TransitionZero

Global Efficiency Intelligence

Global Steel Production Costs

A country and plant-level cost analysis

Janurary 2022

TransitionZero

TransitionZero provides credible analysis and insights to accelerate a zero carbon economy in the electricity and industry sectors. The work of TransitionZero has been made possible by the vision and innovation shown by Quadrature Climate Foundation, Generation Investment Management, Google.org and Bloomberg Philanthropies.

Global Efficiency Intelligence

Global Efficiency Intelligence, LLC. is an energy and environmental consulting and market research firm. We provide global market-based solutions and in-depth technology, industry, business, and policy analysis to tackle the world's energy, environmental, and climate challenges.

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The experts above that contributed to this report are not responsible for any opinions or judgments it contains. Any errors and omissions are solely the responsibility of TransitionZero and Global Energy Efficiency.

Glossary

BF	blast furnace
BOF	basic oxygen furnace
CO_2	carbon dioxide
DRI	direct–reduced iron
EAF	electric arc furnace
EIA	Energy Information Administration (US Department of Energy)
EU	European Union
GHG	greenhouse gas
Gj	gigajoule
IEA	International Energy Agency
IPCC	Intergovernmental Panel Climate Change
kton	Kilo tonne (1000 metric tonne)
MJ	megajoule
Mt	million metric tonne
Worldsteel	World Steel Association

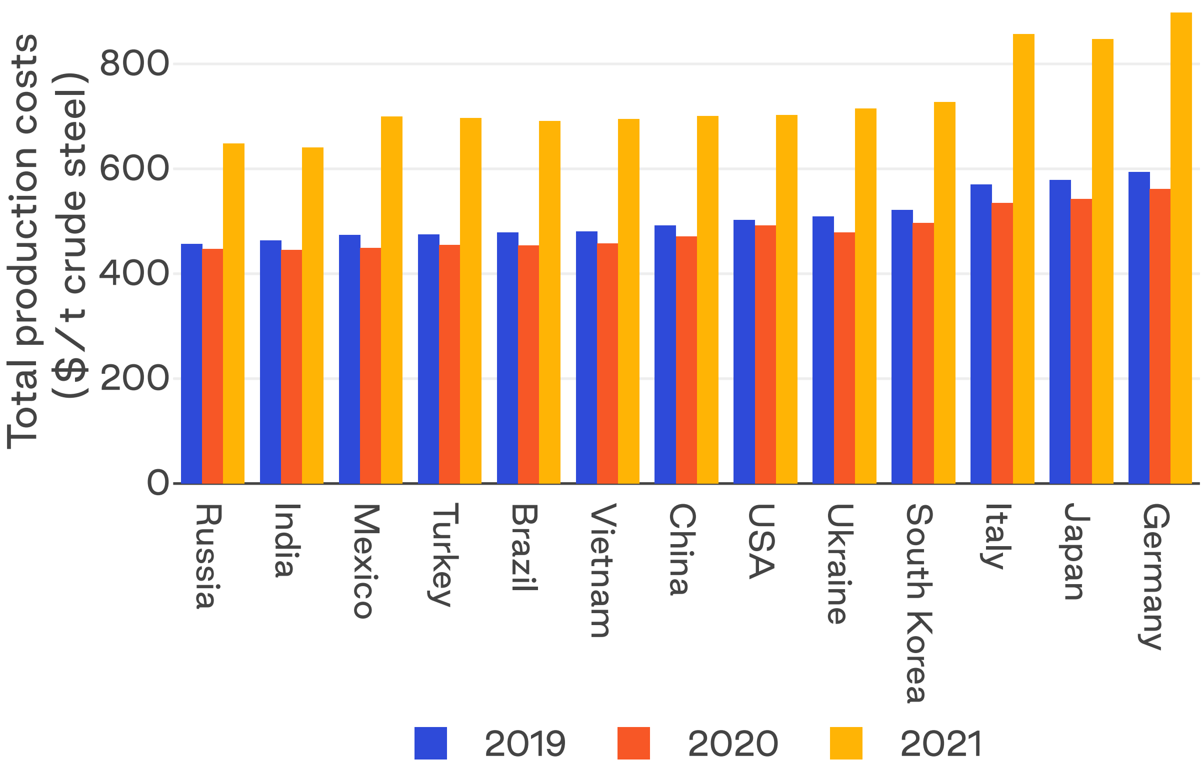
Contents

01 Executive Summary

This report shows the results of our analysis of steel production costs in major steel producing countries around the world. Our estimates of total steel production costs suggest Russia and India have the lowest production costs among the selected countries, driven by lower raw material and energy costs – the two main cost components in the overall costs profile. The two European countries in the modelled countries, Germany and Italy, along with Japan, have the highest production costs of the list (Figure 1). This relative competitiveness of India and Russia remains true even with the exceptional rise in commodity prices seen in 2021, where production cost of steel increased by an estimated 51% year-on-year on average across all major steel producers.

Better knowledge of steel production costs in different countries can help policymakers and other stakeholders to make more informed decisions and design better policies to address the steel industry's high energy use and carbon emissions in this trade-exposed industry. This report aims to provide such information. The analysis is carried out both at the country-level and plant-level, and showcases yearly production costs between 2019 to 2021, broken down by the major cost components of the steel production: namely raw materials, energy, labour, and "other costs". In addition to estimating total steel production cost in each country, we have also estimated the steel production cost for both primary steelmaking using blast furnace and basic oxygen furnace (BF-BOF) and secondary steelmaking using electric arc furnace (EAF), separately.

Figure 1. Total steel production costs in different countries, 2019-2021



Source: This analysis by TransitionZero and GEI

02 Introduction

Total steel production was 1,900 million tonnes (Mt) in 2021. The top 10 steel producing countries accounted for 85% of world steel production (Worldsteel 2021). Steel is used in many applications in manufacturing, construction, transportation, and various consumer products. The steel industry is important in many countries because of economic, employment and national security reasons.

Substantial amounts of steel are traded globally, meaning steel is often considered to be a trade-exposed[1] industry. The cost of steel production is an important factor in keeping a steel producing country or a particular steel plant competitive in such an international market.

Steel production is also an energy-intensive and high-carbon process. The global steel industry accounts for around 11% of total global carbon emissions (see chapter 2.2). Increasingly, countries and steel companies are under pressure to reduce their energy use and carbon emissions in both the short and long-term. In fact, in recent years, some major steel producing companies have committed to carbon neutrality by 2050, with interim milestones. In addition, increasing climate policies are putting pressure on the steel industry. A substantial amount of CO_2 is embodied in traded steel (Hasanbeigi et al. 2018), a concern which new climate policies such as EU's Carbon Border Adjustment Mechanism (CBAM) is aiming to address (European Commission. 2021).

Better knowledge of steel production costs in different countries can help policymakers and other stakeholders to make more informed decisions and design better policies to address the steel industry's high energy use and CO_2 emissions in this trade-exposed industry. This report aims to provide such information.

This report shows the results of our analysis of steel production costs in major steel producing countries around the world. The analysis is carried out both at the country-level and plant-level, and showcases yearly production costs between 2019 to 2021, broken down by the major cost components of the steel production: namely raw materials, energy, labour, and "other costs". In addition to estimating total steel production cost in each country, we have also estimated the steel production cost for both primary steelmaking, using blast furnace and basic oxygen furnace (BF-BOF), and secondary steelmaking using electric arc furnace[2] (EAF), separately.

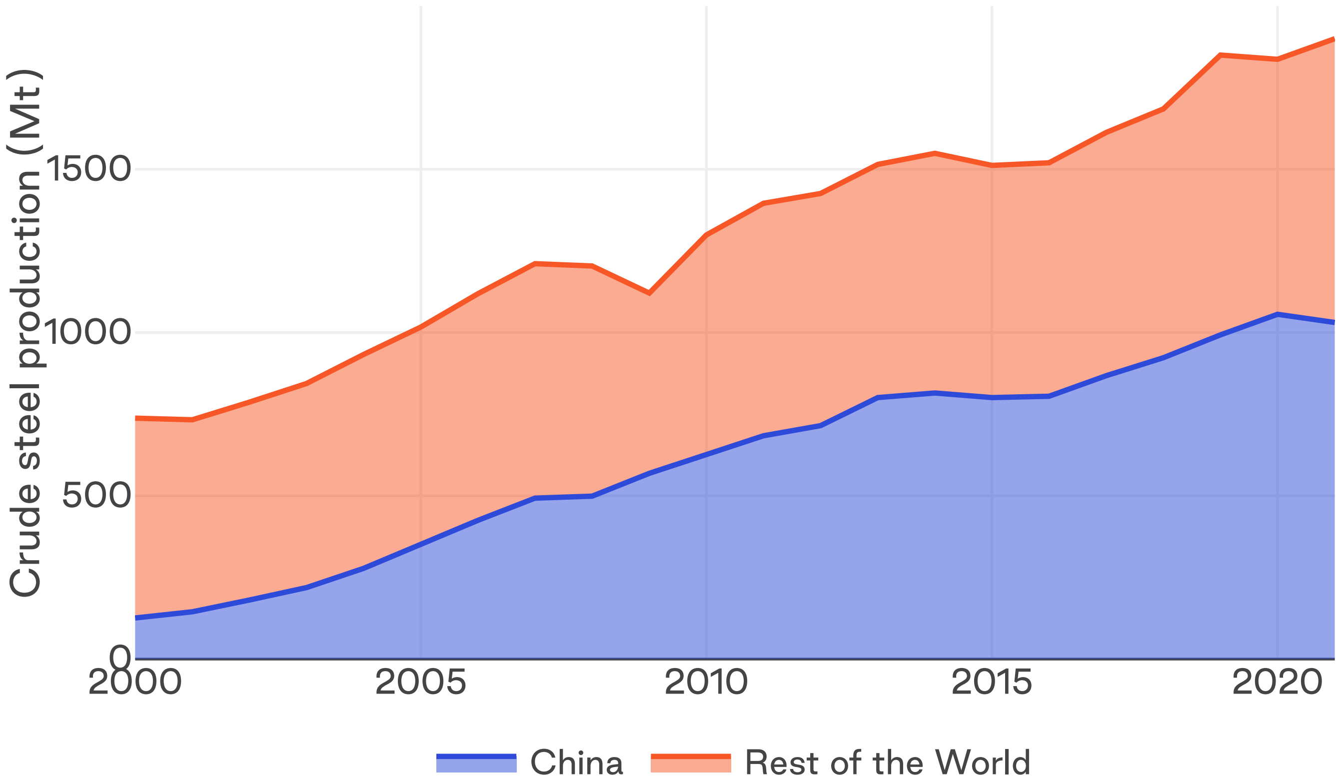
1 Trade exposed is defined as "Industries that are constrained in their ability to pass through carbon costs due to actual or potential international competition". This usually means that the industries are exporters, or they compete with imports (Australian government, 2008).
2 Accounting for both scraped-based EAF and direct reduced iron (DRI) EAF.

03 Steel production, trade and GHG emissions

Global steel industry production and trade

World steel production has more than doubled between 2000 and 2021 (Figure 2). In 2021, China accounted for 54% of global steel production, rising from 15% in 2000. The 2008 drop in world steel production was because of the global financial crisis. The 2014 decline was mainly caused by a slowdown in the Chinese economy and chronic overcapacity, which resulted in shutting down illegal induction furnaces and old steel plants in China. In 2020, the global crude steel production decreased by about 1% because of the global COVID-19 pandemic.

Figure 2. Crude steel production in China and rest of the world, 2000–2021

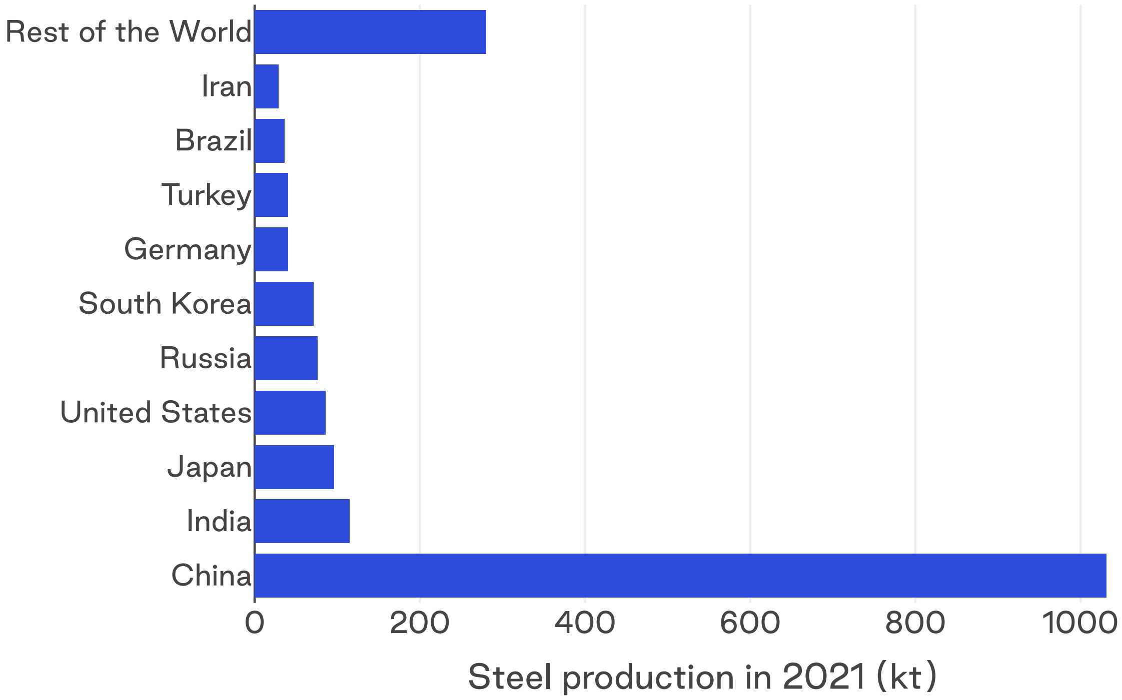


Source: Worldsteel (2021)

In 2020, blast furnace (BF) and basic oxygen furnace (BOF) production accounted for approximately 72% of the steel manufactured worldwide, and electric arc furnace (EAF) production accounted for approximately 28% of global steel production (Worldsteel 2021).

Figure 3 shows the top 10 steel producing countries in the world. In 2021, these top 10 producing countries accounted for 85% of world steel production (Worldsteel 2021).

Figure 3. Top 10 steel producing countries in 2021



Source: Worldsteel (2021), TransitionZero

Top 20 exporting countries account for over 90% of total world steel exports. According to Worldsteel (2021), Russia, Japan, South Korea, Ukraine and China are the top five net exporters (export minus import) and US, Thailand, EU, Philippines, and Vietnam are the top five net importers (import minus export) of steel in 2020. The significant global trade of such a carbon-intensive commodity has substantial implications for the embodied carbon in traded steel as shown in our recent study (Hasanbeigi et al. 2018). This embodied carbon in traded steel often is not accounted for in national and international carbon accounting and climate policies.

Table 1. Top 10 net exporters and importers of steel in 2020 (Worldsteel 2021)

Rank	Net exports (exports – imports)	Mt
1	Russia	26.4
2	Japan	24.8
3	South Korea	16.1
4	Ukraine	13.9
5	China	13.5
6	India	12.1
7	Brazil	8.7
8	Turkey	6.0
9	Egypt	4.2
10	Germany[4]	3.0

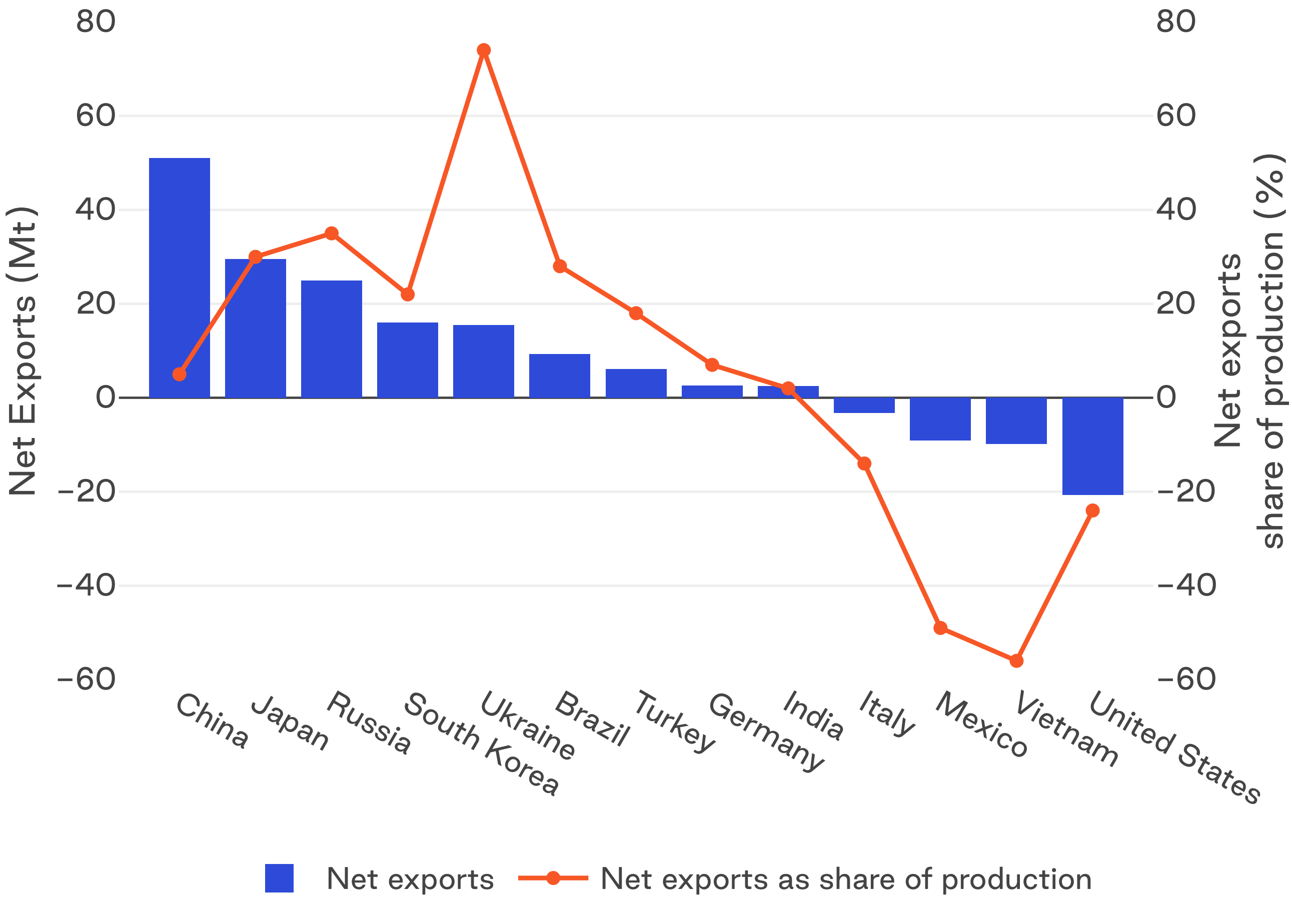
Rank	Net imports (imports – exports)	Mt
1	United States	13.6
2	Thailand	11.9
3	European Union (28)[5]	6.6
4	Philipines	6.0
5	Vietnam	6.0
6	Saudi Arabia	5.7
7	Poland	5.6
8	Mexico	4.5
9	Indonesia	4.2
10	Israel	3.3

Source: Worldsteel (2021)

4 Data for individual European Union (28) countries include intra-European trade
5 Excluding intra-regional trade

Figure 4 highlights the variability in the share of production to net export in the major steel crude producers. While China is undoubtedly the largest steel exporter, Chinese net-steel exports account for only 5% of its total crude steel production. Ukraine, the fifth largest exporter of crude steel, exported 74% of the crude steel produced nationally in 2019. Other big exports include Russia (35% of net exports as share of production), Japan (30%) and South Korea (22%). At the other end of the spectrum, the U.S, Vietnam and Mexico, while being among the top 15 crude steel producers, are also the biggest net importers of steel with net-imports as share of production amounting to 24%, 56% and 49% respectively.

Figure 4: Net exports of major steel producers versus net exports as share of total production

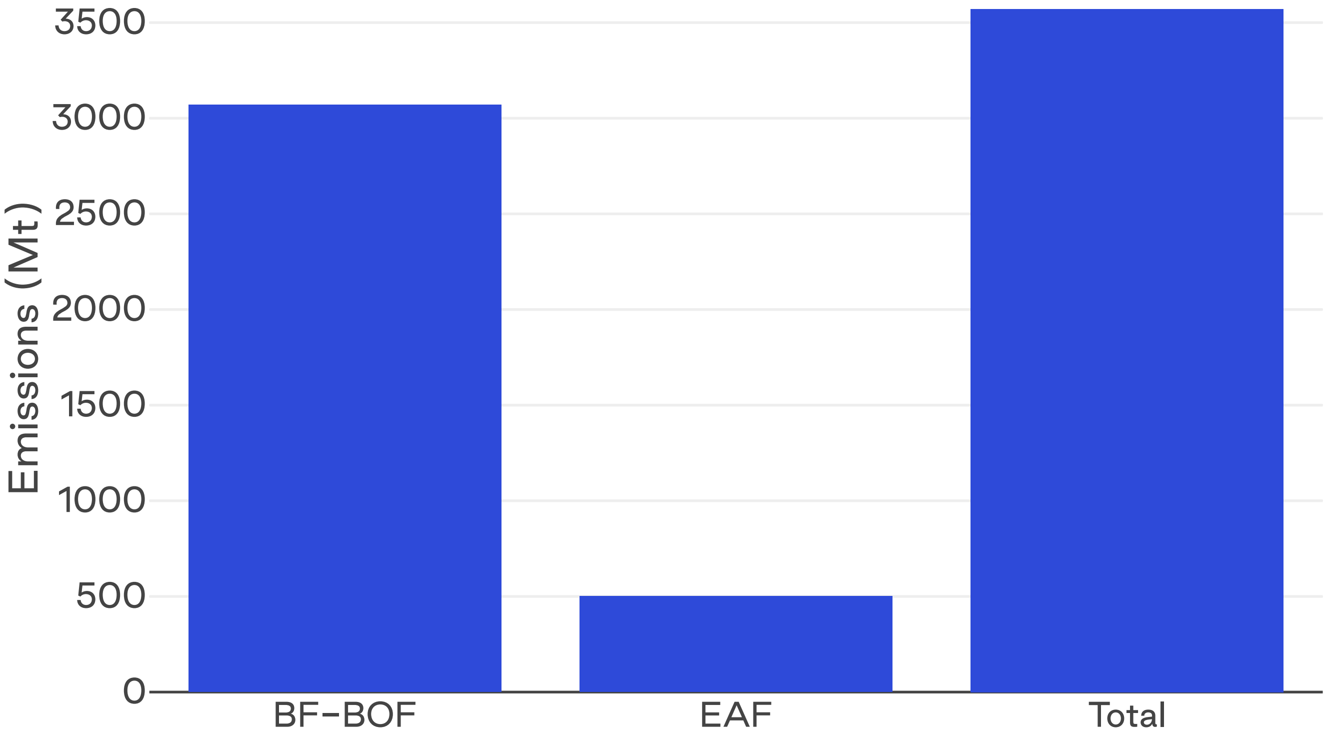


Source: Worldsteel (2021)
Note: Negative net export values correspond to net imports, while negative share of production corresponds to the percentage of net imports from total steel production.

Global steel industry GHG emissions

The global steel industry emitted around 3.6 gigatonnes of CO_2 (Gt CO_2) emissions in 2019 (Figure 5) (Hasanbeigi 2022). Global BF-BOF steel production emitted around 3.1 Gt CO_2 and global EAF steel production emitted around 0.5 Gt CO_2 in 2019. EAFs in China and India extensively use pig iron or coal-based direct reduced iron (DRI) as feedstock instead of steel scrap, creating higher than usual carbon intensities for EAFs and causing an increase in global EAF's CO_2 emissions.

Figure 5: Global steel industry's CO_2 emissions in 2019 by process type



Source: Hasanbeigi (2022)

Based on total steel industry emissions presented above and the global GHG emissions of 52 Gt CO_2 in 2019 (includes all GHG, not just carbon) reported in UNEP (2020) the global steel industry accounts for around 7% of total global GHG emissions. When considering only CO_2 emissions, steel accounts for 11% of the global total (based on 2019 global carbon emissions of 33 Gt carbon, as reported by IEA).

It is worth highlighting that only the annual GHG emissions of China and the U.S. are higher than annual GHG emissions of the global steel industry. In other words, if global steel production was a country, it would be the third biggest emitter in the world.

04 Global steel production costs

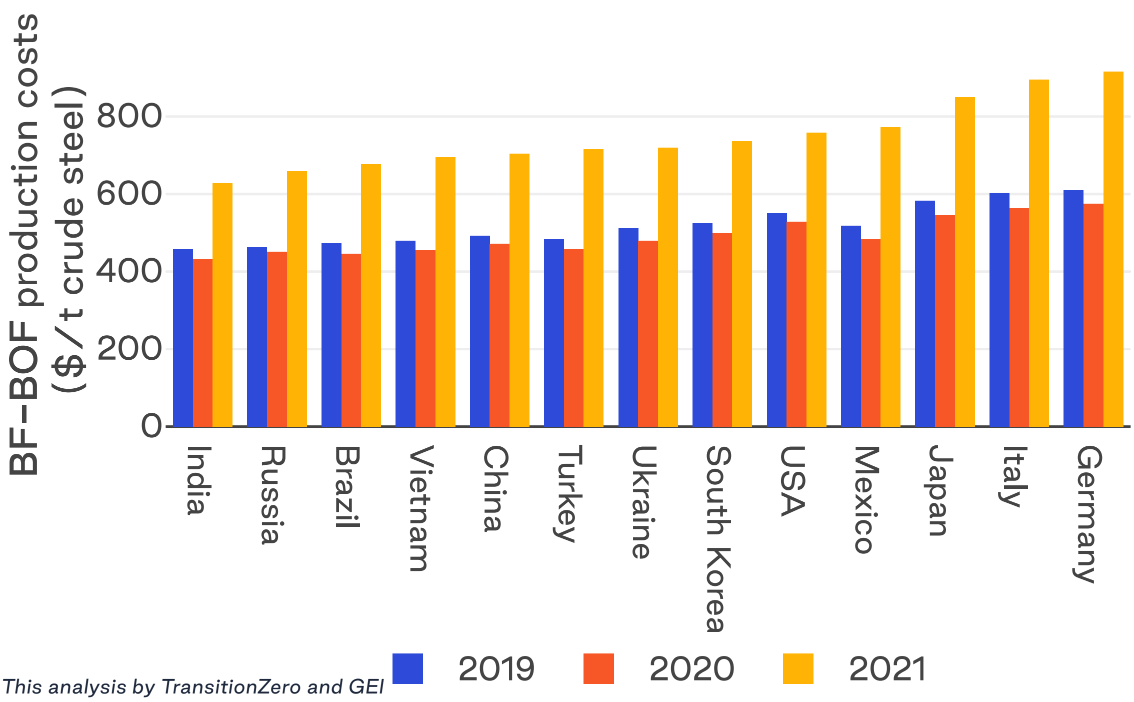
In the following subsections, we present the results of our analysis and estimates for country-level and plant-level steel production costs in major steel producing countries. The cost results are shown for both primary steelmaking using blast furnace and basic oxygen furnace (BF-BOF) and secondary steelmaking using electric arc furnace (EAF), separately for each country. The results of a sensitivity analysis with regards to the impact of a variation in key inputs to these production costs is also available in the following subsection.

Country-level steel production costs

BF-BOF steel production costs

The total production costs by country for the BF-BOF production route over the past three years is represented in Figure 6. According to our analysis and focusing first on 2019, advanced economies[6], among the steel producing countries studied, have the highest production costs. India, Russia and Brazil have the lowest production costs among the countries, while China, the largest BF-BOF steel producer in the world, has the sixth cheapest production costs in that year, slightly below the 500 USD/t mark.

Figure 6: BF-BOF steel production costs in different countries, 2019-2021



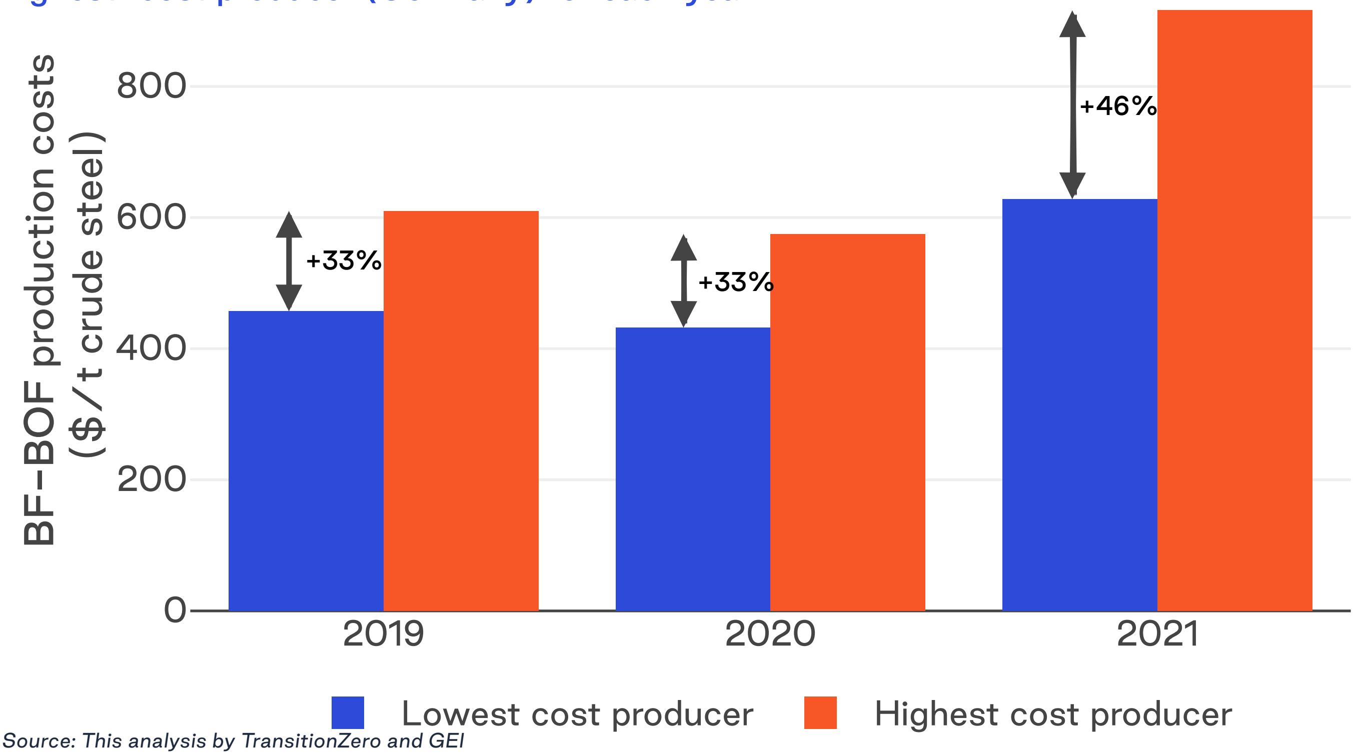
Source: This analysis by TransitionZero and GEI

6 Namely Japan, South Korea, US, Italy and Germany

While the COVID-19 pandemic affected the steel industry in 2020, production costs for the BF-BOF route dropped slightly in most countries (-5% on average compared to the previous year), with the US and Russia showing marginal year-on-year changes in costs (-4% and -3% respectively).

On the other hand, all countries saw their production costs dramatically increase in 2021, driven by the surge of commodity prices (more details in the Cost breakdown structure subsection), with an average of 51% year-on-year increase estimated across the selected countries. Most notably, the gap between the lowest-cost steel producer (India) and the highest-cost steel producer (Germany) also increased, widening from 33% in 2019, to 46% in 2021 (Figure 7).

Figure 7: BF-BOF steel production costs for the lowest-cost producer (India) and highest-cost producer (Germany) for each year



Source: This analysis by TransitionZero and GEI

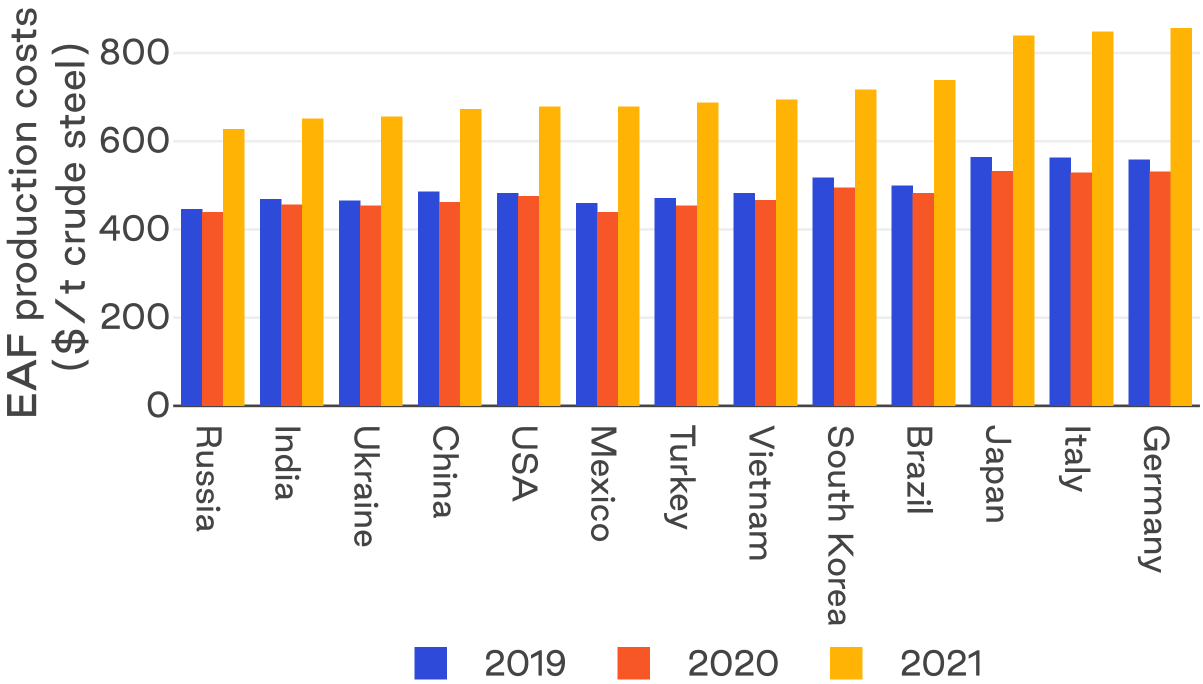
However, it should be noted that the steel production costs at a given plant might be substantially different from the average steel production costs we have estimated for that country here. There are various reasons for this, the main one being that companies and plants may have long-term contracts for their supply of raw materials and energy, which will protect them from short-term sudden price fluctuations like the one we observed in 2021[7].

EAF steel production costs

Similarly, the total production costs by country for the EAF production route over the past three years are represented in Figure 8. According to our estimates, in 2019, Russia has the lowest EAF production costs among the major steel producing countries studied, while advanced economies in Asia and Europe have the highest costs. China and the US have similar EAF production costs and are both in the middle of the pack in 2019.

7 While historically the main procurement modes of raw materials for steel producers were relying on captive plants or through long-term contracts, spot trading has established it-self a third mass-procurement system in recent years (Tanaka et al. 2016).

Figure 8: EAF steel production costs in different countries, 2019–2021



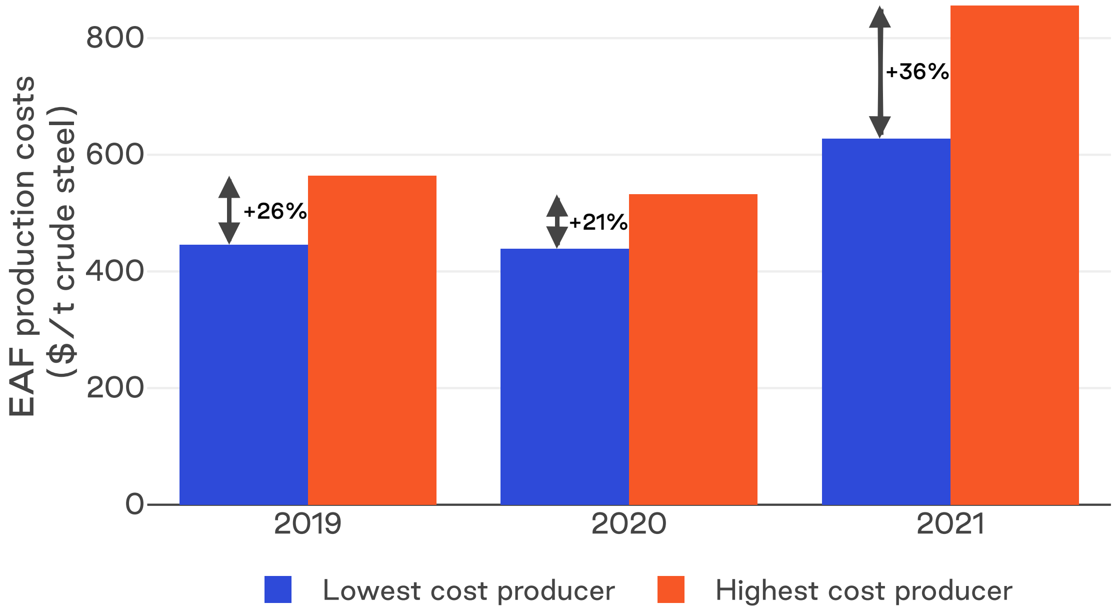
Source: This analysis by TransitionZero and GEI

Similarly to the BF-BOF costs, EAF steel production in all countries saw lower production costs in 2020, dropping 4% year-on-year on average across the selected geographies. The sharpest declines were in Italy and Japan (-6% year-on-year), while the US and Russia saw marginal drops in their production costs over the year (-1% and -2% respectively).

The rise in raw material and energy prices in 2021 had a dramatic impact on the EAF production costs in that year across all geographies, jumping 50% year-on-year on average. Germany and Italy are the most impacted countries, where production costs increased by 61% and 60% respectively, while the US and India experienced the smallest increase among the selected countries, with 42% and 43% year-on-year jumps, respectively.

The gap between the lowest and highest cost producers of EAF steel is slightly narrower, compared to their BF-BOF steel production costs (Figure 9). After a contraction in 2020 to a 21% price difference, the gap widened to 36% in 2021, suggesting again the higher sensitivity to variations in raw materials and energy prices of the highest cost producers.

Figure 9: EAF steel production costs for the lowest and highest steel producer for each year

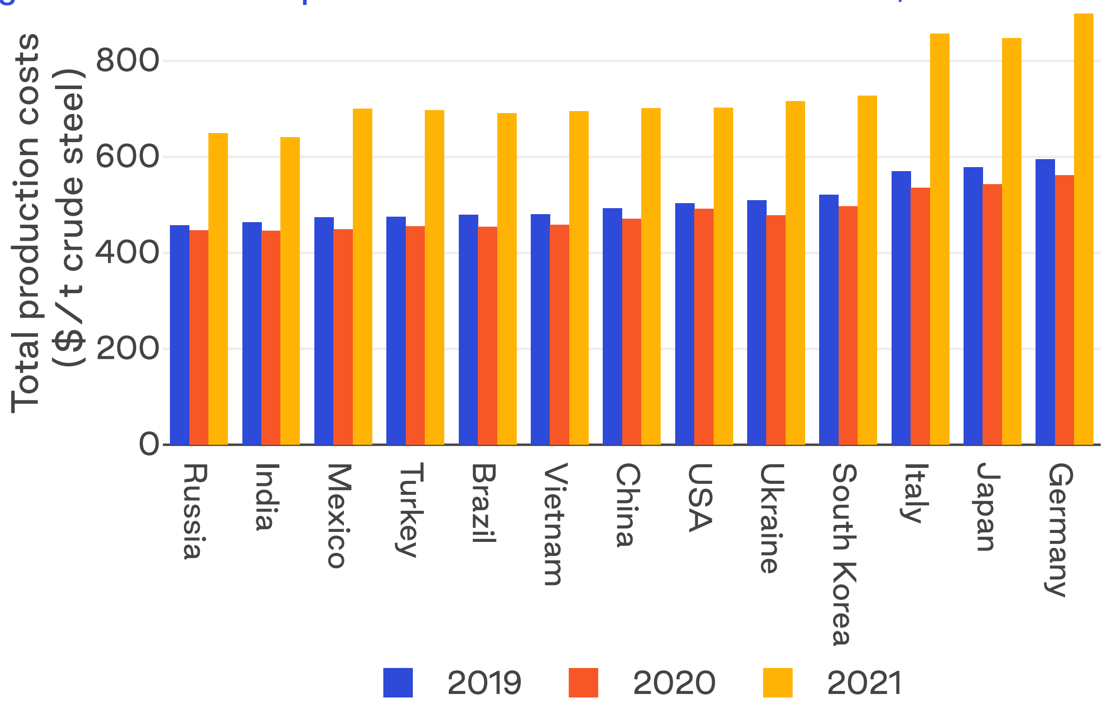


Source: This analysis by TransitionZero and GEI
Note: Lowest cost producer for each year: Russia 2019 to 2021 / Highest cost producer for each year: Japan (2019, 2020) and Germany (2021).

Total steel industry production costs

Figure 10 compares the average costs of total steel produced in each country over the past three years, by taking a weighted average (weighted by production) of BF/BOF and EAF costs. Russia and India have the lowest production costs among the selected countries, and have managed to maintain their competitiveness throughout the years. China and the US have production costs within the lower half of the selected countries, with China showing slightly more competitiveness than the US in 2021 (in a context of high commodity prices). At the other end of the spectrum, Japan, Germany and Italy have the highest average costs of total steel produced among the selected countries over all the years observed.

Figure 10: Total steel production costs in different countries, 2019–2021



Source: This analysis by TransitionZero and GEI

Cost breakdown structure

Figure 11 to Figure 14 give the breakdown of the production costs in 2021 for the selected countries, split between raw materials, energy, labour and "other costs".

We have the following findings for the BF-BOF production route in 2021 (Figure 11 and Figure 12):

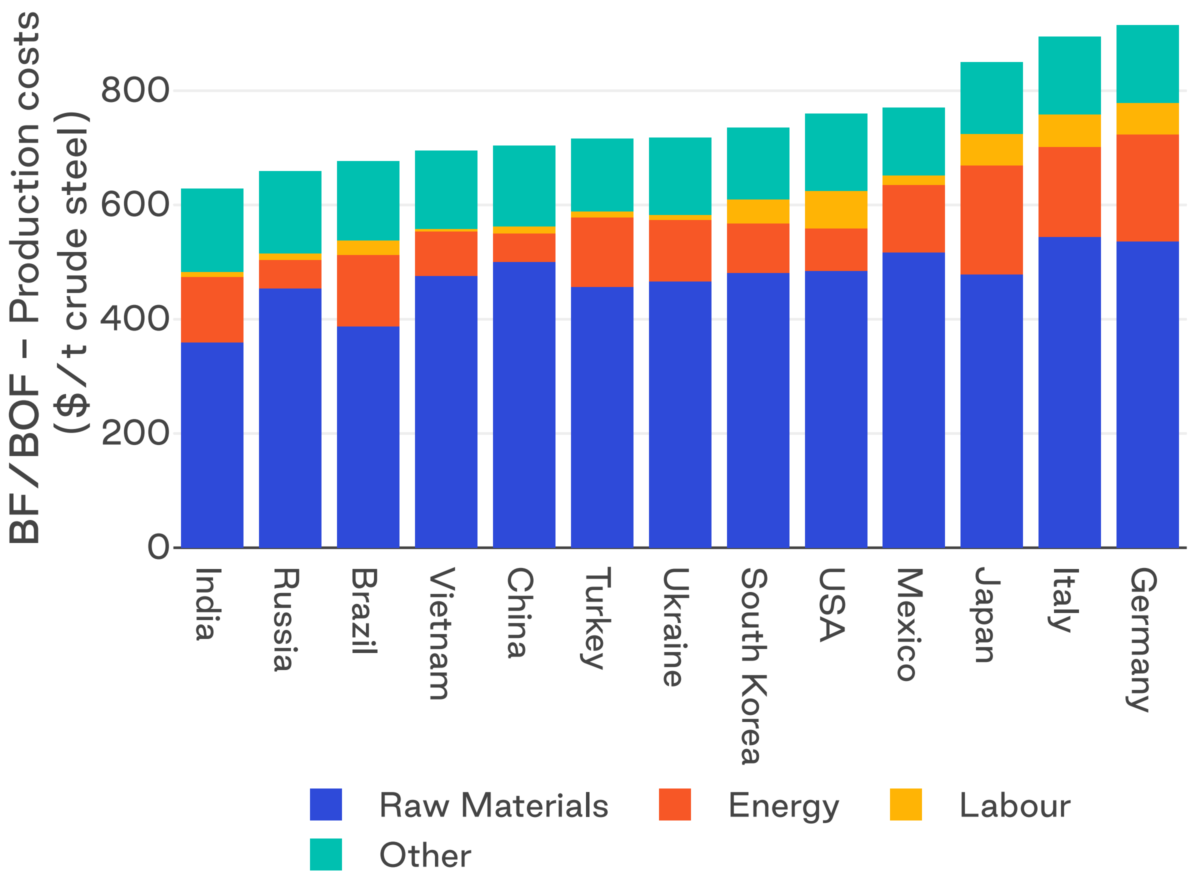
- The raw materials category (e.g. iron ore) represents the biggest share of the production costs across all countries. Most geographies have raw material prices above US$400/t in 2021, with the notable exception of India and Brazil. This represents a share of price varying from 56% of the total cost in Japan, to 71% of the total in China.

- The "other costs" category (refer to Appendix 2. Cost components for a description of other costs) represents the second biggest cost component in multiple countries, with a share of the total costs varying between 15% in Germany to 23% in India.

- Energy costs show greater disparity among countries. Japan, Germany and Italy have the highest energy-related costs, while China and Russia, and to a certain extent the US. and Vietnam have the lowest energy-related costs.

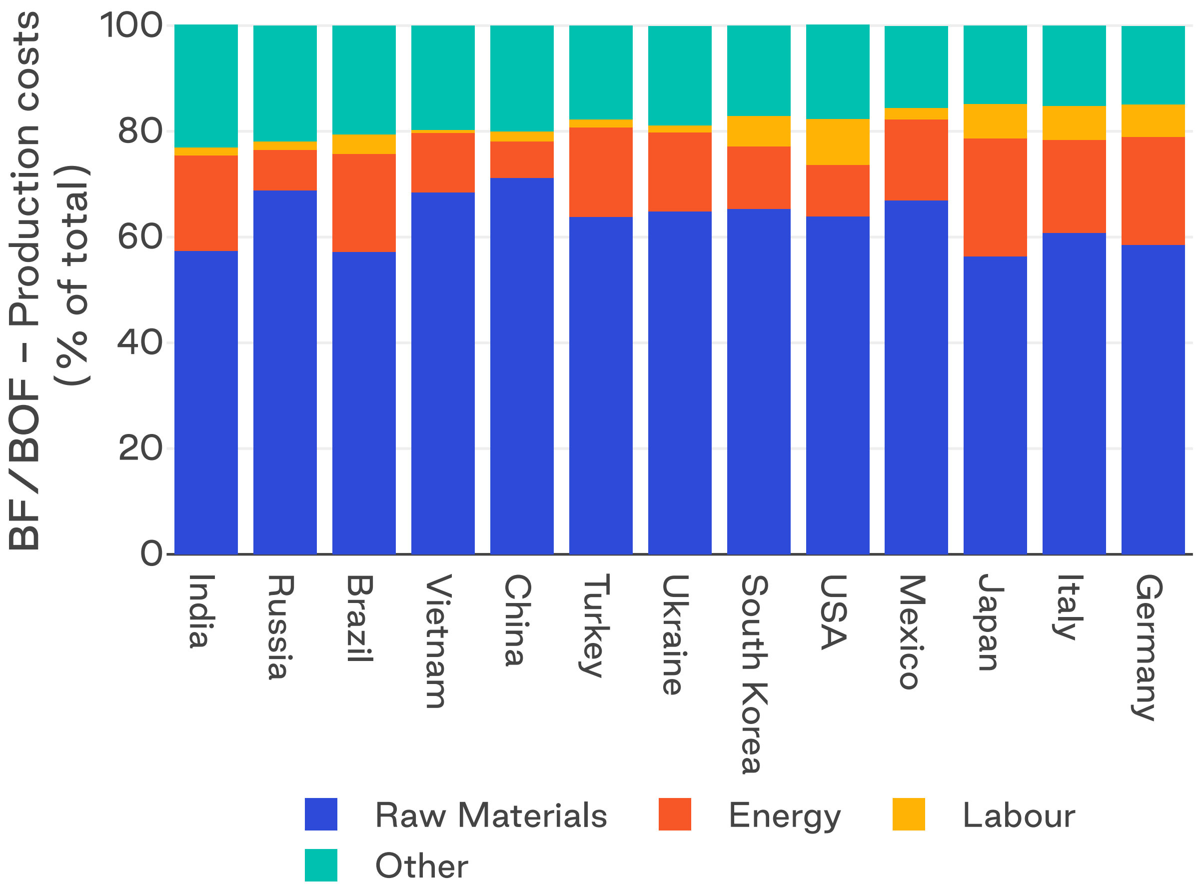
- Labour costs also show a greater disparity between countries, with higher values in developed nations as expected. Vietnam, Ukraine, and India all have labour costs below US$10/t crude steel, while China's labour costs stands at US$13/t crude steel according to our estimates.

Figure 11: Share of different cost components in BF-BOF steel production costs in different countries, 2021 (absolute values)



Source: This analysis by TransitionZero and GEI

Figure 12: Share of different cost components in BF-BOF steel production costs in different countries, 2021 (percentage of total)



Source: This analysis by TransitionZero and GEI

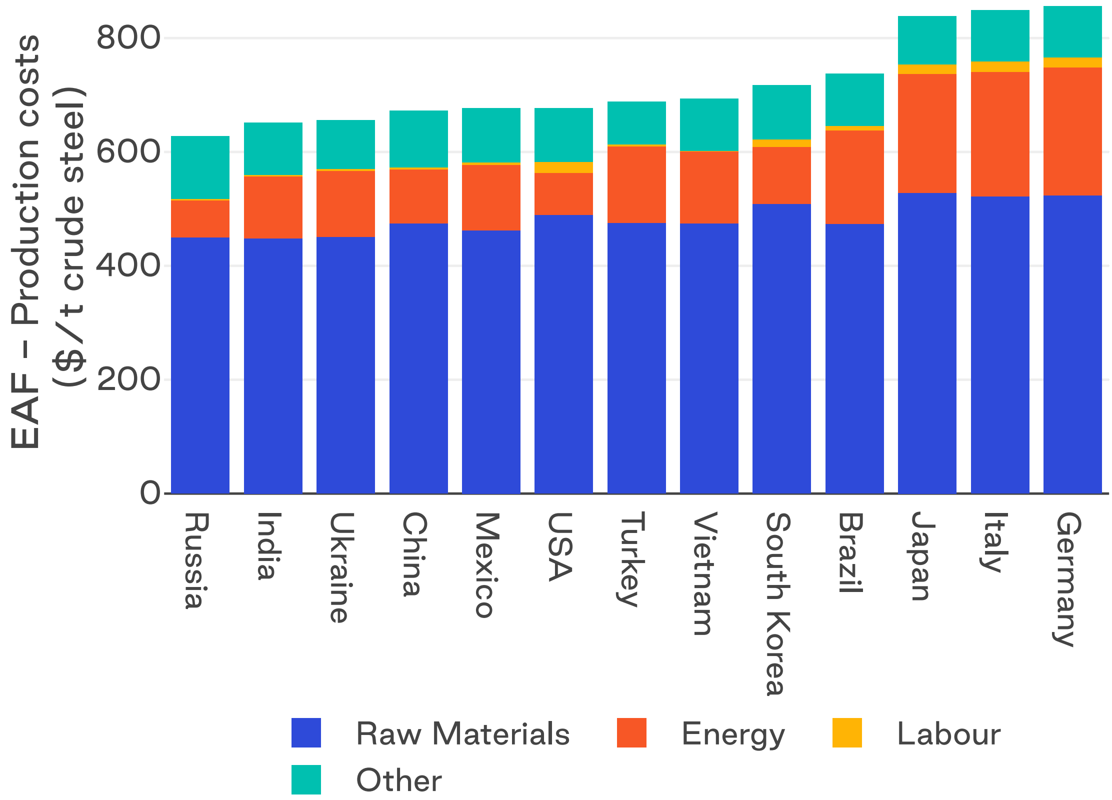
Furthermore, we have the following findings for the EAF production route in 2021 (Figure 13 and Figure 14):

- Similar to BF-BOF steelmaking costs results, the raw materials costs (e.g. scrap cost) also represents the largest share of the production costs of EAF steelmaking across all countries. Costs in this category fluctuate around US$475/t in 2021 across all countries, with India, Russia and Ukraine paying slightly below US$450/t for raw materials, while Japan, Germany and Italy pay above US$520/t.

- We observed the same dynamics in the energy costs as in the BF-BOF route, where EAF steelmaking in Japan, Germany and Italy have the highest energy-related costs, while the US and Russia have the lowest energy-related costs for EAF steelmaking.

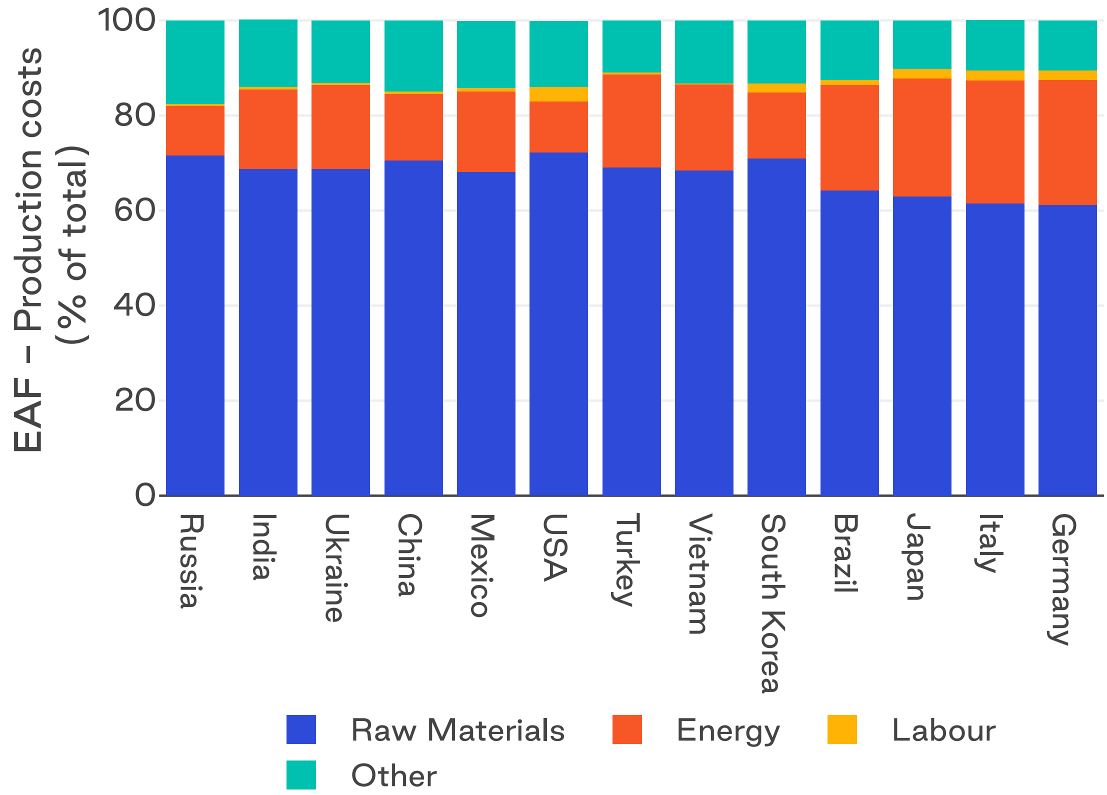
- Labour costs in EAF steelmaking are much smaller compared to BF-BOF plants, representing a small portion of the total EAF production costs across all countries, from less than 1% in Russia and India to 2% in European countries and 3% in the US.

Figure 13: Share of different cost components in EAF steel production costs in different countries, 2021 (absolute values)



Source: This analysis by TransitionZero and GEI

Figure 14: Share of different cost components in EAF steel production costs in different countries, 2021 (percentage of total)

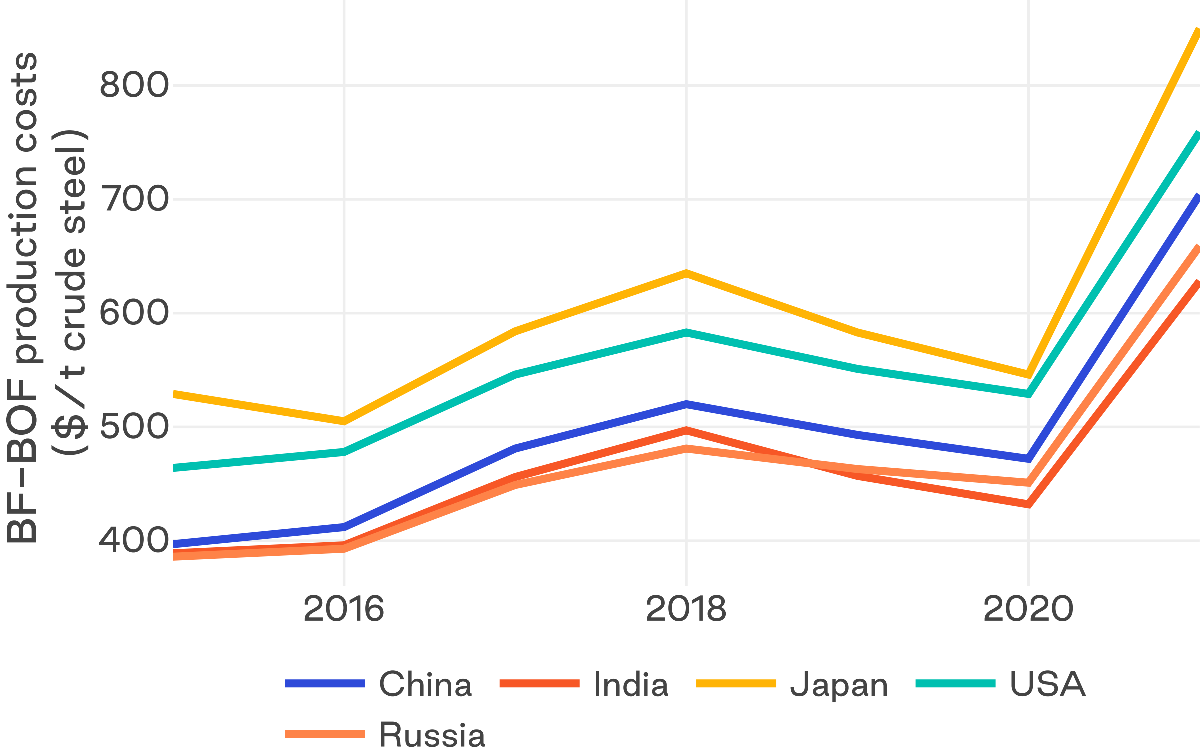


Source: This analysis by TransitionZero and GEI

Evolution of production costs

Figure 15 and Figure 16 show the evolution of the production costs in the top five steel producing countries between 2015 and 2021. For the BF-BOF route (Figure 15), Russia, India and China all have relatively lower production costs over the observed period, compared to the US. and Japan. While the costs of BF-BOF steelmaking in all countries show a mild upward trend from 2015 to 2020 (+3% on average year-on-year), the 2021 price surge appears even more dramatic because of the sudden substantial rise in raw materials and energy prices in 2021.

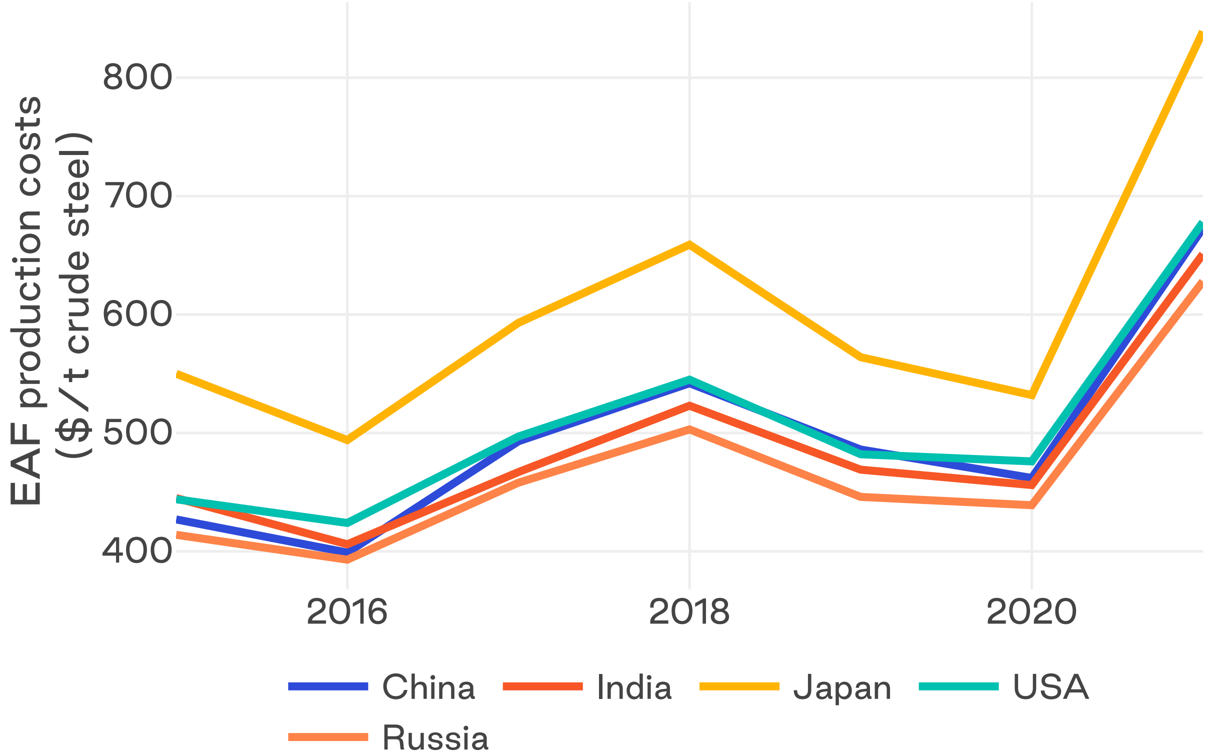
Figure 15: BF-BOF steel production costs in selected countries (top 5 steel producers), 2015-2021



Source: This analysis by TransitionZero and GEI

EAF steel production costs show similar trends across all the top five steel producing countries, with two pronounced downtrend periods (2016 and 2019-2020), interceding two uptrend periods (2017-2018 and 2021). The total production costs show a slight overall growth over the observed period, with an average increase of 2% year-on-year from 2015 to 2020, followed by the sharp increase in 2021 (+46% year-in-year). Japan's EAF steel production has the highest production costs, while Russia's EAF steel production appears to be the most competitive among the top five steel producers.

Figure 16: EAF steel production costs in selected countries (top five steel producers), 2015–2021.



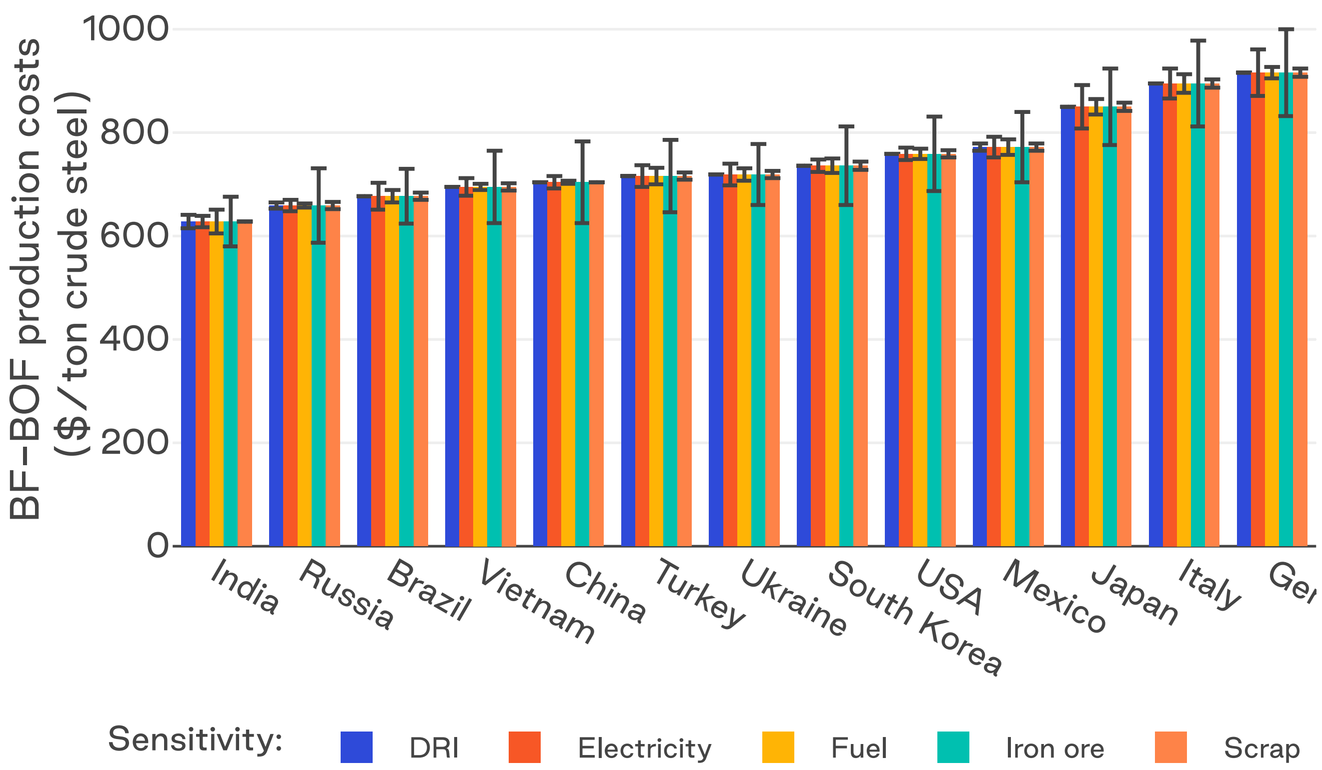
Source: This analysis by TransitionZero and GEI

Sensitivity Analysis

Figure 17 and Figure 18 show the results of a sensitivity analysis of a 30% increase/ decrease of key input prices to total crude steel production costs by country and steel production process type.

For the BF/BOF production route (Figure 17), all countries' estimates are highly sensitive to a variation in iron ore prices, where a 30% change in iron ore prices (both increase and decrease) translates to changes between 8% (Brazil) and 11% (China) in total BF/ BOF production costs across the selected countries. Similarly, a 30% change in electricity prices translates to an average 3% change in total BF/BOF production costs, while the same change in fuel prices leads to an average 2% change in BF/BOF production costs. Overall, sensitivity to changes in key input prices is relatively higher in Germany, Japan and Turkey (where a 30% change across all input prices[8] translates into a 16% change in BF/ BOF production cost estimates) and relatively lower in China and the US (30% change across all input prices translates into a 13% change in production cost estimates).

Figure 17: Sensitivity of steel production costs to 30% lower and higher prices for key inputs to BF/BOF steel production in 2021

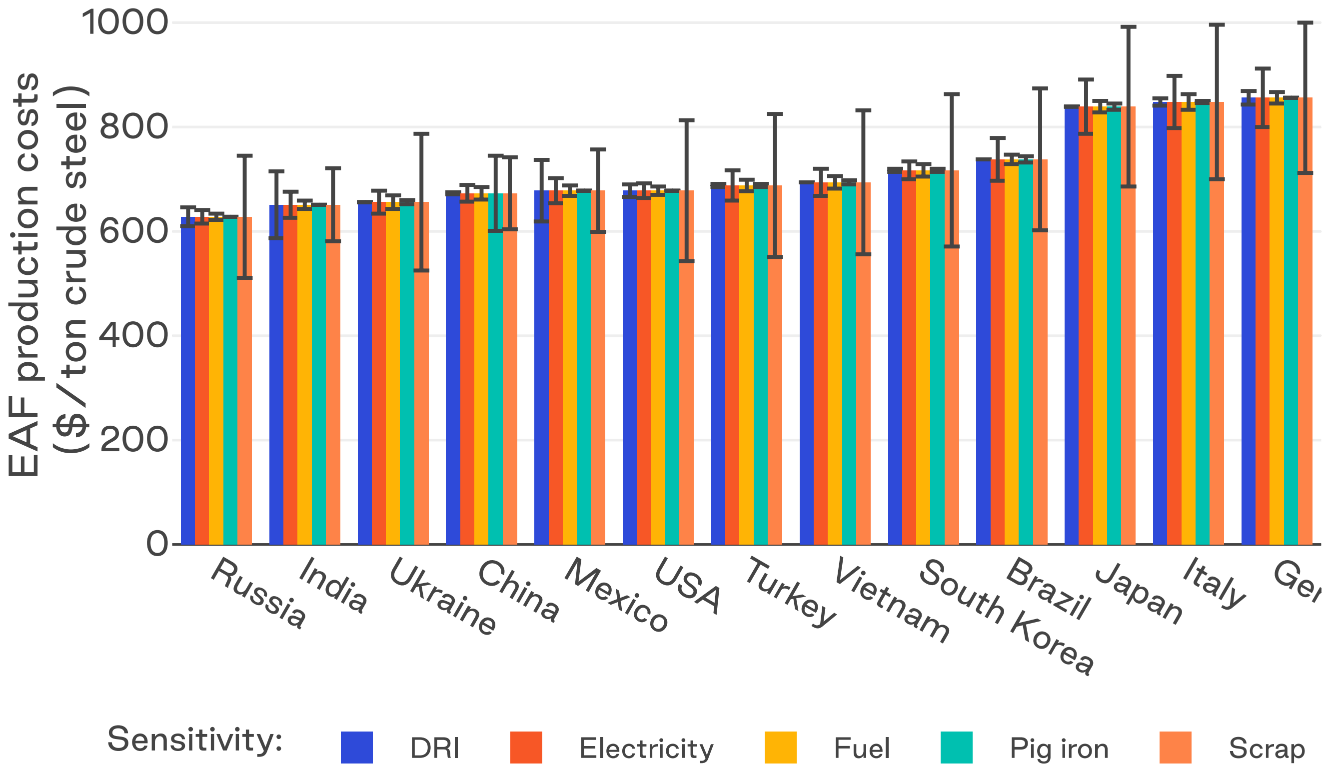


Source: This analysis by TransitionZero and GEI

For the EAF production route (Figure 18), scrap prices are the most sensitive components affecting the total production cost estimates, where a 30% change in prices translates to a change between 10% (China) to 20% (Vietnam) in total EAF production cost estimates. Our estimates for China, contrarily to other countries, are also highly sensitive to pig iron prices (30% change of pig iron prices resulting in a 10% change in production costs). Sensitivity to the rest of the major inputs are relatively lower, where a 30% change in electricity, fuel or DRI prices translate to less than 2% change in estimated total EAF production costs across all countries. Finally, and as opposed to BF/BOF estimates, a 30% change in all input prices leads to an average change in total EAF production costs of 26% across the selected countries (from 25% in the US to 27% in Turkey).

8 Change in all input prices in the same direction (all prices increasing or all prices decreasing).

Figure 18: Sensitivity of steel production costs to 30% lower and higher prices for key inputs to EAF steel production in 2021



Source: This analysis by TransitionZero and GEI

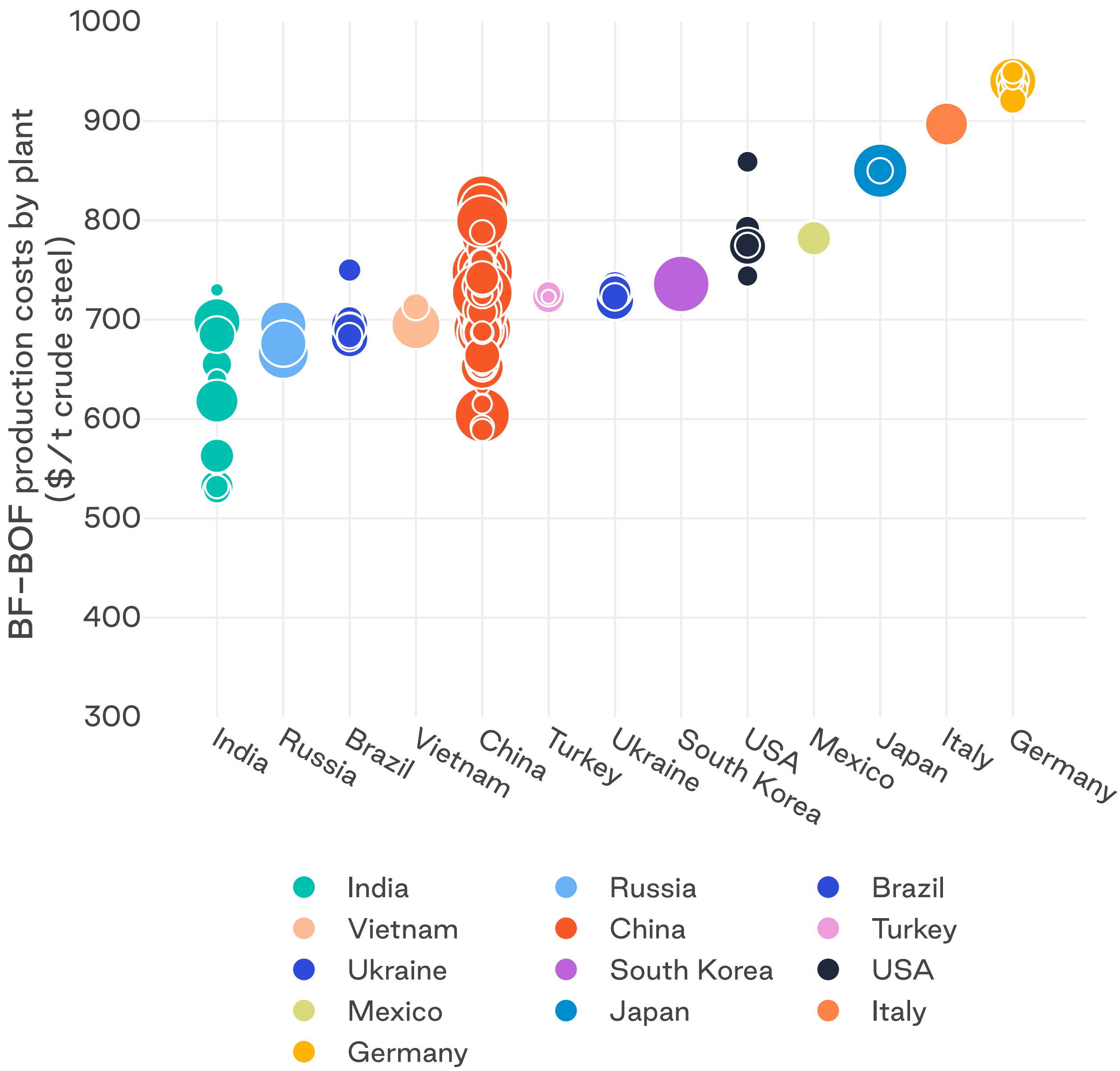
Plant-level steel production costs

The plant-level production costs help quantify the level of cost disparity within countries, when considering local electricity and fuel prices and labour costs, and proximity to mines and import terminals. For more details on the methodology on these plant-level estimates, refer to Appendix 3.

Figure 19 shows the plant-level BF-BOF steel production costs in different countries in 2021. In most countries, national steel plants operate at very similar production costs, with a cost difference of less than US$30/t. The notable exceptions are the US, China and India, where we see high national cost disparities (up to US$110/t cost difference in the US, US$200/t in India and US$230/t in China). This is mainly driven by higher heterogeneity in regional electricity and fuel prices, compounded with higher transportation costs due to larger distances between steel mills and raw material sources.

While China has some of the most cost-competitive BF-BOF steel plants among the selected countries, with estimated costs below US$600/t crude steel for some plants in 2021, some Chinese steel plants have production costs on-par or higher than their counterparts in developed economies such as in the US and South Korea.

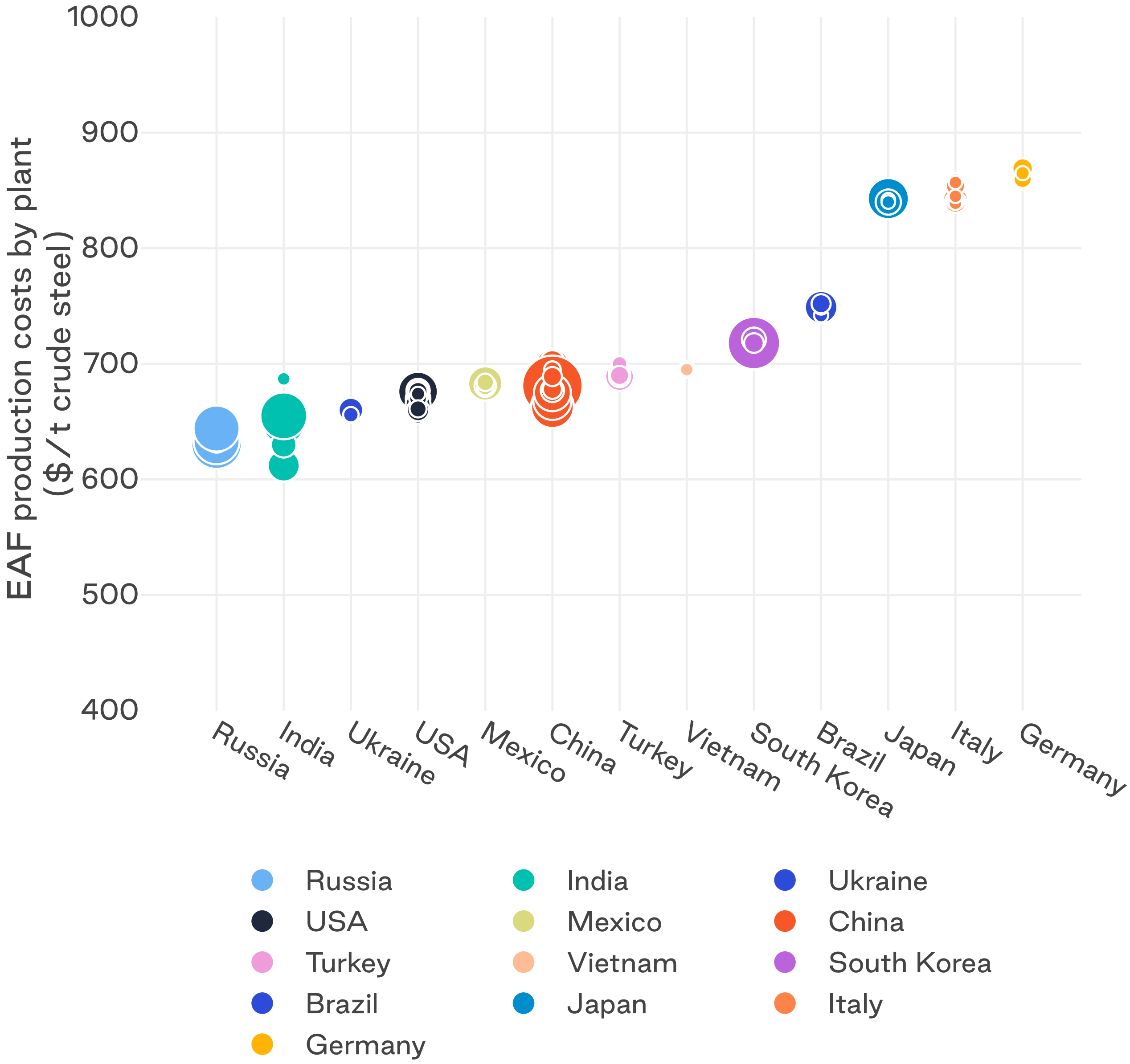
Figure 19: Plant-level BF-BOF steel production costs in different countries in 2021



Source: This analysis by TransitionZero and GEI
Note: Each dot represents a plant, while the size of the dot is proportional to the plant's installed capacity.

Figure 20 shows the plant-level EAF steel production costs in a variety of countries in 2021. Similar to BF/BOF plants, EAF plants within the same country operate at relatively similar costs range, with the exception of India's EAF mills where the price range can vary by up to US$100/t crude steel between the highest and lowest producers. All EAF plants in the top three highest-cost EAF producing countries (Japan, Italy and Germany), have production costs at least 16% higher than the next highest producer in the other countries.

Figure 20: Plant-level EAF steel production costs in different countries in 2021



Source: This analysis by TransitionZero and GEI
Note: Each dot represents a plant, while the size of the dot is proportional to the plant's installed capacity.

05 Conclusion

Our analysis is carried out both at the country-level and plant-level, and showcases yearly production costs between 2019 to 2021, broken down by the major cost component of the steel production, namely raw materials, energy, labour, and "other costs".

When considering BF-BOF steel production costs, raw materials (e.g. iron ore) are the largest expense item, ranging between 52% to 67% of the total cost in the countries studied. India and Russia are the most cost-competitive countries, while Japan, Germany and Italy have the highest costs for BF-BOF steel production over the observed time period. Production costs remained relatively unchanged in 2020, in the wake of the pandemic, but the surge in commodity prices in 2021 impacted all steel producers with the average production costs increasing by 28% year-on-year. In addition, the gap between the lowest-cost steel producer (India) and the highest-cost steel producer (Germany) also increased, widening from 33% in 2019, to 46% in 2021.

For EAF steel production costs, raw materials (e.g. scrap) also account for 61% to 72% of the total production costs, followed by energy-related costs, which range from 10% to 26% of the total EAF steel production cost. Russia has the lowest EAF steel production cost among the major steel producing countries studied, while advanced economies in Asia and Europe have the highest costs over the observed period. EAF steel in all countries saw a slightly lower production costs in 2020, dropping 4% year-on-year on average across the selected geographies, but the surge in raw material and energy prices in 2021 had a dramatic impact on the EAF production costs in that year across all geographies, jumping 50% year-on-year on average.

Looking at total steel industry production, China, the largest steel producer in the world, has the sixth cheapest steel production costs in 2019, and shows even greater competitiveness in 2021 (in a context of high commodity prices), having the third-lowest production cost that year according to our estimates.

This analysis aims to improve the understanding of the regional variations in costs of producing steel in this energy and carbon-intensive sector. This work could serve as a baseline for future studies that aim to tackle the challenges in profiling the costs of transitioning current steel production assets into low-carbon assets in line with net zero by 2050. Transitioning global steel assets to net-zero compatible technologies requires significant financing, a topic we aim to tackle in the future.

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07 Appendices

Appendix 1. Methodology for estimating country-level and plant-level production costs

A.1. General overview

We developed a model to estimate the production costs of steel with the following level of detail:

- Each processing route is modelled separately:
  - Primary steelmaking using blast furnace-basic oxygen furnace (BF-BOF)
  - Secondary steelmaking using electric arc furnace (EAF)
- The granularity of the model is broken down by major components for each process route (refer to the A.2. Cost components section for more details)
- We provide two levels of geographical resolution:
  - A baseline is built at the country level (covering 13 of the major steel producing countries, accounting for ~90% of world steel production)
  - Plant-level steel production costs which are derived from country-level results and calibration of those costs (refer to the first part of the A.3. Spatial and temporal refinement subsection for more details)
- The temporal resolution of the modelled costs is on a yearly basis. First, a baseline is constructed gathering data for the year 2019. Other yearly estimates are then derived from this baseline using available data for 2015 to 2021 (refer to the second part of the A.3. Spatial and temporal refinement subsection for more details)

A.2. Cost components

The components of the cost model are separated into four major categories:

- Raw materials cost: all major raw materials used for any of the two main processing routes considered, including iron ore, scrap, pig iron and direct reduced iron. However, some supplementary raw materials are not considered in this study explicitly and rather are bundled into "other cost" category (refer to Table A.1 to see which raw material is taken into account for each steel production route under raw material cost).
- Energy cost: split between electricity and fuel. The fuel component includes energy and heat created from charcoal, coal, fuel oil, liquefied petroleum gases (LPGs) and natural gas.
- Labour cost: the cost of labour for the steel industry in each country is considered in this study.
- Other costs: include purchased oxygen and inert gases (argon), electrodes, refractories, limestone, other fluxes, oils and acids used in rolling and finishing, and overhead costs. Only overhead costs have been modelled separately, the rest of the listed components were bundled together in a single estimate by country.

Table A.1. Steel production cost components used in this analysis

Cost Component	Description
Raw materials	
Iron ore	A compound of iron, oxygen and other minerals that occurs in nature.
Scrap	Steel that has reached the end of its useful life or has been generated during the manufacture of steel products. It is used in every steelmaking process.
DRI	Also called sponge iron, it is produced from the direct reduction of iron ore into iron by a reducing gas or elemental carbon produced from natural gas or coal.
Pig iron	Pig iron, also known as crude iron, is an intermediate product of the iron industry in the production of steel which is obtained by smelting iron ore in a blast furnace.
Energy	
Fuel	All fuels used in the steel making process either in the blast furnace or in the different converters, including charcoal, coal, coke, fuel oil, liquefied petroleum gases (LPGs) and natural gas.
Electricity	Energy input for every steelmaking process (around 7% for BF/BOF and up to 50% for EAF). Also used in rolling mills and motors.
Labour	Labour is a function of the number of operators per shift required for each process, the productivity of the country and the hourly rates. Labour costs are relatively small in the steel industry, since the processes are generally capital-intensive rather than labour-intensive.
Other costs	
Overhead	Overhead expenses include accounting fees, advertising, insurance, interest, legal fees, labour burden, rent, repairs, supplies, taxes and utilities.
Other costs	Fluxes and other consumables, including oxygen, electrodes, refractories, limestone, inert gases (argon) and oils and acids used in rolling and finishing.

For each cost component, we gathered the relevant prices (domestic and/or international when relevant) in US dollars per unit of commodity of choice (for instance US$/MWh for electricity or US$/tonnes for coal). In the case of an internationally traded commodity, we compute the weighted average price for each country, based on the national production and import volumes of such a commodity. We also computed the estimated amount of commodity required/consumed to produce one tonne of steel.

These estimates are country-specific and rely on publicly reported information and experts' judgment. Refer to the specific following subsections for each cost component for more details on the methodology behind these estimates.

Raw materials costs:

All data gathered to build the steel production cost baselines are using the country-level granularity and the year 2019 as a reference year. For every raw material, Table A.2 contains details on:

- The data sources for the trade and production flows (when applicable)
- The data sources for the prices of the raw material (domestic and/or international when applicable)
- The data sources and relevant processing steps used to come up with estimates of the amount of raw material consumed to produce one tonne of steel

Table A.1. Steel production cost components used in this analysis

Raw material	Data type	Source	Comment
Crude steel	Production	Worldsteel (2020)	2019 country level data available in the publicly available concise version of the report. We also gather the split of the share of production by processing route (BF-BOF v.s. EAF)
Iron ore	Production	Worldsteel (2020)	2019 country-level data available in the publicly available concise version of the report.
	Export	Worldsteel (2020)	Restricted access to the subscribers only.
	Import	Worldsteel (2020)	Restricted access to the subscribers only.
	Consumption	Estimated	Derived from the mass balance equation. Specific share of iron ore consumed by each processing route estimated.
	Price	UNComtrade (2021)	As reported under commodity code "2601 - Iron ores and concentrates; including roasted iron pyrites". Import/Domestic prices are computed as the average of the import/export price, weighted by the quantity traded.
DRI	Production	Worldsteel (2020)	2019 country level data with free access to the concise version, restricted access to the full report.
	Export	Worldsteel (2020)	Restricted access to the subscribers only.
	Import	Worldsteel (2020)	Restricted access to the subscribers only.

Table A.1. Steel production cost components used in this analysis (continuation)

Raw material	Data type	Source	Comment
DRI	Price	UNComtrade (2021)	As reported under commodity code "7203 – Ferrous products obtained by direct reduction of iron ore and other spongy ferrous products, in lumps, pellets or the like; iron having a minimum purity of 99.94%, in lumps, pellets or similar forms". Import/Domestic prices are computed as the average of the import/export price, weighted by the quantity traded.
Pig iron	Production	Worldsteel (2020)	2019 country-level data available in the publicly available concise version of the report.
	Export	Worldsteel (2020)	Restricted access to the subscribers only.
	Import	Worldsteel (2020)	Restricted access to the subscribers only.
	Consumption	Estimated	Derived from the mass balance equation. Specific share of iron ore consumed by each processing route estimated.
	Price	UNComtrade (2021)	As reported under commodity code "7201 – Pig iron and spiegeleisen in pigs, blocks or other primary forms". Import/Domestic prices are computed as the average of the import/export price, weighted by the quantity traded.
Scrap	Export	Worldsteel (2020)	Restricted access to the subscribers only.
	Import	Worldsteel (2020)	Restricted access to the subscribers only.
	Consumption	Estimated	Derived from the mass balance equation. Specific share of iron ore consumed by each processing route estimated.
	Price	UNComtrade (2021)	As reported under commodity code "7204 – Ferrous waste and scrap; remelting scrap ingots of iron or steel". Import/Domestic prices are computed as the average of the import/export price, weighted by the quantity traded.

Energy costs:

The energy category is split between two major components:

- Electricity: electricity prices are gathered from the IEA's World Energy Prices database, filtered for industrial applications (when available).
- Fuels: we look at the individual prices of the different fuels used in a given country's steel industry, and compute the weighted average price using the quantity used in each country's steel industry (as specified by the IEA World Energy Statistics). The different fuels used include charcoal, coal, coke, fuel oil, liquefied petroleum gases (LPGs) and natural gas. The price of heat is computed as the average price of the other fuels.

The amount of electricity and fuel required to produce one tonne of steel (by processing route, by country) is gathered from Global Efficiency Intelligence's study (2021). Assumptions were made on the amount of captive power generation available in each country based on data from the US. steel industry and experts' judgment.

Labour costs:

Labour costs for each country and processing route is estimated based on the following components:

- Hourly wages in the steel industry in each country are derived from the US Bureau of Labour Statistics (BLS 2012), as well as OECD's Average annual wages dataset.
- The total workforce in the steel industry for some countries is gathered from available sources (aggregated by the Statista Research Department) and estimated for the missing countries based on the available data and expert 's judgment.

Other costs:

The "other costs" category is broken down in two different sub-categories:

- Overheads, depreciations and interest
- Fluxes and other consumables, including oxygen, electrodes, refractories, limestone, inert gases (argon) and oils and acids used in rolling and finishing

Each of these sub-categories have been estimated separately using relevant data reported in a study by the Centre for European Policy Studies (2013).

A.3. Spatial and temporal refinement

Using the baseline cost constructed at the country-level for each steel production route, using relevant data for the year 2019, we extend the geographical and temporal granularity of the cost estimates to derive facility-level production costs, for every year between 2015 to 2021.

Plant-level cost specifications:

The inventory of steel facilities we use is the Global Steel Plant Tracker gathered by Global Energy Monitor (2021), listing major steel producing plants along with several metadata of interest, including the plant name, owner, location (latitude/longitude), primary steel production equipment (categorized either BF-BOF or EAF), nominal crude steel capacity, plant age and plant status.

For each plant in the database, we adjusted each of the following country-level cost components to better reflect the local specificity of the plant:

- Raw materials prices are corrected by taking into account the transportation costs from the raw material production sites or import terminals to the selected steel plant. Given the lack of sufficient data regarding the sourcing of the materials for each plant, we assumed each plant is consuming raw materials both imported and sourced locally, by using the country-level statistics on production and imports of a given commodity (weighted average by tonnage).
    - The transportation costs rely on reported freight rates for China, India, the US, Italy and Germany.

- We also rely on a database of major mineral deposits by USGS for the location of the mines, as well as the reported location of major steel processing centers by ENF, and major ports location from Ember.

- Country level electricity and fuel prices are further refined using regional statistics when available:
  - For India, state level electricity and coal prices derived from the Central Electric Authority
  - For China, province level electricity, coal and natural gas prices provided by CREA
  - For the US, state level electricity, fuel oil, natural gas, LPG & NGL and coal prices provided
  - For Italy, electricity prices gathered from ENTSOE
  - For Brazil, regional electricity from EPE and regional coal prices from ABCM

A.4. Yearly costs updates

Several major components of the cost models are updated using time series data dating back to 2015 (until 2021, with partial data as of November). These components include:

- For raw materials:
  - Iron ore prices from FRED St. Louis
  - DRI prices from steelonthenet
  - Pig iron prices from steelonthenet
  - Scrap from LME
- For energy:
  - Natural Gas and Coal prices from IMF
  - Electricity from national power exchange data:
    - China, Fuel and Power from NBS portal
    - India, from the Press Information Bureau of India.
    - Germany from ENTSO day ahead prices
    - Italy from ENTSO day ahead prices
    - Japan from JEPX
    - Brazil from CCEE
    - South Korea from EPSIS
    - Russia from JSC ATS
    - USA from the EIA monthly electricity prices
    - Mexico from CENACE
    - Turkey from EPIAS

We converted each time series into an index (2019 average value equal to 100), before multiplying each baseline cost component by the corresponding index value to convert 2019 value into the desired yearly value.

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