FROM NICHE TO MAINSTREAM:

SHAPING DEMAND FOR GREEN STEEL

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Executive summary

Efforts to decarbonise the steel industry have mainly focused on improving or replacing production processes, concentrating on the supply of materials with lower embedded GHG emissions, but overlooking market unreadiness for the use of green steel. By the end of the decade, many low-carbon steel projects across the EU will come online, but they will be facing a significant obstacle: the green premium. Green steel technologies have higher operating costs that put them at an economic disadvantage vis-à-vis conventional and polluting steelmaking, threatening the business case for a net-zero steel industry. With weak carbon prices and high electricity costs, this gap is set to persist. Thus, in the absence of market differentiation and adequate compensation for improved environmental performance, green steel could end up being relegated to niche applications rather than being mainstreamed across value chains. In such a scenario, upcoming green steel projects risk becoming partially idle or even stranded assets, while investments in new green steel projects could be undermined, jeopardising the broader case for sectoral decarbonisation.

Lead markets by means of public intervention are necessary to de-risks investments in cleaner steelmaking technologies, at least until the operating costs gap between green and conventional production routes is bridged. To achieve this, the first step is to establish a standard for green steel that does not discriminate against scrap, as the sliding scale does, and that brings clarity to the myriad, often conflicting, steel initiatives that already exist. Once green steel has been defined, the material needs to be applied in downstream manufacturing sectors, ideally those that command high volumes and where most of the added value of the final products is developed during the manufacturing stages, such as automotive, so that the premium is well diluted and has the least impact on the willingness of end-users to pay extra. Finally, once the value chain is mapped, public authorities can operationalise lead markets by enacting pull mechanisms as demand-side measures to guarantee the offtake of green steel by manufacturing sectors and the consequent purchase by end-users, de-risking investments and creating a business case for green steelmakers. Pull mechanisms can manifest themselves as Green Public Procurement, quota systems for material sourcing or financial incentives to offset the green premium, as well as trading systems for the exchange of green steel certificates.

Pull mechanisms for the demand of green steel will need to be complemented by push mechanisms for its supply (i.e. the financial conditions that are being put in place to encourage producers to switch to cleaner production technologies, such as subsidies and carbon pricing) until operating costs equalise. These demand-side measures will need to be tailored to replace flat steel, which in the EU is mainly produced via the carbon-intensive BF-BOF route, and designed to absorb fluctuating green premiums that cast uncertainty on offtake agreements with downstream manufacturers.

1. Introduction

In 2021, approximately 70% of Europe's coal-based blast furnaces would have reached the end of their operational life by 2030[1], presenting steel producers with a critical decision: invest in cleaner production processes or opt for relining to prolong their blast furnaces' lifespan. Choosing to extend the life of a blast furnace while maintaining current production processes implies a firm commitment to high carbon emissions. On the other hand, **switching to cleaner steelmaking processes is in line with climate goals, but faces a persistent challenge: higher operating costs**.

While the prospect of a large number of low-carbon steel projects coming online in the EU by 2030 is promising[2], their commercial viability once operational remains uncertain. Significant state aid and EU funding have already been contributing to the high capital costs of some of these projects, but this may not be sufficient to make them competitive. **Weak carbon price signals and high energy prices could put cleaner steelmaking technologies at a disadvantage compared to unabated blast furnaces in the near future**.

To address this challenge, numerous standards for 'green steel' have emerged as a means of differentiating finished steel products on the basis of their environmental performance. This differentiation makes it possible to justify the additional production costs (green premium) to downstream manufacturers and ultimately to end-users of final products made from green steel. The creation of market segments that would bear the cost of the green premium (lead markets) would **bridge the cost gap between conventional and green steel until carbon prices, technological innovation and electricity prices equalise operating costs to make green steel the new norm**.

Alongside the announcement of a few steelmaking projects using renewable hydrogen instead of metallurgical coal, offtake agreement with these steelmakers have been struck with various downstream manufacturers in steel-intensive manufacturing sectors such as automotive, construction and white goods. However, these contracts may not be sufficient to reward those investments or make them viable. **Without established revenue streams to cover the green premium, this upcoming green steel supply capacity risks remaining idle or even becoming stranded assets**.

Pull mechanisms are public policy measures designed to support the viability of clean production technologies. In the hands of public authorities, these tools aim to **drive demand for greener and more expensive products than their conventional counterparts, creating a business case for early deployment**. In the context of green steel, pull mechanisms artificially create lead markets that recognise its environmental benefits and differentiate it from conventional steel, bridging the cost gap and paving the way for its widespread adoption.

This report sheds light on the economic barriers facing emerging green steel projects in the EU, pointing out that there is currently no consistent business case for these assets and that waiting for carbon and energy markets to level the playing field would delay systemic sectoral decarbonisation. Cutting through the maze of the many definitions of green steel, the report demonstrates the need for standards and to address the role of scrap in its production. It then illustrates how steelmakers could see the extra costs associated with the green premium passed on along their value chain. Finally,

[1] Agora Industry, Wuppertal Institute & Lund University (2021) – Global steel at a crossroads: Why the global steel sector needs to invest in climate-neutral technologies in the 2020s.
[2] https://www.eurofer.eu/issues/climate-and-energy/maps-of-key-low-carbon-steel-projects

the report illustrates a number of options for pull mechanisms that could stimulate the offtake of green premiums to develop lead markets for green steel.

2. The burden of operating cleaner technologies

The so-called 'conventional' Blast Furnace/Basic Oxygen Furnace (BF-BOF) steelmaking process – widely used in the EU for the production of flat steel – emits significant amounts of CO_2 per tonne of output and contributes extensively to embedded emissions throughout its value chain. The majority of these emissions occur at the blast furnace stage, well before the steel is subjected to any downstream manufacturing processes on its way to the end-user. Despite efforts by the EU and national governments, initiatives for cleaner steelmaking have yielded only modest results, with attempts mainly focused on marginal efficiency improvements within the conventional route, resulting in only small reductions in the carbon footprint of flat steel.[3]

More effective abatement measures, such as direct hydrogen reduction or carbon capture and storage/use, could achieve higher emission reductions, but their commercial deployment faces high capital and operating costs. Therefore, **a viable business case for the deployment of low-carbon technologies requires an additional revenue stream, either in the form of subsidies or higher prices paid by buyers for the steel they produce**. The cost of producing materials using low-carbon technologies is higher than conventional methods, challenging their commercial viability in a competitive market environment. Due to the sector's narrow profit margins, absorbing additional costs is hard. As a result, **clean technology adopters must prioritise product differentiation as a strategy to pass on the extra costs to consumers**.

The cost of producing flat steel with near-zero embedded carbon emissions – achieved through technologies such as carbon capture or hydrogen reduction – can be 20-30%, and in some cases up to 50%, higher than the conventional production route.[4] Economic viability would ultimately depend on the ability to either pass on an equivalent cost premium to end-users or to have it directly supported by the market. In the context of flat steel production via hydrogen reduction, which is expected to be the main alternative to the conventional BF-BOF route in the EU, there are extreme differences in operating costs. According to Agora Industry's Steel Transformation Cost Calculator[5], **even with electricity prices of €40 per MW/h, a rarity in most EU bidding zones, cost parity requires a carbon price above €150**. The likelihood of such a price in the EU ETS in the near future is low, and even then, it does not ensure a predictable and steady internalisation of operating costs that would allow steelmaking via hydrogen reduction to compete on an equal footing. Therefore, **a premium would need to effectively offset the disadvantages of weak carbon pricing and electricity volatility**.

Balancing the costs between conventional and cleaner steelmaking routes would resolve the business case for EU investment in steel production for the domestic rather than the global market. As an internationally traded commodity, steel is not affected by regional carbon pricing, meaning that the extra cost of finished products, whether due to cleaner technologies or higher carbon prices, has to compete with finished products from third countries that do not face such extra costs. EU exports of finished steel products have been declining steadily, reaching 19.5 million tonnes in 2021 (12.9 million

[3] Joint Research Centre (2022) – Technologies to decarbonise the EU steel industries.

[4] Oxford Institute for Energy Studies (2023) – Stainless green: Considerations for making green steel using carbon capture and storage (CCS) and hydrogen (H2) solutions.

[5] https://www.agora-industry.org/data-tools/steel-transformation-cost-calculator

tonnes of flat products), out of 152,782 million tonnes of domestic production in the same year (84,480 million tonnes of flat products). In contrast, imports into the EU have been increasing, reaching 30.3 million tonnes in the same year (23.9 million tonnes of flat products).[6] Thus, even in the absence of international agreements promoting trade of more expensive steel products with lower embedded emissions, the internal market with a fully implemented CBAM could redirect exports of finished products towards domestic consumption.[7]

The development of markets that pay this premium can be seen as market-based approaches to tackling emissions in carbon-intensive sectors. Such markets would reward steelmakers that use cleaner, albeit more expensive, production processes with a premium for the additional costs they incur. This helps to level the playing field in terms of operating costs with those using more polluting but cheaper methods. They could also reduce the need for public start-up funding, which could then be replaced by private funding in the long term. For this to happen, a definition of green steel is a prerequisite for the operationalisation of its lead markets, allowing its use in certain leading applications until it is fully established in the market and/or carbon pricing has effectively closed the abatement cost gap.

3. What is green steel?

Determining whether a product qualifies as 'green' is a complex and often controversial task that requires tailoring the criteria to each category of goods in order to be able to qualify them as such without committing greenwashing. **The concept of a 'green' product does not fit into a simple binary classification, but exists along a continuous spectrum**. Within this spectrum, the 'greener' a product, the better its environmental performance. On the other hand, 'non-green' or conventional products show no or minimal progress in their environmental attributes.[8]

Table 1 - Definitions of green steel

Source	Definition
Muslemani, H. *et al.* (2021) – Opportunities and challenges for decarbonizing steel production by creating markets for 'green steel' products	[...] *"'green steel' will hereinafter be used to refer to* ***steel products manufactured using less GHG-intensive production processes****, and not to refer to products with lesser amounts of physical carbon content."*
Singh, J.K. & Rout A.K. (2018) – Advances in green steel making technology: A review	[...] *"****green steel is a new steelmaking process lowers greenhouse gas emission****, cuts costs and improves the quality of steel."*

[6] European Steel Association (2023) – European steel in figures.

[7] This is an oversimplification; in reality, there may be cases of domestic oversupply of finished products with certain specifications (alloying elements, shape, etc.) that drive exports to third countries, while there may also be cases of domestic overdemand for finished products with other specifications that are insufficiently met by domestic production and require imports from third countries. However, these supply/demand imbalances are not insurmountable and can be corrected over time.

[8] Driessen P. H., Hillebrand B., W. Kok R. A. & Verhallen T. M. M. (2013) – Green new product development: The pivotal role of product greenness.

Griffin, P. W., Hammond, G. P. (2021) – The prospects for 'green steel' making in a net-zero economy: A UK perspective.	[...] *'green steel' often refers to* ***steelmaking that results in lower air pollutant emissions (e.g., CO, SOx, NOx, or PM2), wastewater contaminants, hazardous wastes (including arsenic, lead, and zinc), and other solid wastes****."*
Wang, C., Walsh, S., Weng, Z., Haynes, M., Feitz, A., & Summerfield, D. (2023) – Green steel: Synergies between the Australian iron ore industry and the production of green hydrogen.	[...] *"****green steel (i.e., steel produced using hydrogen from renewable sources as the reducing agent).****"*
CEPS (2023) – Can the cars we buy drive green steel production?	[...] *"green steel will simply mean* ***'steel produced in a way that is compatible with climate neutrality in the long run, i.e. close to zero GHG emissions'****. Likewise, decarbonised steel means close to zero GHG emissions embedded in the steel, not the carbon grade related to steel quality characteristics."*
SSAB – Not all green steel is fossil-free steel: Here's why	***"Green steel refers to the strategy aimed at making the steelmaking process greener and more sustainable."***
H2 Green Steel – Questions and answers about our establishment in Boden	[...] *"****actual CO2 reduction and improving circularity are both key****. Therefore, green steel must be produced from a* ***combination of a significant amount of green virgin iron and scrap in a production process that uses electricity from renewable energy sources.****"*
World Economic Forum – What is green steel and why does the world need more of it?	[...]*"****green steel is the manufacturing of steel without the use of fossil fuels.****"*

There is no clear definition of what makes steel 'green'. Some definitions focus on environmental factors, such as pollutants released during steel production, as the key determinants of the environmental performance of steel. Others emphasise the technology used to produce steel, either by specifying a particular production route or by excluding fossil fuels from processes entirely. In addition, some definitions link green steel to circular economy principles, praising the role of ferrous scrap. Finally, some definitions opt to also take into account the alleged quality of steel output and cost savings associated with the production of green steel. **For the purposes of this report, a unit of green steel is interpreted as having a reduced climate change impact during its production compared to its unabated counterpart, resulting in lower embedded GHG emissions in the finished product**.

In parallel, the 'green' attribution for steel is sometimes used interchangeably with the terms 'sustainable' and 'clean', although these two denominations are used to capture a value chain perspective that includes and goes beyond the production stages (i.e. mining, use, reuse, disposal), which covers not only the environmental domain but also socio-economic structures and public health.[9,10,11,12,13]

Although green steel would differ from conventional/non-green steel in terms of emission intensity, the physical properties of the two basic materials cannot be discerned, challenging the establishment of markets for green steel. To overcome this obstacle, it is important to implement robust monitoring, reporting and verification (MRV) protocols, as well as clearly defined standards and certification procedures. This is essential to prevent the risk of greenwashing and ensure the credibility of green steel claims.

4. The quest for standards

Setting standards is key to driving demand for green products. In the context of green steel, standards define the criteria that steel producers must meet for each unit of output in order to obtain certifications from recognised schemes, usually verified by third parties. **Certification is a key tool in promoting green markets that ensures consistency, credibility and comparability between units of similar products**. The explicit criteria and measurement methods established by standards increase market transparency throughout the steel value chain, facilitating the procurement process.[14] To be most effective, green steel standards should be consistent with climate science and informed by modelled targets or trajectories consistent with the industry's decarbonisation efforts. **Standards, and associated certifications, serve in turn as the foundations for labelling frameworks that assess and validate the environmental performance of final products sold to end-users, increasing consumer confidence in the environmental claims of these goods**.

However, **the proliferation of standards and certification initiatives aimed at decarbonising the iron and steel sector in recent years has led to fragmentation and inconsistencies**. In particular, steel producers can now choose from more than 20 different steel decarbonisation standards and initiatives, each with their own system boundaries and methodologies. Taking into account the entire steel value chain, including the mining and alloying metals sectors, there are more than 150 sustainability standards and related initiatives. This plethora of different and often incompatible standards creates uncertainty and confusion for both producers and consumers, leading to reduced efficiency and increased transaction costs.[15]

a. The question of scrap and the sliding scale

The existence of several production routes for steel makes it difficult to standardise its green alternative. The conventional BF-BOF route is known to be highly energy and emission intensive, while the EAF route can use more recycled ferrous scrap, resulting in lower emissions and energy consumption. In the EU, emissions for the BF-BOF route average 2 tCO_2/t steel compared to 0.4

[9] Arena M. & Azzone G. (2013) – Process based approach to select key sustainability indicators for steel companies.
[10] Singh R.H., Murty H.R., Gupta S.K. & Dikshit A.K. (2007) – Development of composite sustainability performance index for steel industry.
[11] Fruehan R. J. (2009) – Research on sustainable steelmaking.
[12] Conejo A. N., Birat J. & Dutta A. (2020) – A review of the current environmental challenges of the steel industry and its value chain.
[13] Birat J. (2016) – Steel cleanliness and environmental metallurgy.
[14] Agora Energiewende & CLG Europe (2021) – Tomorrow's markets today: Scaling up demand for climate neutral basic materials and products.
[15] World Trade Organisation (2022) – Decarbonization standards and the iron and steel sector: How can the WTO support greater coherence?

tCO2/t steel for the EAF route.[16] Although in the EU the two steelmaking routes are usually used to produce two different types of products (i.e. flat and long), the introduction of DRI plants is expected to increase the production of flat products via EAFs and allow their producers to use more ferrous scrap in the process, resulting in emission savings both within the installation (less use of reducing agents such as coke, hydrogen or natural gas) and outside it (less use of iron ore and other resources).

The sliding scale is a concept mechanism proposed by industries and steel standardisation initiatives[17] that classifies steel products into tiers based on their embedded emissions and scrap content. It sets CO_2 emission intensity thresholds per tonne of steel output that producers would need to meet to qualify for a green steel certification. 'Sliding' because the thresholds are adjusted based on the ratio of virgin materials to recycled scrap, becoming more stringent (i.e. lower) as the scrap content increases. The proposed concept scheme is divided into different tiers with different CO_2 emission intensity thresholds to reflect a spectrum of steel greenness and recognise (i.e. certify) intermediate decarbonisation progress.

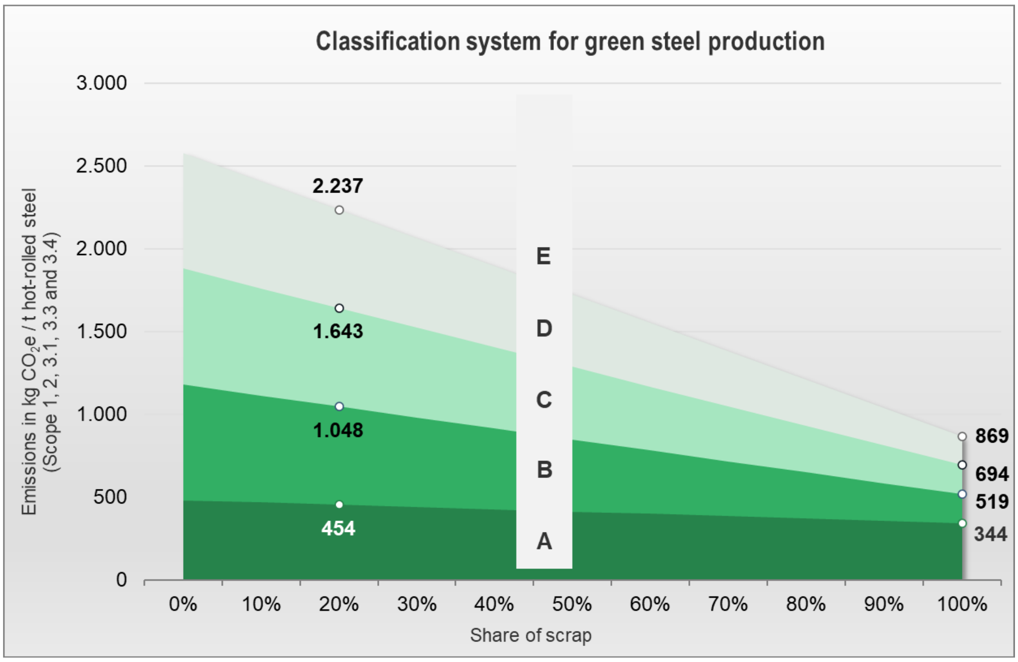

Figure 1 - Sliding scale proposal by Wirtschaftsvereinigung Stahl

The idea behind a sliding scale is to **combine emission reduction efforts, abatement potentials of circularity and product differentiation (flat and long) into a single classification system**. It is designed to be a technology-neutral approach that assesses on-site GHG emissions performance and creates a level playing field between steelmaking routes, taking account of their ability to incorporate scrap into their finished products.

The concept of a sliding scale has been developed to address the challenge of attributing GHG emissions associated with recycled inputs and recyclable outputs in steel production.[18] **Standardising green steel solely on the basis of embedded GHG emissions at the production site could overlook the carbon footprint of scrap, which could lead to an underestimation of the overall carbon footprint**. This is particularly relevant for the EU, where the production of long products relies heavily on recycled

[16] European Commission (2015) – Ex-post investigation of cost pass-through in the EU ETS.
[17] Responsible Steel, ArcelorMittal, Wirtschaftsvereinigung Stahl [German Steel Association].
[18] Broadbent C. (2016) – Steel's recyclability: Demonstrating the benefits of recycling steel to achieve a circular economy.

ferrous scrap.[19] A comprehensive understanding of the embedded emissions in steel products requires the use of life cycle methodologies that allow comparisons between different green variants of the same material and assessments against alternative materials, such as aluminium, for potential substitution in different applications. However, there are significant challenges in tracing the previous life cycle of ferrous scrap, making it difficult to accurately attribute embedded emissions to the new steel product. **Assigning a fixed linear reduction factor to thresholds, as the sliding scale does, with variations for each green tier, highlights that its proponents themselves ignore the embedded emissions associated with scrap**.

The rationale for adjusting the emission requirements for green steel based on the proportion of ferrous scrap used, under the guise of technological neutrality, is to allow green steel standards to be met regardless of technology and scrap input. This is presented as creating a level playing field for all production methods to meet the standards with comparable effort. The argument suggests that steelmakers should be given the flexibility to invest in technologies in line with their business models, take into account customer requirements, integrate renewable energy and consider regional scrap availability. However, despite advocating for an equal footing, **the technological neutrality argument favours the BF-BOF route**. This is because, due to its technical constraints of only allowing up to 15-20% scrap blending in the final product, it would otherwise be outperformed by the less carbon and energy intensive DRI-EAF route, which is more flexible in terms of scrap utilisation.

Another justification put forward by the proponents of the sliding scale is the limited availability of scrap to fully replace virgin ore in flat steel production and the risk that green steel standards, not adjusted for scrap content, could drive up its price. However, the availability and price of scrap is partly linked to its market value for new steelmaking cycles. Encouraging the use of scrap to reduce emissions could improve scrap recovery rates and quality as its market value increases. However, indexing green thresholds to scrap content reduces the incentive to use scrap to qualify for green steel status, undermining the principles of circularity. **Penalising the use of scrap, as the sliding scale approach would do, could hinder the development of more efficient secondary markets and the closing of material loops in the steel sector**.

Overall, from a climate perspective, this levelling approach could lead to paradoxical results, where a producer using a higher proportion of scrap could potentially be awarded a lower green steel certification tier than a producer with a lower scrap content, even if the former achieves lower embedded emissions. From an energy perspective, a classification system that incentivises steel producers to deliberately include more raw materials than scrap in their product mix in order to secure a higher green steel certification tier would result in increased energy consumption, as the processing of raw materials is more energy intensive than the processing of scrap.

A leaner and fairer approach to the sliding scale would be to create two distinct tiered sets of green steel certifications: one for flat products and another for long products, where the only variable considered would be that of embedded emissions from production. This approach would allow steel production routes to openly compete for lead markets, allowing the most cost-competitive technologies that can meet the most stringent green steel standards to emerge as the most viable for sectoral decarbonisation. In contrast to the sliding scale, scrap should not be seen as an obstacle to

[19] Oxford Institute for Energy Studies (2023) – Stainless Green: Considerations for making green steel using carbon capture and storage (CCS) and hydrogen (H2) solutions.

emissions reductions, but as a complementary tool for decarbonisation alongside the shift to cleaner steelmaking technologies.

The introduction of a green steel certification scheme specifically tailored to long products would incentivise producers to improve the environmental performance of their production. This encouragement becomes crucial as, in the EU, long steel producers already employ 100% scrap and electricity, leaving limited avenues for further emission reduction. However, there are opportunities for additional abatement within the EAF route, depending on the electricity procurement strategy of individual steel plants. A tiered green steel standard would reward long steelmakers for entering into Power Purchase Agreements (PPAs) with renewable energy providers and/or Demand-side Response (DSR) programmes to operate profitably only when the electricity grid is within a certain carbon intensity limit.

5. Shaping green steel demand via lead markets

Producing green steel is similar to producing green energy in that it does not affect the functionality of the product or the end-user experience.[20] But unlike renewables blending into the power grid and becoming tangibly indistinguishable from their fossil-based counterpart, products using green steel can be traced back to manufacturers and suppliers of materials.[21]

From a value chain perspective, steel producers do not usually sell their products directly to individual end-users, but to downstream manufacturers. These downstream manufacturers in turn process the steel into final products, which are then made available to end-users. This is because steel producers are usually not equipped to produce the wide variety of steel products that end-users buy. Consumers of green steel therefore refer to the manufacturing industries that are customers of steel producers, such as car manufacturers or engineering companies, while end-users of green steel refer to the customers of those manufacturing industries that purchase green steel as a material for their final products, such as cars or tools.

The main advantage for manufacturers who voluntarily purchase green steel lies in the reputation gained from purchasing materials manufactured using cleaner production methods.[22] In this context, the customer for green steel would be a company that is committed to environmentally friendly practices and chooses more sustainable and expensive materials over standard and cheaper alternatives. This preference is often driven by environmental values or concerns manifested in environmental, social and governance (ESG) commitments. **Similarly, the end-user of a product made from green steel would be an individual who adopts environmentally friendly consumption patterns, and who is willing to pay a premium for a product with the same characteristics, but produced and sourced in a way that is consistent with their environmental positions**.[23] Therefore, **in the absence of market-based regulations that equalise the costs between green and conventional steel borne by manufacturers, the size of the market for green steel would depend on the pool of end-users willing**

[20] Sardianou E. & Genoudi P. (2013) – Which factors affect the willingness of consumers to adopt renewable energies?
[21] Oxford Institute for Energy Studies (2022) – Steeling the race: 'Green steel' as the new clean material in the automotive sector.
[22] Olson E. L. (2013) – It's not easy being green: The effects of attribute tradeoffs on green product preference and choice.
[23] Chekima B., Wafa S. A. W. S. K., Igau O. A., Chekima S. & Sondoh Jr. S. L. (2016) – Examining green consumerism motivational drivers: Does premium price and demographics matter to green purchasing?

to pay the extra costs of procuring green steel that is not absorbed by the manufacturer and is passed it on to them.

The steel supply chain is often more complex than a straightforward producer-manufacturer-consumer relationship, involving more intermediate stages of manufacturing. This complexity arises because steel serves as a basic input material for different manufacturers, each of which may have its own set of intermediaries and customers in the supply chain.[24] Often, manufacturers using green steel as a material do not sell the final product directly to end-users. Instead, they may pass it on to other manufacturers further down the value chain.

For example, a factory might use green steel to make components for a mechanical engineering company, which in turn incorporates the components into its machines and sells them to end-users, such as construction companies. This two-stage separation between green steel producers and end-users of products containing green steel poses a challenge in establishing a transparent chain of accountability throughout the manufacturing stages. This challenge stems from the difficulty of ensuring that all steel materials in the final product are truly green.[25] For example, the same engineering company that sources green steel components for its machines from one factory might source other steel components for the same machine from another factory that uses conventional steel. As a result, the machine that leaves the manufacturer is only partially made with green steel and it could be less appealing to a construction company committed to green purchasing.

Facilitating an informed consumer base is essential to increasing demand for green steel in the marketplace. Misleading claims about the environmental benefits of a product not only diminish the influence of consumers, but also discourage those who wish to make effective choices through their market preferences.[26]

A labelling system plays an essential role in assuring end-users that products using green steel, even when indistinguishable from less green alternatives, have been procured, processed and distributed through lower-carbon pathways.[27] Such a scheme would also improve market efficiency by mitigating information asymmetry along the marketing chain, benefiting both producers and consumers,[28] while mitigating the risk of fraudulent claims or greenwashing.[29] End-users who are aware of the energy and carbon footprint of the final products they buy, may be more inclined to change their purchasing behaviour and encourage manufacturers to adapt their production strategies.

However, the potential environmental benefits of green products alone are not always enough to persuade customers to buy them, especially if they come at a higher price than their conventional alternatives.[30] **Estimating the premium that end-users would be willing to pay for a product made**

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[24] Grubb M., Jordan N. D., Hertwich E., Neuhoff K., Das K., Bandyopadhyay K. R., van Asselt H., Sato M., Wang R., Pizer W. A. & Oh H. (2022) – Carbon leakage, consumption, and trade.
[25] Shekari H., Shirazi S., Afshari M. & Veyseh S. (2011) – Analyzing the key factors affecting the green supply chain management: A case study of steel industry.
[26] Centre for European Policy Studies (2023) – Can the cars we buy drive green steel production?
[27] Janssen M. & Hamm U. (2012) – Product labelling in the market for organic food: Consumer preferences and willingness-to-pay for different organic certification logos.
[28] Lohr L. (1998) – Implications of organic certification for market structure and trade.
[29] Feinstein N. (2013) – Learning from past mistakes: Future regulation to prevent greenwashing.
[30] Ritter A. M., Borchardt M., Vaccaro G. L. R., Pereira G. M. & Almeida F. (2015) – Motivations for promoting the consumption of green products in an emerging country: Exploring attitudes of Brazilian consumers.

with green steel is a significant challenge, and misinterpretation of this aspect could affect manufacturers' sales and consequently the demand for green steel.

The cost of steel purchased by manufacturers does not have a consistent impact on the price of final products, as it varies significantly across the different value chains in which steel is used. The main reason for this variability is that most of the added economic value influencing the market prices of final products, is generated during the manufacturing stages. At these stages, the cost of procuring materials such as steel is often dwarfed by the cost of actually producing the goods. **Understanding the extent to which the cost of steel affects the price of the final product is essential in assessing a manufacturer's ability to either pass on or absorb the additional cost of sourcing green steel**.

Table 2 - Green steel costs passed through the end-user: car vs. shipping container

	Passenger car *Average mid-size passenger car weighing 1.5 tonnes and priced €32,000*	Shipping container *Intermodal freight shipping container weighing 2 tonnes and priced €3,000*
Amount of steel in the material composition of the final product (Price)	0.9 t (€594)	2 t (€1,320)
Proportion of the price of the final product, when sold to the end-user, which can be attributed to the cost of procuring conventional steel	1.9%	44%
Cost of purchasing green steel for the final product borne by the manufacturer	€891	€1,980
New price of the final product as sold to the end-user, if the manufacturer chooses to pass on the premium for using green steel (Price difference)	€32,297 (+0.9%)	€3,660 (+18%)

Both final products are made from hot-rolled flat steel, which in the summer of 2023 costed an average of €660/t on the European markets.[31] The premium assumed for its green equivalent is 50% (€330/t). It is assumed here that all the steel used in cars comes from flat products. However, this is an oversimplification. In reality, the ratio of flat to long steel products in a car is closer to 75% flat and 25% long, rather than 100% flat. Therefore, the realistic premium (combining flat and long) to be passed on to the end-user for green steel would be lower.

In the absence of market-based regulations that provide financial incentives for manufacturers to source green steel, not all manufacturing sectors are in a position to make such a switch. To illustrate, consider the examples of car and shipping container manufacturers above. For the former, the cost of sourcing conventional steel is a small fraction of the final product price, only 1.9%. For the latter, the cost of steel is a significant proportion, around 44%. If the additional costs for sourcing green steel were fully passed on to the end-user, the switch to green steel would result in a price increase of only 0.9% for passenger cars, but a significant increase of 18% for shipping containers. In this scenario, while environmental concerns may persuade a customer to pay 0.9% more for a car made from green

[31] https://eurometal.net/european-steel-hrc-prices-largely-flat-in-seasonally-slow-market/

steel, the same may not be true for a shipping company buying containers in bulk and operating on thin profit margins to pay 18% more for the same item made from green steel.

Alternatively, a car manufacturer may be able to absorb this 0.9% increase in steel cost per unit as it represents a relatively small shift from 1.9% to 2.8% of material costs compared to the same passenger car price. However, the shipping container manufacturer would face a much greater challenge as the shift from 44% to 66% of steel costs per unit is much less manageable.

Therefore, **in absence of public intervention, the uptake of green steel may be limited to a few niche sectors, specifically in those where the cost of sourcing steel, whether green or conventional, is a small fraction of the price of the final product**. In such cases, manufacturers have more flexibility in determining the extent to which they absorb the premium or pass it on to the end-users.

5.1 Sectoral dive: Automotive

The automotive industry is an ideal candidate to lead the uptake of green steel across EU manufacturing sectors, both from an economic perspective of flexibly managing the extra costs associated with the green premium, and from a climate perspective of slashing GHG emissions through the substitution of carbon-intensive materials. This is due to three key factors:

1) The automotive sector is the largest consumer of flat steel in the EU, representing a significant customer base for steel producers.[32]
2) Automotive manufacturers have a relatively simple and often well-integrated supply chain, with few players in the intermediate stages of manufacturing, which facilitates traceability.[33]
3) The cost of sourcing steel is marginal compared to the value added to the vehicle during the manufacturing stages and its final price when sold to end-users.

The costs associated with the green premium become proportionally less significant as the price of a vehicle increases. At higher prices than in the passenger car example above, the target end-users may either have a greater willingness to pay for a vehicle made with green steel, or have sufficient purchasing power to overlook the marginal price differences. Alternatively, automakers operating in these market segments may be more flexible in absorbing the cost of the premium, as they are likely to operate with higher profit margins than more mass-market manufacturers.

Besides breaking down costs, **the switch to more expensive green steel in the automotive industry becomes more justifiable and marketable to end-users when framed in the context of the wider goal of decarbonising the transport sector**. The embedded GHG emissions associated with conventional steel components represent a considerable proportion of the total life cycle emissions of a vehicle powered by an internal combustion engine (~10%).[34] The use of green steel in vehicle components would therefore become increasingly important in reducing Scope 3 emissions in the transport sector as the industry gradually shifts to the production of electric and hybrid vehicles. Vehicles designed for minimum or zero tailpipe emissions have a higher share of embedded GHG emissions from material

[32] European Steel Association (2023) – European steel in figures.
[33] Muslemani H., Liang X., Kaesehage K., Ascui F. & Wilson J. (2021) – Opportunities and challenges for decarbonizing steel production by creating markets for 'green steel' products.
[34] International Council on Clean Transportation (2021) – A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars.

components and manufacturing stages in their total life cycle GHG emissions than vehicles solely powered by internal combustion engines.[35]

While switching to greener versions of steel may appear to be the most straightforward way for the automotive industry to reduce a vehicle Scope 3 emissions, replacing steel with other materials becomes more economically viable as we move up the price range. Lightweight materials such as aluminium and plastic composites, although more expensive, offer comparable performance in terms of durability and strength, while also reducing weight, which in turn improves fuel economy.[36]

In addition to cars, buses and heavy-duty vehicles also benefit from the fact that steel makes up a significant part of their weight but only a marginal part of the market price of the vehicle. However, as these vehicles are usually purchased in batches, passing on the accumulated premiums directly to the end-users could discourage buyers who do not prioritise the environmental benefits from purchasing. Nevertheless, unlike passenger cars, the substitution of steel by alternative materials in the body of heavy-duty vehicles and buses is not always feasible for safety reasons, especially in view of the demand for higher payloads.[37]

5.2 Sectoral dive: Construction

The construction sector is the largest consumer of steel in the EU, accounting for 37% of steel demand in 2022. While this large use may suggest a significant opportunity for a successful transition to green steel, **it is important to note that the majority of this demand is for long products (rebar, wire rod, merchant bars and sections)**. In terms of demand for flat products (sheets and plates), the construction sector ranks in the EU second after the automotive industry.[38] In addition, it is worth noting that **the use of flat steel products as a material in the construction sector is mostly limited to buildings (e.g. roofing sheets, cladding panels, door frames, etc.) as opposed to infrastructure projects (e.g. bridges, tunnels, rails, etc.), which further limits the overall penetration of flat (green) steel in this sector**.[39]

In the context of buildings, steel is to some degree substitutable with cement, which means that regulating the environmental performance of only one material may lead to partial substitution with the other: for example, partial substitution of green steel with 'conventional' cement.[40]

Regarding the use of green steel in buildings and willingness to pay, homeowners and tenants do not typically associate the environmental impact of buildings with GHG emissions during the construction phase, but rather with energy use and emission intensity once the building is in use. Therefore, demand for green steel in the building sector, as for electric and hybrid vehicles, would be better perceived if it were associated with high performance buildings to justify the premium, as the

[35] Centre for European Policy Studies (2023) – Can the cars we buy drive green steel production?
[36] Maw I. (2018) – The battle of the bodies: Steel vs aluminum in automotive production.
[37] Santos J., Gouveia R. M. & Silva F. J.G. (2017) – Designing a new sustainable approach to the change for lightweight materials in structural components used in truck industry.
[38] European Steel Association (2023) – European steel in figures.
[39] World Steel Association – Steel in buildings and infrastructure.
[40] Oxford Institute for Energy Studies (2023) – Stainless Green: Considerations for making green steel using carbon capture and storage (CCS) and hydrogen (H2) solutions.

embodied emissions from the construction of these types of buildings play a relatively larger role in the total life cycle emissions of the structure.[41]

To draw further parallels with the automotive sector, **the construction supply chain is risk-averse, highly decentralised and highly fragmented**.[42] It involves a large number of actors, such as architects, manufacturers, contractors, clients, and the owners and tenants of completed buildings. **Coordinating these actors and tracking green steel across these stages would be challenging**. In addition, most of these actors operate with small profit margins in a highly competitive environment, making it difficult to pass on the green premium unless it is regulated and guaranteed.[43]

6. 'Pull' mechanisms to set up green steel markets

In absence of regulatory-driven demand, the market for green steel products may primarily serve specific niches of manufacturers committed to reducing the embodied carbon in their products and passing on the additional cost to environmentally conscious consumers willing to pay a premium for the green choice made by the manufacturer. However, **the spontaneous development of these niche markets for green steel may not contribute significantly to the decarbonisation of the industry unless regulatory support is steered in such a way that it moves from a niche to mainstream practice over time**.[44]

Pull mechanisms are strategic tools in the hand of public authorities to support the operational viability of clean production technologies. While push mechanisms create the necessary financial conditions for producers to switch to cleaner production technologies, using incentives such as subsidies or disincentives such as carbon pricing, pull mechanisms take a different approach. They focus on making these investments financially sound compared to dirtier alternatives, even in the face of higher operating costs. This is achieved by stimulating markets for products derived from these cleaner technologies. Therefore, **in conjunction with incentives and regulatory frameworks aimed at channelling producers towards investing in cleaner production pathways (push), public authorities can design strategies to overcome the financial barriers associated with sustaining operations after the switch (pull)**. These strategies achieve this by incentivising or mandating certain customers to steelmakers, to pay a premium for cleaner products, creating market demand for sustainability.[45]

6.1 Green Public Procurement (GPP)

The European Commission describes Green Public Procurement (GPP) as "*a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured."*[46] Unlike traditional public procurement practices, GPP requires a tailor-made approach that includes capacity-building within government agencies to integrate sustainability considerations into the tendering process. **Rather than relying on lowest cost**

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[41] Muslemani H., Liang X., Kaesehage K., Ascui F. & Wilson J. (2021) – Opportunities and challenges for decarbonizing steel production by creating markets for 'green steel' products.
[42] Blayse A.M. & Manley K. (2004) – Key influences on construction innovation.
[43] McAdam R. & Brown L. (2001) – Strategic alignment and the supply chain for the steel stockholder sector: An exploratory case study analysis.
[44] Foxon T. J. (2010) – Stimulating investment in energy materials and technologies to combat climate change: An overview of learning curve analysis and niche market support.
[45] International Energy Agency (2022) – Achieving net zero heavy industry sectors in G7 Members.
[46] European Commission (2008) – Public procurement for a better environment.

as the primary criterion for awarding contracts, GPP requires different methodologies tailored to achieve specific objectives.

The design of GPP policies is critical because they need to be aligned with the intended impact throughout the targeted value chain, whether it is reducing emissions, protecting the environment or conserving resources. To maximise the certainty of achieving the desired outcomes and creating targeted demand, the most effective GPP policies should incorporate appropriate methodologies both at the project level (the goods/services contracted) and the material procurement level (the materials used).

This approach would enable public authorities to commit to a forward-looking market and, contingent upon the specific requirements of covered public project categories and the consistent recurrence of similar tenders, ensure the long-term viability of green material production where standard commercial revenues would otherwise be insufficient to sustain it. By providing this long-term guarantee of higher revenues, GPP incentivises both existing and potential new producers to participate in this publicly supported market, guaranteeing stable revenues to offset any additional operating costs.

However, the adoption of GPP policies impose two financial burdens on public authorities in addition to traditional public procurement. As mentioned above, one challenge is to absorb the premium associated with the environmental attributes of the project, while the other is the need for increased capacity. Designing and implementing GPP tenders requires the development of expertise and skills within public administrations to establish and monitor life-cycle performance criteria in public procurement. This capacity may be lacking in public administrations that traditionally prioritise procurement decisions based on cost effectiveness.[47]

When it comes to pulling green steel, GPP can be designed to set specific emission thresholds per tonne of output for a proportion or totality of materials purchased for public projects. This approach can be extended beyond individual project management by incorporating demand pull mechanisms into regulatory requirements, setting adjustable minimum quotas for the use of green steel in publicly funded projects. These quotas themselves can then also be adjusted in both stringency and proportion to align with climate targets. However, there is a caveat.

Sectors dominated by public procurement, such as, infrastructure, energy and water management, rely mainly on long steel products, such as reinforcing bars, rails and sections.[48] Within the EU, these products are already produced through the low-emission secondary steelmaking route, using ferrous scrap and electricity.[49] As a result, **the potential impact of GPP in promoting the uptake of green steel in these sectors may be somewhat limited when it comes to supporting the decarbonisation of conventional steelmaking for flat products**.

It is important to note that public authorities do not normally procure materials as this is usually the responsibility of the contractors. Furthermore, while the introduction of green steel as the exclusive material of choice may appear attractive in terms of de-risking investment in steelmaking, **it could**

[47] Chiappinelli O. & Zipperer V. (2017) – Using public procurement as a decarbonisation policy: A look at Germany.
[48] Marron D. (2004) – Greener public purchasing as an environmental policy instrument.
[49] There are exceptions in notable applications such as pipelines and wind turbines, where flat products are used as structural components, or in projects such as highways, bridges and dams, where predominantly long products are used but steel plates are still an integral part of the structures.

paradoxically stifle innovation by limiting the exploration of alternative low-carbon material options which, combined with the provision of more generous funding under GPP policies, could become commercially viable.

There is, however, **one exception to the limitations of GPP in promoting the uptake of green flat steel products and that is in the context of public vehicle fleets**. The already existing interest of public authorities seeking to reduce tailpipe emissions by procuring electric, hybrid or low carbon vehicles for public transport and other public services can be further enhanced by incorporating life cycle criteria beyond Scope 1 and 2. Public vehicle fleets – which include mass transit vehicles such as buses, trains and light rail, as well as light-duty trucks and passenger cars – offer opportunities for a diverse and consistent baseload demand for vehicles made with green steel. For car manufacturers, public contracts would act as a catalyst for product differentiation with a guaranteed passed-through premium.

6.2 Quota system

Quota systems are regulatory tools public authorities can use to drive the private sector's uptake of green materials. These regulatory measures allow public authorities to **oversee the material procurement practices of targeted domestic manufacturing industries**. Quota systems based on the greenness of steel would mandate the use of a proportion of green steel in specific products or entire sectors. **To meet these quotas and avoid penalties, the manufacturing sectors subject to the quota system would be forced to pay a green premium**.[50] These financial obligations would in turn create a parallel – or lead – market for green steel producers, separate from conventional steel. Typically, regulatory schemes that govern quantities have three main components:

- setting minimum quantity requirements and identifying targeted sectors
- issuing certificates to monitor compliance with these requirements
- implementing MRV mechanisms to ensure compliance.[51]

Similar to GPP, quota systems require administrative capacity to track the consumption of green materials within specific sectors.[52] However, setting and monitoring minimum quantity requirements for manufacturing sectors under the quota system is arguably less burdensome than stimulating demand for green steel through individual public projects on a case-by-case basis under a GPP policy. This is because the responsibility for tracking compliant materials shifts to the manufacturers, rather than relying on the oversight of public authorities, as a quota system rates suppliers rather than the specific products they supply.

The administrative burden of the quota system depends on the scope and depth of the criteria to be met. **The application of sectoral minimum quantity requirements is more practical for covered manufacturers, as they can apply these requirements on average across their range of final products sold to end-users**. This approach is also easier for public authorities to monitor, as opposed to product-based criteria where the minimum green material content would have to be met across the whole range of final products available to end-users (e.g. in the automotive sector as opposed to individual vehicles).

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[50] International Energy Agency (2022) – Achieving net zero heavy industry sectors in G7 Members.

[51] Hepburn C. (2006) – Regulation by prices, quantities, or both: A Review of instrument choice.

[52] Vogl V., Åhman M. & Nilsson L.J. (2021) – The making of green steel in the EU: A policy evaluation for the early commercialization phase.

Implementing a quota system for green steel in the private sector allows public authorities to strategically target manufacturing sectors that play a significant role in driving demand for flat steel products produced via the polluting conventional route. However, **when imposing mandatory minimum quantities without accompanying financial incentives, public authorities must ensure that the additional cost of the premium imposed does not adversely affect competitiveness** *vis-à-vis* manufacturers in other jurisdictions who are not subject to similar material restrictions but who continue to export to the affected market. Nor should the purchasing power of low and middle income end-users be adversely affected.

With regard to end-users, and in conjunction with obligations set at the manufacturing stages, a quota system could be applied to groups of end-users who make large purchases of final products or steel as a material component. This could include companies purchasing corporate cars or leasing companies purchasing fleets, thus reducing uncertainty for automakers as to whether there will be buyers willing to pay for cars made with green steel. **In the construction sector, restrictions on the embedded emissions of the material could be imposed on private developers**, sending signals to steel producers – either directly or through intermediate steel traders who process the materials – that the green premium is guaranteed to be paid. The latter is particularly important as buildings are generally not the focus of GPP policies.

6.3 Tradeable certificate scheme

In order to reduce the administrative burden for public authorities and entities driving demand for green materials, whether through a project-by-project approach such as GPP or through minimum quantity requirements with quota systems, the use of certification schemes linked to material's performance standards could potentially reduce the implementation burden and increase monitoring efficiency.

Mirroring the model of tradable renewable energy certificates, in a tradable green steel certification scheme, green steel producers would issue certificates based on their units of green steel production, which would then be available for purchase in a certificate market as if they were guarantees of origin.[53] The price of these certificates would vary in response to shifts in supply and demand, mechanically reflecting the cost of the premium. Downstream manufacturers, either compelled by the regulatory quota system or seeking to reduce their Scope 3 emissions for ESG compliance or eligibility in public tenders under GPP policies, can choose to **either purchase green steel and its associated certificates as a package from green steel producers, or buy conventional steel from any steel producer and purchase green steel certificates separately from a green steel producer**.

Coupling the scheme with a quota system ensures a consistent demand for green steel certificates and guarantees that green steel producers receive the associated premium on a predictable basis. Integrating the quota system into a tradable certificate scheme has three benefits:

(1) It enables public authorities to enforce minimum green steel requirements without the burdensome administrative capacity of having to monitor individual plants' material procurement strategies.

[53] Centre for European Policy Studies (2023) – Can the cars we buy drive green steel production?

(2) It allows them to set and track the reduction in GHG emissions resulting from the substitution of conventional steel with green steel.

(3) It designates a jurisdiction for eligible transactions between green steel producers and manufacturers subject to the quota system, thereby ensuring that the certificate scheme de-risks investments in clean steelmaking technologies within the jurisdiction and preventing manufacturers from fulfilling their green steel quota by importing material from green steel producers in third countries free riding the regulatory obligations.

The introduction of a tradable certificate system combined with a quota system gives green steel producers the **flexibility to decouple the additional operating costs of the premium from their finished product**. They can either build the premium into the product or sell it separately as certificates. This strategy allows manufacturers under the quota system to source steel from the market as usual, whether green or conventional. It also allows green steel producers to expand their customer base beyond the sectors covered by the quota system and to compete effectively with conventional steel producers. From a systemic perspective, a tradable certificate scheme ensures that the overall demand for green steel driven by the quota system is met on average across the market, regardless of whether specific green steel applications are made by sectors subject to the quota system.[54]

The seemingly lower capacity building requirements for setting up a quota and certificate system need to be balanced by careful **attention to avoiding cases of greenwashing or ineffectiveness in substituting conventional steel produced by the most carbon-intensive route**. It is therefore important to distinguish between the origin and value of a green steel certificate by taking into account whether the green steel produced is in the form of flat or long products. This distinction is necessary because the green versions of the two final products result in different avoided GHG emissions compared to their conventional counterparts and reflect different additional operating costs borne by steel producers switching to green steel. In particular, the decoupling of green steel from green steel certificates could lead to **gaming opportunities for manufacturers sourcing conventional steel and purchasing certificates that do not reflect the same green material substitution in other applications**.

In addition, the **decoupling of green steel certificates from units of green steel may also lead to potential cases of 'double counting'**. If a green steel producer sells green steel certificates corresponding to the units of green steel produced to a downstream manufacturer within the jurisdiction where the certification scheme is enforced, but then exports the same units of green steel to a manufacturer outside the jurisdiction, there is a possibility that both manufacturers will claim the environmental attributes of the same units of green steel. This is because the manufacturer inside the jurisdiction may be using conventional steel but has purchased the premium (in the form of a green steel certificate), while the manufacturer outside the jurisdiction is actually using green steel.

Regarding imports, **restricting domestic manufacturers to purchasing green certificates only from domestic steelmakers could be perceived as a protectionist measure**, as it would prevent domestic manufacturers from purchasing green certificates from steelmakers in third countries, thereby restricting their exports to the jurisdiction implementing the trading scheme.

In order to address this issue, as well as the 'double counting' concern mentioned above, a solution to the international trade aspects of green steel within a certification trading scheme could be to

[54] International Energy Agency (2022) – Achieving net zero heavy industry sectors in G7 Members.

require that green steel (material) entering or leaving the jurisdiction where the certification trading scheme is in place be accompanied by the corresponding green steel certificates. However, in doing so, the framework would not de-risk investments exclusively within the jurisdiction in which it is implemented.

6.4 Financial incentives

In addition to instruments regulating the material sourcing of green steel in the value chain, subsidies could support lead markets by reducing the cost burden on downstream steel manufacturers or end-users. This would involve **public authorities covering the costs of the premium, thereby reducing uncertainty about the marketability of final products with better environmental performances**. Public authorities can offer a number of financial purchase incentives to offset the price difference between conventional and green steel in the final product:

- Point-of-sale subsidies: The public authority directly reduces the purchase price of products made with green steel at the point of sale to the end-user, providing a discount at the time of purchase in the form of a grant to the retailer or to the manufacturer.
- Tax exemptions: The public authority can reduce VAT or sales taxes to offset the price difference at the time of purchase.
- Post-purchase rebates: The public authority can offer direct payments to end-users after they have purchased final products made with green steel.
- Tax credits: The public authority can offer tax credits to end-users who have purchased products made with green steel against their income or corporate tax liability in the next fiscal year. [55]

Subsidies can be extended to the steel manufacturing level, particularly where the wholesale nature of final products makes it difficult for public authorities to trace individual transactions by end-users. However, there is a potential downside in that **subsidised manufacturers may be able to cumulate these subsidies with a green premium applied to some customers as a marketing gimmick to increase profit margins**.

Financial incentives are a useful tool to avoid the drawbacks of quota systems for end-users with limited purchasing power, who may ultimately refrain from purchasing final products made with green steel if the premium is passed on to them. **Subsidies can thus be efficiently tailored to focus on the lower price ranges within the same category of final products, reaching a segment of end-users who are less likely willing to pay for improved environmental performance and have a more elastic demand**. This way public authorities could avoid wasting resources for end-users' segment who either have the purchasing power to willingly pay the premium or overlook the marginal price increases.

Ultimately, financial incentives to reduce the premium face two main challenges. Firstly, the resources involved are essentially taxpayers' money, unless they are redirected carbon price revenues. Secondly, **the premium is dynamic, varying from one steel plant to another and influenced by the seasonal and intra-day penetration of renewables in the specific bidding zone where the plant operates**. As a result, disbursing financial incentives without accurate material tracking becomes a complex task, prone to either overpayment or underpayment of the premium.

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[55] Hardman S., Chandan A., Tala G. & Turrentine T. (2017) – The effectiveness of financial purchase incentives for battery electric vehicles: A review of the evidence.

7. Conclusion

While effective push mechanisms and competitive power prices would ideally eliminate the need for pull mechanisms for green steel in lead markets, **the current limitations of the EU ETS and the dominance of thermal power plants in European electricity markets hinder the competitiveness of cleaner steelmaking routes compared to conventional methods**. In this context, the lack of differentiation of finished products based on their environmental performance and the lack of guaranteed off-take for the green premium further discourage investment in green steel production. To bridge this gap and support the business case for clean steelmaking projects today, public intervention to create lead markets for green steel is essential.

A critical step in establishing these lead markets is to develop a standardised definition of green steel, agreed by public authorities. This definition should clearly delineate the required criteria for green steel and stand out from the myriad of existing overlapping initiatives. The standard should not penalise the use of scrap as a means of reducing embedded emissions and should focus solely on the environmental attributes of the targeted production cycle.

Identifying appropriate market segments for green steel is another critical aspect of this process. The fragmented nature of the downstream steel value chain poses challenges in tracking the material's journey and allocating the green premium to the cost of the final product. In addition, accurately measuring end-user willingness to pay for final products made with green steel is a complex task. **Key sectors to target include those with high demand for flat steel and where the value of the basic material is marginal compared to the total cost of the final product available to the end-user**. These include the automotive sector and part of the construction sector, with a focus on the building environment and, to a lesser extent, infrastructure.

Based on the composition of the domestic manufacturing sector, its demand for flat steel and the potential annual capacity of green steel within the covered jurisdiction, lead markets are formed by implementing pull mechanisms such as public procurement (GPP), material obligations on industry (quota system) or subsidies by public authorities to offset the cost of the premium from the value chain. In line with climate science-based green steel standards, **pull mechanisms should be tailored to meet climate targets and progressively expanded in scope to encourage the substitution of cleaner steelmaking processes over conventional methods**. While long steel producers can further minimise the environmental footprint of their finished products, **it is flat products that should be prioritised as their greener counterparts offer higher levels of abatement relative to the premium they command**.

At the heart of the green steel challenge is the price premium. While the conventional BF-BOF route has predictable operating costs that can be replicated across plants and locations, cleaner production processes are subject to greater fluctuations depending on technological and regional factors. A green premium that adequately compensates for the additional operating costs of one green steel plant may not be sufficient for another, making pull mechanisms a potential source of uncertainty in terms of inflation, increased public spending or undue profits. In essence, **mitigating the risks associated with investment in clean steelmaking technologies requires either public authorities or the steel value chain to bear the burden of unclear costs**.