_{x_2}(\cdot) - p_p \cdot \theta_2\right] dx_2^s\end{aligned}$$

$$+ t \cdot \theta_2 dx_2^F$$
$$+ \frac{V_E}{V_m}\left[dx_2^F - (1-\alpha)dx_1^s\right] \tag{5}$$

where we use a subscript to denote differentiation of the cost-functions. Note that $dx_1^s > 0$, and $dx_2^s, dx_2^F < 0$. Global emissions decrease because Stegra displaces dx_2^F units of imported conventional steel within the EU and $(1-\alpha)dx_1^s$ units outside the EU. However, this displacement also results in a loss of tariff revenue. Emissions reductions from dx_2^s are effectively neutralized because the released permits are used by other market agents.

Assuming profit-maximizing firms, market clearing, and setting $p_p = t \cdot \theta_2 = -\frac{V_E}{V_m}$, we obtain:

$$\frac{dV}{V_m} = \left[\alpha p_d + (1-\alpha)p_w - C^1_{x_1}(\cdot) - p_p \cdot \theta_1\right] dx_1^s - \frac{V_E}{V_m} \cdot (1-\alpha)\Delta x_1^s \tag{6}$$

where $\Delta x_1^s = x_1^{s1} - x_1^{s0} = x_1^{s1}$.

If $p_d = p_w + p_p$, it becomes equally profitable for Stegra to supply steel within the EU or to export it globally.

Finally, converting all monetary values to euros and integrating over $[x_1^{s0}, x_1^{s1}]$, with marginal damage costs $-\frac{V_E}{V_m}$ treated as constant and equal to p_p, yields, together with the assumptions above,

$$\frac{dV}{V_m} = \int_{x_1^{s0}}^{x_1^{s1}} \left[p_d - C^1_{x_1}(\cdot) - p_p \cdot \theta_1\right] dx_1^s \tag{7}$$

This rule is the basis for our empirical implementation. It can be intuitively appreciated by using a standard supply and demand diagram (of the steel market here) used in introductory international trade courses. Again, the rule is a general equilibrium result, but the partial equilibrium intuition is still valid. We next explain the basic intuition behind the rule.

Let us initially ignore tradable permits for emissions of greenhouse gases. Suppose that we take the "domestic country" to be the area covered by the EU Emissions Trading System, EU ETS, i.e., EU plus Iceland, Liechtenstein, and Norway, known as the European Economic Area, EEA. The domestic supply curve is assumed to have a positive slope while "foreign" supply is perfectly elastic at the price p_{w_0}. At the initial world market price p_{w_0} domestic supply is equal to x^{s_0} while domestic demand equals x_{d_0}.

Next, let us introduce permits. Currently, permits are distributed free to steel producers (known as grandfathering) based on historical emissions. Grandfathering is used because domestic firms are assumed to be unable to pass through increases in cost. Producers located outside the European Economic Area typically do not face permit schemes or emission charges, hence they can supply as if the cost of emissions is zero.[2] There is also evidence that there is price dumping in the European steel market. For example, the European Commission has imposed anti-dumping duties on some Chinese steel products (Fastener and Fixing, 2024).

Even if steel producers receive permits free of charge, there is an opportunity cost of using them because firms could abstain from producing steel and instead sell the permits. Viewed in this way, it does not matter whether permits are auctioned or distributed for free (at least in a single-agent world, i.e., setting aside distributional issues). Nevertheless, the EU Fit-for-55 package proposes a gradual shift from grandfathering to auctions.

Introducing permits (for free or by auction) shifts the steel supply curve upwards by the permit price. If domestic supply is perfectly elastic and it is equally costly to produce foreign steel, domestic production would disappear when permits are introduced. In this scenario, Stegra cannot expect to gain from the prevalence of a permit scheme. Recall that domestic producers of fossil-based steel are assumed to be price takers and produce such that the steel price received equals their marginal costs (inclusive of permits). Therefore (and ceteris paribus), if a domestic steel producer is displaced by Stegra, then p_{d_0} correctly reflects the social benefits of the steel supplied by Stegra; if the total number of permits is given, total emissions of climate gases are unchanged. On the other hand, if a foreign fossil-based steel producer is displaced, then there is, as shown, a climate gain to be added in a cost–benefit analysis. (Here we disregard the fact that Stegra requires some permits for its own production.)

CBAMs purpose is to protect domestic producers that in the future will have to purchase permits rather than receive them free of charge (Keen et al., 2022). Here the mechanism is taken to mean a uniform tariff equal to $t = p_e$. This raises the domestic steel price from p_{d_0} to p_1. Then, with respect to domestic production we are back to the initial case where the industry supplies x_0^s units, while total domestic demand falls.

If Stegra displaces a foreign supplier, there is a loss of tariff income equal to t (times the emission coefficient) per ton of steel. There is a climate gain which can (but need not) be approximated by the permit price, which in turn equals the tariff t. If this approximation is reasonable, the social value of a ton of steel produced by Stegra is equal to p_d regardless of whether it displaces domestic or foreign steel supply.[3]

If also the global supply curve has a positive slope, which is a reasonable assumption, the increase in the domestic steel price is smaller than p_e (unless domestic demand is completely inelastic). Recall that the climate gain is approximated to be equal to the loss of tariff revenue. Provided that p_{e} reflects the marginal damage cost of climate gases, the new equilibrium price reflects the social value of the steel produced by Stegra.

[2] However, besides the EU ETS, national or sub-national systems are already operating or under development in Canada, China, Japan, New Zealand, South Korea, Switzerland, and the US.

[3] Under linear supply–demand the tariff causes a deadweight loss equal to $\frac{1}{2}\Delta p_d \Delta x_d$. There is an additional deadweight loss equal to $\left(\frac{1}{2}\right) \cdot \frac{\Delta p_d}{\Delta x}$. The impact of Stegra on these areas has not been possible to estimate.

4. An economic evaluation of the green steel plant

We now explain how we have estimated the different components of the cost–benefit rule displayed above. We begin with the benefit side.

4.1. Benefits

To approximate the steel prices we proceed as follows. The price estimate is based on a steelmaker using blast furnace-basic oxygen furnace which is slightly more expensive than electric arc furnace. M'barek et al. (2022, Figure 6) show costs for 13 steel producing countries out of which the marginal producer is Germany. In 2019, which we assume is a "normal" year, Germany's average long-run cost per ton of crude steel is around EUR 540. Stegra will refine its crude steel into hot rolled coil. EUR 540, which is the upper limit of our price interval for crude steel (but deducting any impact of permits as discussed below), is similar to the average European price (for Germany, Belgium, and the Netherlands) of crude steel processed into hot rolled coil during the period 2011–2020 (Consensus Economics, 2024). Hence, this estimate is likely to provide a reasonable upper bound for the project's benefits, ceteris paribus.

Next, assume that the permit price was EUR 15 in 2019, that on average 1.5 permits are needed per ton of steel, and that this is reflected in the estimated cost.[4] Moreover, assume that a reasonable long-run permit price is EUR 85 (as compared to today's price of around EUR 70). Therefore, add EUR $(85 - 15) \cdot 1.5$ to the assumed long-run cost of EUR 540. Then, EUR 645 represents a kind of simple upper bound for the equilibrium price per ton when the tariff on imports is equal to EUR $85 \cdot 1.5$ per ton. Recall that the global supply curve probably has a positive slope. If so, the German (and possibly other European) production capacity with the highest production costs is forced to close down its operations.

Alternatively assume that the production cost of China, with more than 50 percent of the global market, reflects the EEA crude steel price before any tariff. Then the long-run price is expected to be EUR 450 + 127.5 = 577.5, assuming an infinitely elastic supply, and a tariff of EUR $85 \cdot 1.5$ per ton crude steel. The long-run price is then expected to be EUR 450 + 127.5 ≈ 575, assuming an infinitely elastic supply, and a tariff of EUR $85 \cdot 1.5$ per ton crude steel. In this scenario there is probably a considerable reduction of "conventional" European steel supply.[5] As discussed above, there are many green steel projects under way; the risk is obvious that competition becomes so fierce that also some green producers will go bankrupt.

In the economic evaluation, the crude steel price received by Stegra is assumed to be in the range of EUR 575 to 645. Provided the tariff on imports of conventional steel reflects the marginal cost of climate gases, there is no reason for rational end-users of green steel to pay a premium over and above the aforementioned prices, i.e., EUR 575 to 645. Rather, a willingness to pay a premium seems to be due to other reasons. For example, an end-user might want to signal that the user cares for the climate; compare warm-glow giving (Andreoni, 1990).

4.2. Costs

Turning to the cost side, according to Koch Blank (2019) the cost of producing a ton of green steel, exclusive of the electricity cost, is EUR 485/1.11, where 1.11 is the assumed exchange rate converting USD into EUR. However, his price of iron ore is increased from EUR 60 to EUR 121 to better reflect expected costs (and multiplied by 1.6 to reflect the quantity of iron ore needed in producing a ton of crude steel). We also add the cost of permits needed by Stegra. The production of one ton of steel requires 0.11 permits valued at EUR 85. Finally, a ton of crude steel is assumed to require 4 MWh of electricity.[6] Therefore, the estimated cost of a ton green steel equals EUR 544 plus 4 times the electricity price per MWh.

Before digging into a reasonable electricity price, let us compare our cost estimate to some other estimates. Pawelec and Fonseca (2022, Figure 29) estimate the levelized cost of producing a ton of green crude steel at EUR 704 at expected ("normal") energy prices. It seems as if the estimate assumes that the electricity price, reasonably including any transmission cost, is EUR 20/MWh; see Pawelec and Fonseca (2022, p. 81). At this electricity price, our estimate of the levelized cost is EUR 624. This suggests that it is unlikely that we have overestimated the cost. However, the electricity price assumed by Pawelec and Fonseca (2022) seems low, to say the least, in the present context. Assuming a total electricity price equal to EUR 30 per MWh (to make the numbers comparable), our cost estimate is around 20 percent above the cost for conventional (electric arc furnace) steel that M'barek et al. (2022, Figure 8) report for countries like the US, Japan, Germany, and Italy for 2019 and 2020 (costs were exceptionally high in 2021 but have retreated since then). It is often claimed, for example by the Swedish steel maker SSAB, the company behind the green steel project HYBRIT, that fossil-free steel cost 25 to 30 percent more to produce than conventional steel. Pawelec and Fonseca (2022, Figure 29) report an even higher number of 39 percent.

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[4] 1.5 is a rough average of an interval running from 0.7 to 2.2. Refer to International Energy Agency (IEA) (2024, pp. 38–39).

[5] Steelmaking using electric arc furnace (like Stegra) is slightly cheaper than the process considered here; refer to Table 8 in M'barek et al. (2022). However, for the CBA we rather provide reasonable upper bounds rather than lower ones for the benefits of Stegra.

[6] 20 TWh is required to produce 5 million tons of steel, hence $20 \cdot 10^9/(5 \cdot 10^6)/1000 = 4$ MWh. Goodall (2024) estimates that one ton of green steel requires 4 MWh of electricity. Thus, 20 TWh are required to produce 5 million tons, just as we assume.

4.2.1. Electricity prices

The Stegra process is energy-intensive, requiring substantial amounts of electricity. Thus, the price of electricity is important for the outcome of the CBA. We next discuss our approach to estimating a price of electricity that is a useful approximation to the opportunity cost from society's point of view.

According to Energiforsk (2021, Table 6), a Swedish research institute, the Swedish levelized unit cost of a new 500 MW offshore wind farm is around EUR 45 to 50 per MWh (with EUR 1 = SEK 11). However, given that demand in the northern part of Sweden is expected to increase by some 90+ TWh, transmission capacity must be increased. The two Northern bidding areas are also connected to the Southern areas. Moreover, to the west they are connected to Norway and to the east to Finland. As a consequence, the average monthly spot price in Bidding Area 1 (covering Norrbotten and parts of Västerbotten) varied between around EUR 23 and EUR 191 per MWh in 2022. The price is heavily influenced by the connection to other markets and bottlenecks in transmission. The annual average price per MWh in 2022 was around EUR 58 (Elpriser24, 2024). Svenska kraftnät, the authority that is responsible for the Swedish transmission system for electricity, forecast for Bidding Area 1 that the average price in 2027 is EUR 71 per MWh; refer to Svenska kraftnät (2022, Figure 11). We use this figure in our computations. It is noteworthy that Svenska kraftnät predicts even higher electricity prices in almost all countries that the Swedish transmission system (directly or indirectly) is connected to; see Svenska kraftnät (2022, Figures 11–12). In addition, soaring costs are derailing offshore wind projects around the globe; capital costs and prices for turbines, cables and other equipment have gone up sharply, see e.g. The Japan Times (2023).

5. Results of the economic assessment

Putting together the different pieces of the economic evaluation we have the following net present value (NPV) for the upper and lower bounds of the social surplus of the plant:

$$\begin{aligned} \mathrm{NPV}^{\mathrm{Upper}} &= \sum_{t=1}^{20} [645 - (544 + 71 \cdot 4)] \cdot 5 \cdot 10^6 \cdot (1+r)^{-t} - 5.48 \cdot 10^9 \\ \mathrm{NPV}^{\mathrm{Lower}} &= \sum_{t=1}^{20} [575 - (544 + 71 \cdot 4)] \cdot 5 \cdot 10^6 \cdot (1+r)^{-t} - 5.48 \cdot 10^9 \end{aligned} \tag{8}$$

where 645(575) denotes benefits per ton of steel, 544 is the assumed cost/ton steel net of electricity cost, which is $71 \cdot 4$, $5 \cdot 10^6$ is the level of production (tons of steel); the final term denotes the present value transmission cost. r is the social discount rate to be discussed further below. The time horizon has been set to 20 years. Following our discussion above, the first line provides the upper bound for and the second line the lower bound of the net benefits.

As explained above, the electricity price, excluding transmission costs, is set equal to EUR 71 per MWh; as noted the price is expected to exceed EUR 70 already in 2027 in the bidding area in question, while Stegra is planned to reach full capacity in 2030.[7] Recall that there is expected to be a huge increase in electricity demand in the area if the green investments become operational. Recent events have lowered expectations, but even without such investments outside of Stegra, price convergence within Sweden and Europe will, as indicated, tend to push prices upwards. Furthermore, electrification of other parts of society will also have an effect on demand.

Most likely, the demand by Stegra will cause the electricity price to increase, resulting in losses of consumer and producer surpluses of electricity customers. However, due to the price increase, the net expansion in electricity production will fall short of the 20 TWh needed by Stegra. We assume that these surplus changes sum to zero in monetary terms.

Turning next to the discount rate, a private sector project most likely displaces other investments. Therefore, in Eq. (8), the social discount rate r is taken to be 7 percent. Refer to, for example, Johansson and Kriström (2016, pp. 65–73) for a discussion about the choice of discount rate in CBA. Many guidelines on economic evaluations propose to use a discount rate equal to 3–4 percent. This is the case for the guidelines used by, for example, the European Commission (2022) and European Investment Bank (2023). These lower discount rates are typically based on a Ramsey model, where consumption is displaced; refer to Ramsey (1928). We therefore add a sensitivity analysis below where the social discount rate equals 3 percent.

The final term in Eq. (8) refers to the project's present value cost of electricity transmission. According to Swedenergy, a trade association for producers and distributors of energy, drawing on Holm et al. (2023), Sweden must invest around EUR 90 billion in the Swedish transmission network because electricity demand is expected to increase by some 190 TWh over the next 20 years. The levelized cost is around EUR 18.41 per MWh when the discount rate is 3 percent; the economic life of the network is assumed to be 50 years (ignoring any maintenance costs and transmission losses). Transmission is a natural monopoly and tariffs are therefore subject to regulation. The Swedish Energy Markets Inspectorate, EI, uses the weighted average cost of capital, WACC, to regulate tariffs; refer to, for example, Farber et al. (2006) for details on this concept. The latest WACC is 2.16 percent but has been challenged in court by transmission companies (Energimarknadsinspektionen (EI), 2019). In previous years, the companies have been successful and able to obtain a higher WACC than imposed by the EI. Therefore, it seems justified to use a discount rate equal to 3 percent in this case. Applied to Stegra, who is assumed to be operational for 20 years and demand 20 TWh annually, the present value

[7] The company might obtain electricity at a lower price, for example by concluding a power purchase agreement, PPA. However, then other consumers will be displaced from cheap electricity and have to switch to more expensive alternatives. For more on PPAs, see, for example, US Environmental Protection Agency (EPA) (2024).

Table 3
Outcome of the CBA in billions of EUR.

CBA	r = 7%	r = 3%
NPV^{Upper}	−15.2	−19.1
NPV^{Lower}	−18.9	−24.3

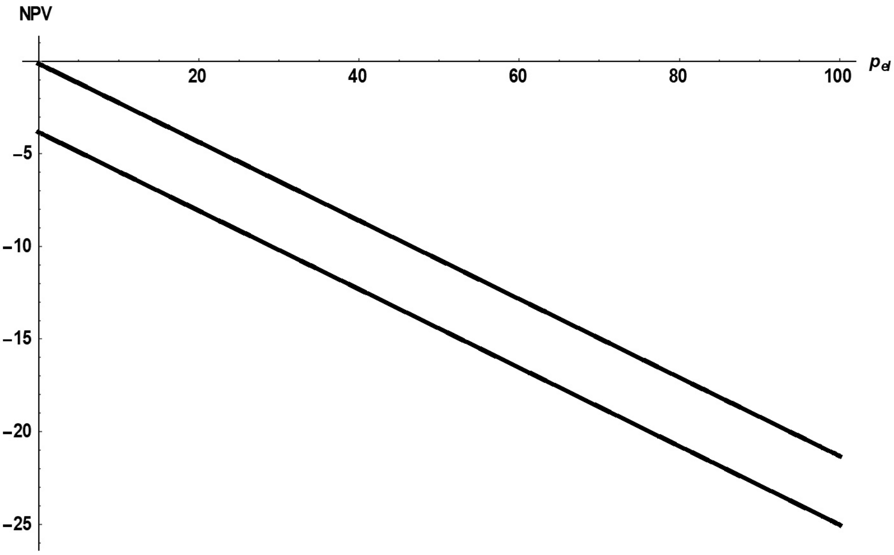

Fig. 1. The social net present value, NPV, of the investment in billion EUR when r = 7 percent as a function of the production cost of electricity in EUR per MWh, p_{el}. The upper (lower) curve refers to a crude steel price equal to EUR 645 (575) per ton.

investment cost amounts to around EUR 5.48 billion in Eq. (8).[8] If the transmission investment is discounted at 7 percent, the levelized cost increases to EUR 34.3 per MWh, which could be added to the electricity cost of EUR 71 in Eq. (8) or added as EUR 7.3 billion in total.

The results are summed up in Table 3 based on Eq. (8). The social present value loss is considerable in all four cases. The loss ranges from EUR 15.2 billion (10^9) to EUR 24.3 billion.

Fig. 1 illustrates how the social net present value in Eq. (8) varies with the electricity production cost p_{el} when the social discount rate is 7 percent. In both considered scenarios, NPV is negative even if the social cost of producing electricity equals zero. But note that the transmission cost has been accounted for, as is seen from Eq. (8).

6. Discussion

This study has identified significant economic challenges and risks associated with the green steel investment in Boden, specifically concerning the company Stegra. In the sequel, we discuss additional pros and cons relating to the economic viability of the project.

Competition and Subsidies The green steel market is increasingly competitive, with companies aggressively competing for market share and government support. This dynamic resembles the European steel crisis of the 1960s and 1970s, when massive subsidies caused overcapacity, market distortions, and severe economic consequences (Jörnmark, 2023; see also Jörnmark, 1993). Despite EU efforts to support green hydrogen through mechanisms such as the European Hydrogen Bank, the industry remains vulnerable to overinvestment, market saturation, and financial instability.

Technological Uncertainties Emerging technological innovations, such as the TC-BF-BOF steelmaking system proposed by Kildahl et al. (2023), hold promise for decarbonizing steel production. This method recycles carbon dioxide during steel production, reducing the need for coal and thus lowering emissions. Essentially, this technology aims at capturing and reusing carbon emissions at the plant. However, their cost-effectiveness, scalability, and market acceptance remain uncertain. Yet, such technological uncertainties could further undermine the profitability and competitiveness of Stegra's project.

Regional Economic Impact Arguments that Stegra will significantly boost regional employment in Norrbotten are weakened by existing labor shortages. With both private and public sectors already struggling to fill vacancies, the actual employment benefits

[8] $\sum_t 18.41 \cdot 20 \cdot 10^6 \cdot 1.03^{-t} \approx 5.48 \cdot 10^9$ assuming that the transmission capacity can be fully utilized also after the closure of Stegra. Alternatively, add $18.41 \cdot 4 \cdot 1.03^{-t}$ to the costs within parentheses in Eq. (8).

of the plant may be limited. The recent bankruptcy of Northvolt could partially ease local labor constraints, though the broader implications of Northvolt's failure remain uncertain.

Infrastructure and Financial Risks Substantial infrastructure investments required to support Stegra — including port expansions, transportation infrastructure, and housing developments — pose significant financial risks, particularly for the municipality of Boden. Municipal commissioner Claes Nordmark has indicated that Boden has already borrowed approximately 1 billion SEK, with additional borrowing anticipated (Sveriges Radio, 2024). A failure of Stegra could thus impose severe economic consequences on the municipality and region as a whole.

The counterarguments There are several economic arguments in favor of subsidizing green steel, primarily linked to market failures. For instance, asymmetric information may hinder private investment if businesses lack clarity about future climate policy directions, while innovation externalities may lead to socially suboptimal investment levels. Quantifying the strength of these arguments for Stegra is challenging. Still, we have excluded certain factors that could worsen the project's economic outlook, thus, we argue, conservatively estimating its risks.

Stegra has received state support, including direct subsidies, loan guarantees and loans. This includes 250 million EUR from EU Innovation Fund, a direct subsidy of about 100 million EUR (1.2 billion SEK) from the Swedish Energy Agency, and 960 million EUR in loan guarantees from the National Debt office (see Swedish National Debt Office (2023), Stegra (2024) and Energimyndigheten (2024) for a summary of the financing of Stegra).

Conclusion

Evaluating the economic viability and associated risks of green steel projects is crucial. While transitioning to sustainable steel production aligns with EU policy goals, investments must be rigorously assessed to ensure long-term economic sustainability. Our study offers a blueprint for conducting thorough cost–benefit analyses of green steel projects, explicitly incorporating aspects of EU climate policy, such as the EU-ETS and CBAMs. Given the significant differences in carbon pricing, similar analyses in other regions, such as the US, might yield different conclusions.

Ultimately, extensive EU subsidies to green steel ventures risk repeating past mistakes reminiscent of the steel crises of the 1960s and 1970s. While history suggests caution, the critical lesson here is the necessity of rigorous economic evaluations prior to committing substantial public resources. Cost–benefit analysis provides a tool for ensuring informed, economically sound decisions in the emerging green steel sector.

CRediT authorship contribution statement

Per-Olov Johansson: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Bengt Kriström:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The authors have no competing interests to disclose.

Appendix

Finally, we provide a simple robustness check of our result. Hasanbeigi et al. (2024) provide estimates of the cost of green steel (in USD). The average for the EU equals around EUR 766 if the exchange rate between USD and EUR is 1.11, and the cost of a kg of hydrogen is EUR 5/1.11. If the cost of H_2 increases by EUR 1, the cost of producing a ton of green steel increases by around EUR 56. Our assumed electricity price results in a cost of a kg of H_2 equal to EUR 7 for Sweden. Thus, we add EUR 112 to 766. Given our upper bound price estimate for green steel, we obtain the following present value outcome:

$$\sum_{t=1}^{20}(645 - 766 - 112) \cdot 5 \cdot 10^6 \cdot 1.07^{-t} - 5.48 \cdot 10^9 \approx -1.78 \cdot 10^{10}.$$

This is quite close to our estimate, $-1.5171 \cdot 10^{10}$.

Data availability

The data is in the article.

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