Challenges for the European steel industry: Analysis, possible consequences and impacts on sustainable development

Stefan Vögele[a,*], Matthias Grajewski [b], Kristina Govorukha [c], Dirk Rübbelke [d]

[a] Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research - Systems Analysis and Technology Evaluation (IEK-STE), D-52425 Jülich, Germany, s.voegele@fz-juelich.de
[b] FH Aachen University of Applied Sciences, Heinrich-Mußmann-Straße 1, 52428 Jülich, Germany, grajewski@fh-aachen.de
[c] TU Bergakademie Freiberg, Schloßplatz 1, 09596 Freiberg, Germany, Kristina.Govorukha@vwl.tu-freiberg.de
[d] TU Bergakademie Freiberg, Schloßplatz 1, 09596 Freiberg, Germany, Dirk.Ruebbelke@vwl.tu-freiberg.de

*Corresponding author

Abstract

The steel industry in the European Union (EU), important for the economy as a whole, faces various challenges. These are inter alia volatile prices for relevant input factors, uncertainties concerning the regulation of CO_2-emissions and market shocks caused by the recently introduced additional import duties in the US, which is an important sales market. We examine primary and secondary effects of these challenges on the steel industry in the EU and their impacts on European and global level. Developing and using a suitable meta-model, we analyze the competitiveness of key steel producing countries with respect to floor prices depending on selected cost factors and draw conclusions on the impacts in the trade of steel on emissions, energy demand, on the involvement of developing countries in the value chain as well on the need for innovations to avoid relocations of production. Hence, our study contributes to the assessment of sustainable industrial development, which are aimed by the Sustainability Development Goal "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation countries". By applying information on country-specific Human Development (reflecting aspects of life expectancy, education, and per capita income), we show that relocating energy-intensive industries from the EU may not only increase global energy demand and CO_2-emissions, but may also be to the disadvantage of developing countries.

Keywords:

Energy-intensive industry; steel industry; competitiveness; floor prices; energy efficiency

1 Introduction

The iron and steel sector is relevant for the global economy with respect to employment and economic growth, as according to World Steel Association [1] worldwide more than 6 million jobs are directly or indirectly linked to the iron and steel sector.[1] According to IEA, it consumed 466 Mtoe of energy worldwide in 2016, a share of 5 % on the global final energy consumption [3]. With a share of 17 % in the energy consumption of the industrial sector, "iron and steel" belongs to the sectors with highest relevance with respect to reduction measures for energy consumption. Since mainly coal is used as energy carrier, this sector contributes to around 27% to the global industrial CO_2-emissions [4], approx. 5% of the global man-made CO_2-emissions. Efficiency improvements have been more than offset by growing steel production, increasing energy consumption and CO_2-emissions of this sector (see e.g. [5]). Hence, the future of this sector is in interest of different kinds of stakeholders as well as of the scientific community. The future of the iron and steel industry is framed by developments on technological, economic, environmental and social levels. Thus, an appropriate assessment of the future of the iron and steel industry requires an approach which takes all of these aspects into consideration and which prepares the ground for an optimized use of energy resources by taking environmental, social and economic impacts of energy policies and usage into consideration.

The European Union (EU) is the second largest steel producer in the world after China accounting for nearly 11% of the global steel output. It represents one of the three largest EU-28 subsectors in terms of value added and employment. The status of the EU steel industry is therefore of strategic importance for future prospects of economic growth, innovation and welfare. Among the EU member states, Germany has the highest value added from manufacturing basic metals (including iron and steel), and fabricated metal products [6].

The steel industry in the EU faces various serious challenges and risks. Major challenges for the steel sector arise from the ambitions of European climate policy to reduce greenhouse gases, from uncertainties regarding the development of production cost and potential threats to free trade due to protectionist activities in some steel producing countries.

In this study, we assess implications of these challenges on cost, energy demand and CO_2-emissions. As another aspect of sustainability, we consider the impact of relocation to least developed and developing countries by applying information on country-specific Human Development (reflecting aspects of life expectancy, education, and per capita income). Our study aims at analyzing the conditions under which the steel industry in the EU can meet the challenges and be competitive. By providing information on impacts of possible relocations of steel production, we want to support decision-making on the steel industry.

The EU ambitions to mitigate global warming affect the steel industry in particular, as it is a very energy-intensive sector and accounts for about 20 % of the CO_2-emissions of manufacturing industries in the EU in 2017 [7]. While the CO_2-emissions in the EU are to be lowered by at least 40% below 1990 levels by 2030, Germany as dominant steel producer in Europe approved an even more ambitious plan [8]: It aims to emit only 45% of 1990 greenhouse gas level in 2030, for which steel producers would have to cut CO_2-emissions nearly by half compared to the current amount of 60 million metric tons per year [9]. A recent proposal of the European Commission (EC) [10] to revise the terms of the European Emission Trading System (ETS) for the period 2021-2030 triggered an immediate reaction of the German steel producers. They published an open letter that urged against the new regulations foreseeing a further increase of production costs, a decrease in profits and lowered competitiveness of e.g. the German steel industry on the international market [11].

Besides the expected heavier burden due to climate policy, there are uncertainties about the development of production costs and floor prices in different respects that challenge the European

[1] Taking all kinds of indirect effects into account, Eurofer [2] expect an multiplier effect of 7.7 for jobs.

steel sector. These uncertainties are, amongst others, those about the future design of European environmental policy, the development of transport costs and the prices of raw materials.

The third challenge stated above is closely related to present international disputes about trading rules and the renegotiations of international trade agreements. The US administration, for example, has recently started collecting duties on those imports of steel and aluminum that exceed stipulated import quota. The duty rate is 25% for a range of steel products from primary and semi-finished to hot and cold rolled flat products. Besides direct effects on competitiveness on the US market, indirect effects will influence the European market. A modification of US tariffs could induce steel exporting countries like Brazil, India and Russia to expand their supply in Europe, for example. This tends to trigger more intensive competition on the European steel sector.

Studies on developments in the steel sector predominantly address technological aspects: Focusing on China, An et al. [5], Wu et al. [12], and Li and Zhu [13] analyzed cost of technological option or energy conservation. An et al. [5] analyzed the effects of phasing out backward production capacity in accordance with the current policies, of increases in the share of electric arc furnace steelmaking, of extension of the promoting of low-carbon technologies, and of a use of clean fuels. Wu et al. [12] provided information on technology specific cost as well as on SO_2, NO_x, PM10, CO_2 and AP_{eq} emissions. Li and Zhu [13] used information on 41 energy saving technologies for calculating energy conservation supply curves. Chen et al. [14] stress the role of scrap for the future of iron and steel production.

Studies on the future of the iron and steel production in China have been furthermore conducted by Price et al. [15], Liu et al. [16], Zhang et al. [17], Wang et al. [18], Ma et al. [19] and Hasanbeigi et al. [20].

Arens et al. [21] and Schleich [22] focused their studies on the development of the specific energy consumption of the German steel sector from a historical point of view. Hasanbeigi et al. [23] compared developments in the steel sectors of the US, Germany, China and Mexico. Karali et al. [24] showed how technological learning can impact the future of the iron and steel industry and how technological learning can be included in a model.

Kim and Worell [25], Oda et al. [26] and Xu et al. [27] focused more on the development of CO_2-emissions and provided information on trends in the CO_2-emissions of the steel production of different countries. Additional scenarios on the future of the iron and steel industry were provided by Hasanbeigi et al. [20], Hildalgo et al. [28], Moya & Pardo [29], Oda et al. [30] and IEA [31].

In particular, the EC stressed the relevance of the iron and steel industry for the European economy, for economic growth as well as for CO_2-reduction strategies [32]. Among others, Branger et al. analyze competition aspects with respect to the European steel market [33].

In contrast to these studies as well as to others we stress uncertainty factors like e.g. fluctuations of prices for raw materials and transport cost: If the competitiveness of the steel industry in the EU declines, relocation of steel production from the Europe is likely to occur. To assess such relocation processes in terms of global sustainability, we need to consider a broad range of aspects including impacts on environment (e.g. CO_2-emissions), on the use of resources (e.g. fuels), on economic factors (e.g. economic growth) as well social factors (e.g. employment). With respect to “industry, innovation and infrastructure” the UN formulated “building resilient and sustainable infrastructure and promotes inclusive and sustainable industrialization” as Sustainability Development Goal (SDG). This goal includes inter alia targets for the promotion of sustainable industrialization in all countries (including e.g. increases in the resource-use efficiency of industries and extension of the use of clean and environmentally sound technologies) and stresses the need for actions in least developed and developing countries.

The Sustainability Development Goal on “industry, innovation and infrastructure” (SDG 9) frames the focus of our study and the selection of indicators being used for assessing scenarios. We take environmental effects into consideration using CO_2-emissions on national and global level as indicator. Although relocation will lower CO_2-emissions in the EU, it may even increase global CO_2-emissions due to larger transportation distances and the possible use of less energy efficient production technologies elsewhere ("carbon leakage"). Thus, we pay special attention to the transport of goods. SDG 9 stresses the importance of least developed and developing countries. Hence, we assess impacts of production relocations from the EU on the participation of these countries in the value chain and on the economic balance between industrialized and developing countries.

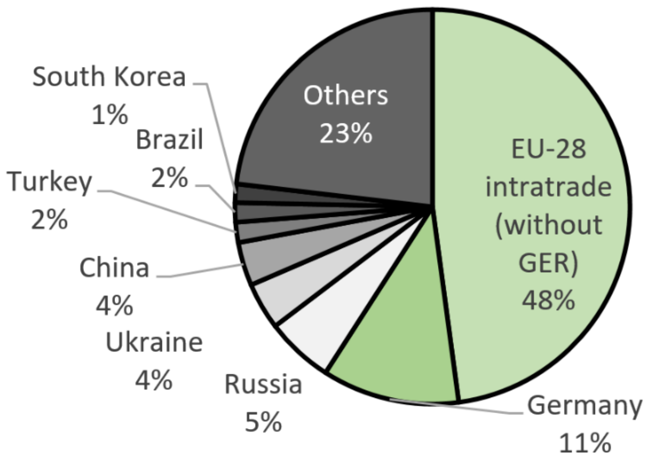
To work on the research objectives formulated above we examine in this paper the competitiveness of the EU steel industry on the European market based on floor prices and assess both economic consequences and implications on social and ecological sustainability aspects of possible relocation processes, which in turn can be a consequence of declining competitiveness.

We organize our work as follows: After giving an overview over status and perspectives of the steel industry in Section 2, we describe in Section 3 our extended floor price model we apply to examine the influence of the three aforementioned challenges on differences in floor prices with respect to selected competing countries. We describe how we model the aforementioned consequences of relocations. In Section 4, we present the results of our analysis; Section 5 concludes.

2 The Steel Industry

2.1 The steel industry in Europe: Overview and Perspectives

In the EU-28, the apparent steel use reached 159 million tons corresponding to 16.7% of the world steel consumption in 2016 [34]. About 41% of the imported iron and steel products originate from non-EU countries like Russia, Ukraine, China, Turkey Brazil and South Korea. Germany contributes 11% to the imports of the EU-28 countries (Fig. 1).



Source: [35]

Fig. 1: EU-28: Cross-border trade with "Iron and Steel" (SITC 67) in 2016

The EC insists on the need to restructure the steel sector to reduce its production capacity aiming to counter negative consequences of the growing overcapacity in Europe [36]. However, the overcapacity in Europe is small compared to that of China, which contributes to 46% of the global overcapacity [37]. This is one of the factors that keep sectoral profits on an extremely low level. The steel sector has not been prone to technological changes, since re-investment in primary production endangers long-term economic viability of production plants [38] and affects employment (see e.g. [39]).

The EC enforced anti-dumping and anti-subsidy duties on imports of certain steel products against steel producers from countries like China, Korea, Russia and Brazil in order to strengthen the position of the EU-28 steel producers. Tab. 1 gives an overview of import duties on steel products. Actually, these duties are specified for individual companies. For the sake of simplicity, we present upper and lower bounds of these.

	China	India	Korea	Russia	Brazil
High fatigue performance steel concrete reinforcing bars	18.4-22.5%				
Stainless steel wires		6.8-12.5%			
Grain-oriented flat-rolled products of silicon-electrical steel	21.5-36.6%		22.5%	21.6%	
Ferro-silicon	15.6- 31.2%			17.8-22.7%	
Stainless steel cold-rolled flat product (7219)	24.4-25.3%				
Stainless steel cold-rolled flat product (7209)	19.7-22.1%			18.7-36.1%	
Hot-rolled flat products of iron, non-alloy or other allow steel	0-31.3%			53.3 Euro/t-96.5 Euro/t	53.4 Euro/t-63.0 Euro/t
Heavy plate of non-alloy or other alloy steel	65.1-73.7%				
Cast iron articles	15.5-38.1%				
Iron or steel ropes and cable	60.4%		60.4%		
Tubes & pipes of ductile cast iron		4.1-19%			
Certain seamless pipes and tubes of stainless steel	29.2-71.9%			24.1-35.8%	
Welded tubes and pipes, of iron or non-alloy steel	90.6%			10.1-20.5%	
Threaded tube or pipe cast fittings of malleable cast iron	30.7-64.9%		32.4-44%	23.8%	
Corrosion resistant steel	0-27.9%				
Wire and stranded wire of non-alloy	0-46.2%				
Wire rod	7.9-24%				

Source: Own compilation based on [40, 41]

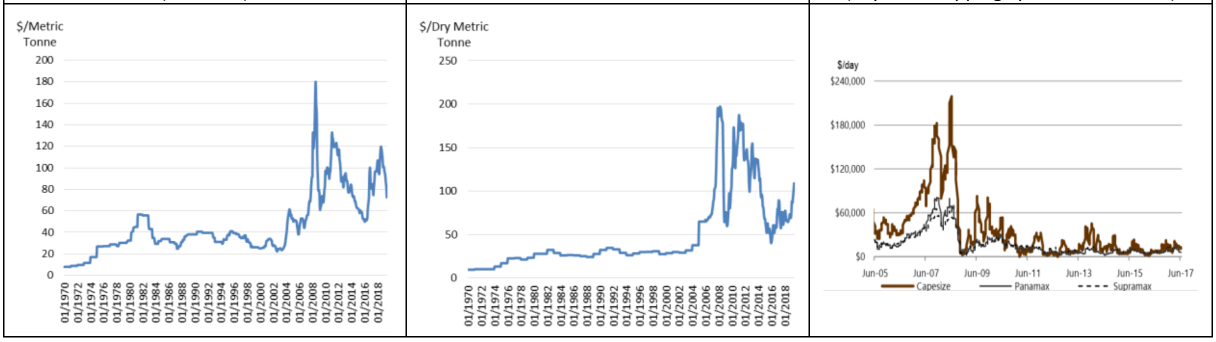
Tab. 1: Examples for import duties on company level in the steel sector

Besides pressure resulting from dumping prices[2], uncertainties about the future of the emission permit trading system challenge the European steel industry. Currently, "manufacture of basic iron and steel and of ferro-alloys" and "manufacture of tubes, pipes, hollow profiles and related fittings, of steel" are sectors deemed to be at risk of carbon leakage [42]. To avoid carbon leakage caused by competitive disadvantages on the international markets resulting from introduction of emission allowances, these sectors get emission allowances for free. The revised EU ETS Directive paves the way for free allowances for energy-intensive sectors like the steel sector for the period 2021-2030. The criterion for getting free allowances reads *intensity of trade * emission intensity > 0.2*. Here, intensity of trade stands for the ratio between the total value of exports to third countries plus the value of imports from third countries and the total market size for the European Economic Area (annual turnover plus total imports from third countries). The emission intensity is calculated as emissions (in kg CO_2) divided by gross value added (in euros). Although "Manufacture of basic iron and steel and of ferro-alloys" is still included in the third carbon leakage list (which is linked with getting a high share of free allowances) and the introduction of a market stability reserve (MSR) in order to adjust the stock of CO_2-allowances, many uncertainties remain. Uncertainties regarding updates of the benchmarks which determine the level of free allocation of CO_2-allowances [43], uncertainties about the impacts of the phasing out of coal-fired power plants in Europe on the market for CO_2-allowances [44], modifications on CO_2-pricing in countries like Germany [45], and uncertainties how the effectiveness of MSR (see e.g. [46] and [47]) will directly and indirectly challenge the steel sector.
Because of its high relevance with respect to CO_2-emissions, the steel sector will be urged to contribute to the national and global CO_2-reduction targets even if it gets emission allowances for free. Reaching ambitious targets like the 80% CO_2-reduction target set for the German Energy Transition ("Energiewende") will be impossible without incorporating the steel sector.
Besides uncertainties regarding the future treatment of the steel sector by the ETS, uncertainties about the development of cost parameters challenge the steel sector: In the past, the cost for inputs needed

[2] In principle, dumping prices are unsustainable. However, as long as there are huge excess capacities, there will be suppliers that offer products to prices covering only running cost.

for steel production has fluctuated dramatically (Fig. 2). The price for coal for example increased by 600% from 2000 to 2008. Afterwards, it dropped by 70% followed by a renewed increase. The price for iron ore was similarly volatile. Therefore, we need to consider a broad range of possible developments. Focusing on one selected pathway for costs can result in misjudging challenges and options.

Coal (Australia)	Iron Ore	Transport Cost (Dry Bulk Shipping Spot Charter Rates)



Sources: [48], [49]

Fig. 2: Changes in prices for coal, iron ore and in transport cost

With the argument that steel is imported “in such quantities and under such circumstances as to threaten to impair the national security” [50, p. 1], the US administration introduced a 25% ad valorem tariff on specific steel mill products ranging from primary and semi-finished to hot and cold rolled flat products imported from countries other than South Korea, Brazil, Argentina and Australia in 2018. For South Korea, Argentina and Brazil the US introduced quotas limiting the quantities of imported steel. Since the EU-28 is affected by these tariffs as well, European actors expect their share of the US steel market to shrink. The European Union requested consultations at the WTO with the United States concerning the measures imposed by it towards steel and aluminum imports. A final report is expected no earlier than autumn 2020. In comparison to the EU-USA dispute, the conflict between China-USA shows characteristics of trade-war with imposing trade tariffs on both sides (see e.g., [51]).

The increased US tariffs could encourage steel producing countries with low production costs to search for alternative markets. Thus, Germany might be facing higher competition on the European steel market from major current and emerging competitors. As the value of Germany’s exports to Europe far exceeds that to the US (20.2 billion $ vs. 1.19 billion $ [52]), we expect these secondary effects caused by the US tariffs to dominate direct effects on the European steel industry and we therefore consider particularly secondary effects in our analysis. Hence, besides China, we consider Brazil, India and Russia as competitors on the European market.

For an assessment of the competitive position of steel producers in Europe and of possible impact of relocations of steel production on emission and energy demand it is necessary to take effects resulting from the transport of goods (including both raw material and steel) into consideration. With respect to impacts on developing countries feedbacks of relocation on the distribution of value added among developed and developing countries is strongly recommended. In the following we present an approach that allows to assess changes in cost, energy consumption, and CO_2-emissions on national and global level as well as changes in the distribution of values added in the steel sector taking uncertainties with respect to prices of material, changes in efficiencies and transportation cost into consideration.

2.2 Technological aspects

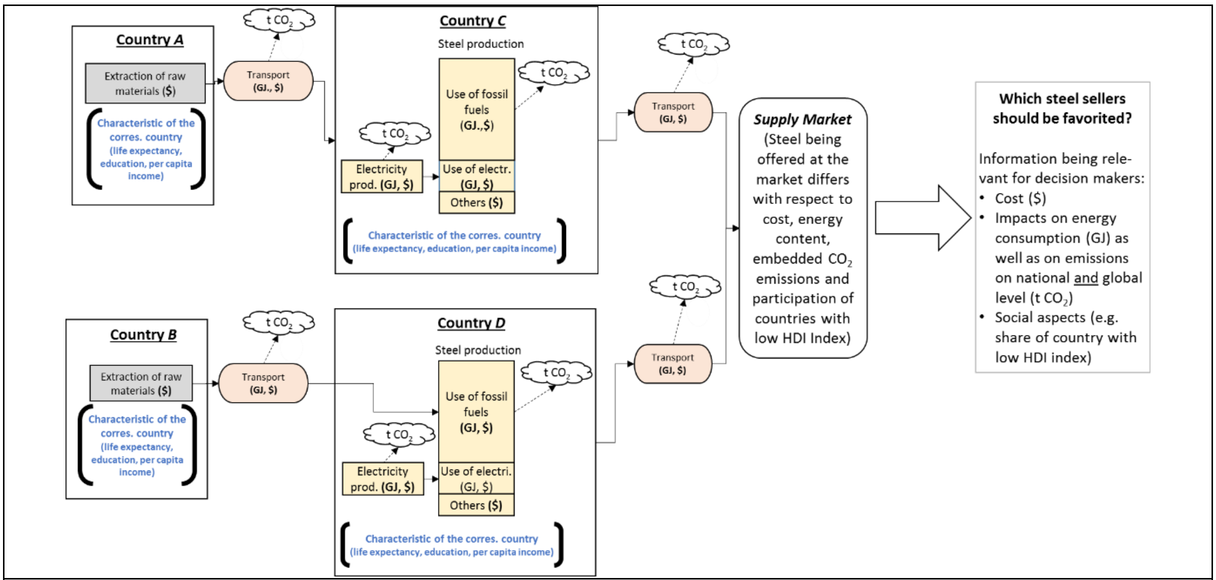
In Europe there are two dominant technological processes or routes in use: the blast furnace/basic oxygen furnace (BF/BOF) and the electric arc furnace (EAF) route. These routes differ by the structure of the main inputs and energy intensity. BF/BOF (also called *primary* route) is highly energy intensive and causes more CO_2-emissions than other routes. Within the BF/BOF route, iron ore is reduced to pig iron in a blast furnace (BF) using coke or coking coal and other reducing agents. Pig iron together with ferrous scrap is processed further in a basic oxygen furnace (BOF), and afterwards transformed into crude steel products: coils, plates, sections or bars. EAF (also *secondary* route) is less energy intensive than the primary route [53]. Its main inputs are ferrous scrap and electricity. Depending on the configuration of the EAF plant, this route may require some quantities of iron from BF (pig iron) or from the direct reduced iron (DRI) process route, which demands natural gas or coal as energy inputs. Downstream casting and rolling processes yield steel products similar to those generated by the BOF route. However, the capacity of the EAF route to meet steel demand is limited by the availability of scrap and the quality requirements of steel products. Production of high carbon steel needs additions of either pig iron, which implies the extensive use of either energy intensive BF, or DRI. Thus, demand for high carbon steel from the EAF route increases energy intensity and CO_2-emissions [54].

In Europe, the BF/BOF route dominates the EAF route. The same applies to the German steel sector, where the ratio between both routes has not changed significantly within the last 15 years. Meanwhile, China has increased its BF/BOF production capacities by almost 10 times, substituting for EAF and other minor production routs. The DRI route has not become prevalent in Europe due to economic reasons [9]. If DRI (and pig iron) is imported from regions with relatively cheaper gas and electricity as from Asia, Middle East and Northern Africa, it may replace production from BF/BOF and contribute to emission reductions in the importing country [55], although the global effect on emissions remains uncertain. In terms of the EU environmental targets, no large-scale replacement of BF/BOF by DRI/EAF route in Europe is seen as economically viable [54]. Further emission reductions appear possible due to technological progress even with the current mix of routes [56].

The BOF route offers considerable opportunities for improving energy efficiency, where by-product gases can be fully reused as direct fuel substitute or indirectly for internal generation of electricity [53]. Significant reduction of CO_2-emissions may be reached if carbon capture technologies prove effective on the pilot scale (see e.g., [57]). If carbon capture and storage technologies succeed and are routinely implemented by 2030, it may be possible to limit global warming to 2°C [31]. The German steel industry achieved significant improvements in energy efficiency and emission reductions over 1991 – 2007 primarily due to structural change towards the EAF (less energy intense) route. In contrast to that, improvements in BF and BOF routes had comparatively smaller impact [58].

3 Method

Our approach consists of three steps: In a first step we calculate cost of (crude) steel production taking uncertainties about e.g. prices for raw materials, transportation cost, changes in energy efficiencies and CO_2-allowances assuming Europe as supply market. Hence, we are able to assess the competiveness of Germany as representative European steel supplier. For the assessment of implications of a relocation of production activities resulting from in the deterioration of the competitive situation of Germany we calculate energy demand and CO_2-emissions which are related to steel production in a second step. In a third step we extend the assessment by including information on key characteristics of countries being involved in the production chain aiming to include impacts on countries which still need to be supported since they show low life expectancy, education, and per capita income (Fig. 3).



Uncertainties: e.g. cost (prices for raw material, transportation cost, cost for CO_2-allowances), and technological changes

Fig. 3: Approach used for the assessment of impacts of relocation of steel production

3.1 The extended floor price model

In order to compare floor prices, we apply an extended technology-based floor price model. Our model reflects the floor price structure of crude steel production in a typical steel plant in the country analyzed and for different routes. The model determines the floor price of crude steel production (Eq. 1). The index a stands either for the BF/BOF or the EAF route, i.e. $a =$ BF/BOF, EAF and n for the country that is regarded. In our model the costs depend on the prices of input materials (p_i^n) and their respective use in the considered production route $(x_{a,i}^n)$. We include costs for CO_2-emission allowances where appropriate. Our model accounts for the CO_2-emissions due to the energy carrier used in the BF/BOF and EAF routes, as well as for emissions occurring from the transportation of steel products and raw material inputs to the producing country applying respective emission factors to each type of carrier and its utilization. We set

$$c_a^n = \sum_{i=1}^{l} x_{a,i}^n * (r_i^n + env_i^n), \qquad (1)$$

where

	c_a^n	-	total cost of producing one tonne of crude steel in country n using production route a [$/tonne]
	n	-	index of the country
	a	-	index of the production route
	i	-	index of the input factor
	$x_{a,i}^n$	-	production coefficient i reflecting the demand for e.g. raw materials, electricity, gases, or labor used for production of one tonne of crude steel using production route a [tonne/tonne], [GJ/tonne], [m3/tonne] or [working hour/tonne]
	r_i^n	-	average price the steel industry in country n pays for input factor i [$/tonne], [$/GJ], [$/m^3] or [$/working hour]

env_i^n - additional cost resulting from environmental regulations – i.e. costs for CO_2-emission certificates [$/tonne]

Moreover, our model considers the floor prices of steel offered at market l assessing additionally the transportation costs ($tr_a^{n,l}$) and minimum normal profits ($prof_a^n$) of the producer in country n. We calculate the floor price $p^{n,l}$ of steel delivered to country l as follows:

$$p^{n,l} = \left(c_a^n * (1 + prof_a^n) + tr_a^{n,l}\right) * (1 + d\_exp^n) * \left(1 + d_{imp}{}^l\right),$$

where $p^{n,l}$ - floor price of one tonne of crude steel produced in country n and delivered to steel market *l*

$tr_a^{n,l}$ - cost for transporting crude steel from country *n* to steel market *l*

$prof_a^n$ - envisages the normal profit rate for the producer in country n by route a

d_exp^n - reflects export duties on steel in the country n

$d_{imp}{}^l$ - reflects import duties on steel in EU from the country n

To assess the price of raw materials in country n, which are purchased from foreign producers, the model calculates the average price of the input factor. It is determined by the free on board (FOB) price (c_i^m) set by the producing country, freight cost ($tr_i^{m,n}$) for overseas transport and by additional costs from export duties ($d\_ex_i^m$). Average price is adjusted with respect to the import structure (Eq. 2), where $\alpha_i^{m,n}$ reflects the share of imported raw material input i from the foreign producer m to the overall demand for i in the country n:

$$r_i^n = \sum_{m=1}^{r} \left[\alpha_i^{m,n} * \left(c_i^m * \left(1 + d_{ex}{}_i^m\right) + tr_i^{m,n}\right)\right]$$
$$0 \leq \alpha_i^{m,n} \leq 1, \qquad \sum\nolimits_i \alpha_i^{m,n} = 1 \tag{2}$$

where r_i^n - average price of the input of raw material i in country n

$\alpha_i^{m,n}$ - share of imported raw material input i from the foreign producer m to the overall demand for i in country n

c_i^m - free on board (FOB) price of the raw material *i* in country *m*

$d\_ex_i^m$ - additional costs from export duties from country m

$tr_i^{m,n}$ - cost for transporting raw material *i* from country *n* to m

For the assessment of floor prices, it is important not to consider only prices of raw materials but also transportation cost. Therefore, we need to consider the complete value chain from delivery of raw materials to distribution of steel products to the markets. Transportation routes are represented in the model in detail, which allows to analyze changes of the steel cost due to changes in freight provided that rawest material inputs are transported by sea. The model applies an approach presented in [59] and assumes two types of bulk carriers: Capesize, a large cargo vessel primarily used for transporting coal and iron ore, and Panamax, which can cross the Panama channel. Thus, the model covers major transportation routes connecting major cargo ports. It incorporates the duration of transport, charter rates as well as fuel, harbor-specific and other costs:

$$ts_{i,v}^{m,n} = d_{i,v}^{m,n} * r_v + f_{i,v}^{m,n} + c_v^{harb} + e_v^{m,n},$$

where $ts_{i,v}^{m,n}$ - transportation costs of input i on vessel type v from country m to country n

$d_{i,v}^{m,n}$ - $d_{i,v}^{m,n}$ days needed for transportation

r_v - charter rates of vessel type v

$f_{i,v}^{m,n}$ - fuel cost incurring from transportation of input i on vessel type v from country m to country n

c_v^{harb} - harbor-specific cost for vessel type v

$e_v^{m,n}$ - other costs for vessel type v on the route from country m to country n (e.g. fees for using the Suez canal)

We additionally consider fuel costs, accounting for specific fuel use during the time on route and congestion time:

$$f_{i,v}^{m,n} = \left[\left(d_{i,v}^{m,n} - b_{i,v}^{m,n}\right) * o_v^{sea} + b_{i,v}^{m,n} * o_v^{cong}\right] * p_{oil}$$

where o_v^{sea} - fuel consumption for vessel type v during the time on route [tonnes/day]

o_v^{cong} - fuel consumption for vessel type v during congestion time [tonnes/day]

p_{oil} - average price for fuels used for the vessels: model differentiates between heavy fuel oil and marine diesel oil [$/tonnes]

Taking into account countries that are rich in raw materials or located close to the export partners, as well as close to inland delivery routes of raw material inputs, the model includes the cost of other transportation means.

BOF steelmaking production data is based on the cost structure for a typical steel plant as defined by the best available technique for a typical plant in the region. Energy consumption is determined by a representative plant type for the producing region, energy carrier and is given per one tonne of crude steel. The model accounts for byproducts as steam and gases that can be reused for heating, onsite electricity production and other purposes. These energy byproducts are considered as opportunities to increase energy efficiency. We calculate the overall energy consumption by summing up the energy used for steel producing processes, for the transport of goods and for electricity production. Raw materials like coking coal are taken into account by using information on their specific energy content (see Appendix). We then calculate CO_2-emissions by multiplying energy use with fuel specific emission coefficients (see Appendix).

The model is calibrated using data for 2014. In order to reflect uncertainties with respect to prices of coal and iron ore as well as to the transportation cost and technological progress, we consider ranges for future developments of these factors: Regarding raw material prices and the transport cost, we assume an increase up to 400% until 2030 (compared to 2014). Variations of the energy efficiency (EE) in the model may be comparable with the results of the study of Arens et al. [9] , where the authors assess the technical potential for EE improvements and CO_2-savings. However, this study by Arens et al. does not discuss whether such a combination of technological pathways would be sufficient to stay competitive with other producers. In this way, we may add to their analysis a deeper economic perspective. According to [9], the model assumes a range up to a max. 20% EE increase of the BF/BOF processes with respect to the specific energy use at different stages of these technological processes. We do not specifically consider different technology options other than BF/BOF and EAF, represented here by a typical production plant in the modelled countries. We assume changes in the energy efficiency and CO_2-emissions as a result of changes in the specific fuel and electricity use, improved utilization of the byproduct gases and energy.

Sustainable steel production includes that developing countries participate in the value chain for creating a fair economic balance. Hence, we extend our assessment by including information on countries being involved in the steel production chain either by providing raw materials or by hosting steel production. Since a complete assessment of sustainability is beyond the scope of this study, we adapted an approach of UNDP and use the Human Development Index (HDI) as proxy [60]. This indicator comprises aspects of long and healthy life, knowledge and standard of living and is available for 189 countries. Following UNDP we cluster countries based on HDI into the categories very high (HDI > 0.8), high (0.8 > HDI >= 0.7), medium (0.7 > HDI >= 0.55) and low (0.55 > HDI) (see Appendix Tab. A-

9). Using our extended floor price model and information on the share of the countries in the various parts of the value chain, we assess the part of the different HDI-categories on overall cost. Based on that we conclude to which extend and how countries with medium or low HDI are affected by relocating steel production from the EU.

3.2 Meta-modeling and sensitivity analysis

The cost tr of transport and the price r of raw material significantly influence the floor price and fluctuate strongly over time (Chapter 2). Therefore, we analyze variations in the floor price difference with respect to these parameters more in depth. Additionally, we investigate the variations in the floor price difference caused by alterations of the energy efficiency e_G of Germany's steel production and the respective efficiency e_C in the competing country, as the steel industry may influence them by investing in steel mills. For including uncertainties with respect to cost resulting from changes in environmental regulations, we moreover consider the pricing level for European CO_2-emission certificates and analyze the difference in floor price for obtaining emission certificates for free (CO_2_0, current situation), and for a pricing level of $30/tonne CO_2-emissions (CO_2_30) and $50/tonne ($CO_2$_50).

Treating tr, r, e_G and e_C as variables and fixing all other input parameters, we set $x = (tr, r, e_G, e_C)$ and interpret the differences in floor prices $\Delta p^l(x) \coloneqq p^{l,C}(x) - p^{l,G}(x)$ as a deterministic function of x. Here, $p^{l,G}$ and $p^{l,C}$stands for the results of our floor price model for Germany and the competing country, respectively, for the values of tr, r, e_G and e_C provided. For convenience, we consider the relative increase of the input factors instead of their absolute values, e.g., $tr = 1$ indicates that the cost of transport exceeds the level in 2014 by 100%.

For $\Delta p^l(x)$, there is no closed formula available; evaluating Δp^l for a fixed x implies running the floor price model twice (for Germany and for the competing country). In this analysis, we seek to replace Δp^l with a simpler albeit not simplistic meta-model $\Delta \hat{p}^l$, which reproduces the behaviour of Δp^l with sufficient accuracy. It is generally difficult to find a suitable approach for a meta-model because it should reflect the essential properties of the actual model without being too complex. It is commonplace to select a priori a parametric approach like, e.g. a linear model and then to determine its parameters by least-squares fitting to sampled data $(x_i, \Delta p^l(x_i))$. Afterwards, the resulting meta-model may be validated by some goodness-of-fit test. However, such tests alone are not suitable for assessing whether the approach chosen was appropriate for the properties of the data [61].

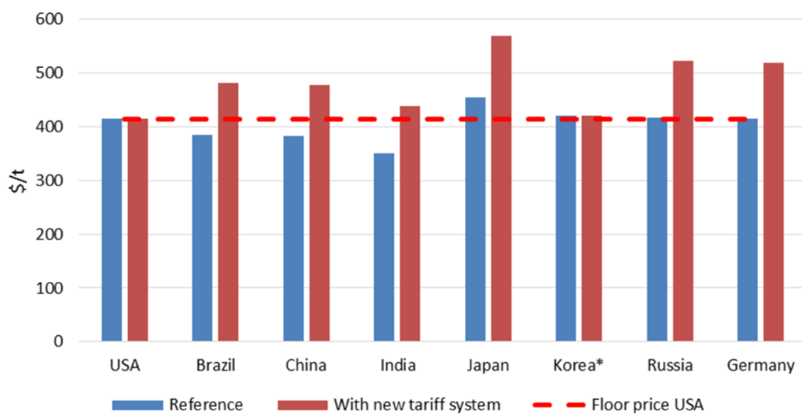
In order to find a suitable parametric approach for $\Delta \hat{p}^l$, we employ a visualization of Δp^l. For that, we run our model with systematically varied parameters. Fixing one of the four variable parameters for a visualization, we identify any combination of the other three parameters with a point in the three-dimensional space and color-code the value of Δp^l at this point. We compute our visualization of Δp^l from that raw data using interpolation with Radial Basis Functions. We prefer this approach over more traditional ones like interpolation with polynomials or splines due its superior flexibility and accuracy [62].

4 Results

In the following, we present the result of our calculations. As mentioned above our analysis focuses on factors which are directly relevant for the cost of crude steel production and which have fluctuated in the past. We are aware that other factors may influence the cost of steel production, too. As far as they affect prices of raw material, transportation cost and efficiency, they are taken into consideration implicitly. An extensive discussion of the sensitivity of the results on a broader range of factors could become confusing for the readers and will beyond the scope of this article. Hence, regarding closer discussion of challenges and uncertainties we refer to Eurofer [63] and Vögele et al. [64].

4.1 Competition and floor prices on the US-steel market

In 2017, the USA imported 26.8 Mio. tonnes of steel from Canada, 4.7 Mio. tonnes from Brazil, 3.4 Mio. tonnes from South Korea, 2.9 Mio. tonnes from Russia and 1.7 Mio. tonnes from Japan. About 4.5% of the steel exports of Germany are sold on the US market [52]. The imports from Germany accounted for 4% (1.4 Mio. tonnes) of the total US steel imports [65]. According our calculations, the floor price of crude steel produced in Brazil and transported to the US is about \$377/tonne under today's conditions. The recently introduced US tariffs (25%) turn the current advantage for Brazil into a slight disadvantage in floor prices (\$427/tonne vs. \$414/tonne for US made steel). Therefore, we expect Brazil to lose significant market share in the US steel market.[3]



Remarks: * South Korea is exempted from the US duty.
Source: own calculations

Fig. 4: Floor prices for crude steel (Supply market USA)

We obtain similar figures for Germany, Russia and China (Fig. 4). India loses its former advantage in terms of floor prices completely. Unless the disadvantages due to rising floor prices can be balanced by e.g. higher quality, we expect these countries to offset the expected loss of market share in the US by expanding their activities in the European market. Only South Korea being exempted from the US duty remains competitive with respect to floor price in the US market under current conditions (Fig. 4). These findings indicate that some of the steel exporting countries considered, in particular China, Russia, South Korea and Brazil, may redirect exports towards Europe. As India's share of the US market is already low, the displacement effect described here towards the European market will be less pronounced for India. However, because of the low floor price and because India is an emerging industrial country, we include India in our further analysis. These considerations motivate to look more closely at the competitiveness of these countries in the EU market. As indicator for that we consider the floor price difference.

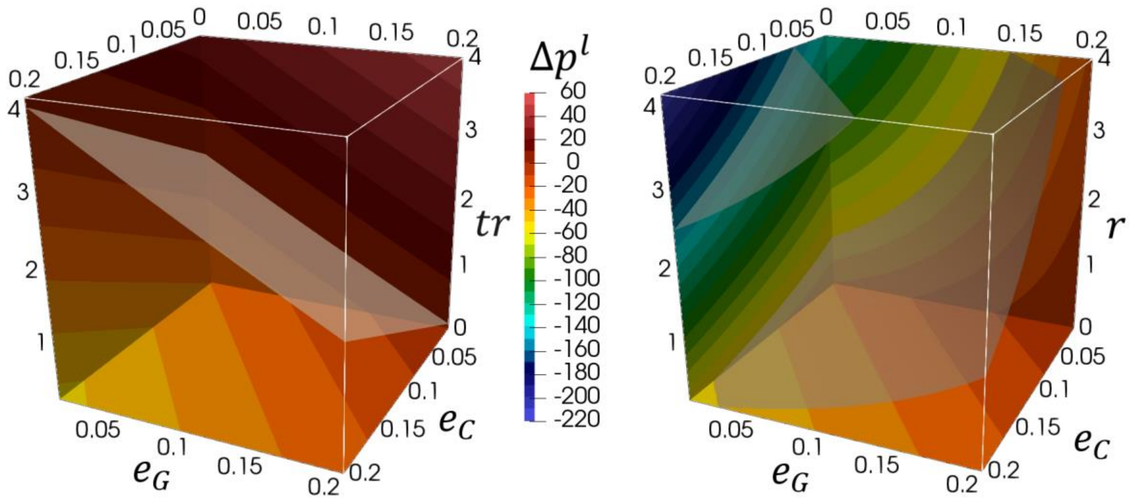
4.2 Results of Meta-modeling

Visualizations of our floor price model indicate that Δp^l is mainly linear for r fixed (Fig. 5, left), but not for r variable (Fig. 5, right) and another variable fixed. Guided by this, we at first chose for fixed r a linear approach

$$\Delta\hat{p}^l(tr, r, e_G, e_C) = \begin{pmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ \alpha_4\end{pmatrix} \cdot \begin{pmatrix}1\\ tr\\ e_G\\ e_C\end{pmatrix}$$

[3] For reasons of simplicity, we ignore cost for trading steel within a country.

and determined the coefficients α_i for any r fixed by least-squares-fitting to the raw data. However, a visualization of the difference $\Delta p^l - \Delta\hat{p}^l$ still for r fixed (Fig. 6, left) reveals a small but systematic deviation.



Remarks: e_G: Improvement in efficiency in Germany compared to 2014, e_G: Improvement in efficiency in competing country compared to 2014, r: changes prices for raw material [1: increase by 100%, 4: increase by 400% compared to 2014], Δp^l: differences in floor prices [$/t], tr: increases in cost for transport

Fig. 5: Difference in floor prices between China and Germany (left: $r = 0$ fixed, right: $tr = 0$ fixed), CO2_0. For r fixed, we show the level set Δp^l = $0/tonne (floor price equality) as translucent grey surface; for tr fixed, we display level sets for Δp^l = $-50; $-150/tonne.

A comparison with a plot of the function $f(x,y) = xy$ (Fig. 6, right) hints that this may be caused by neglecting contributions of $e_G tr$ and $e_C tr$. Therefore, we modify our approach to

$$\Delta\bar{p}^l(tr, r, e_G, e_C) = \begin{pmatrix}\beta_1\\ \beta_2\\ \beta_3\\ \beta_4\\ \beta_5\\ \beta_6\end{pmatrix} \cdot \begin{pmatrix}1\\ tr\\ e_G\\ e_C\\ e_G tr\\ e_C tr\end{pmatrix}$$

and proceed as before. Plots exhibit a linear relationship between β_i and r, such that we make the ansatz $\beta_i(r) = \beta_{i,1} + r\beta_{i,2}$ and determine these coefficients by linear regression (Tab. 2).

	β_1	β_2	β_3	β_4	β_5	β_6
Brazil	-22.96	0.075	143.68	-138.66	3.51	-0.090
	-1.86	0	102.47	-99.34	0	0
China	-29.83	13.68	143.68	-116.55	3.51	-0.16
	-24.78	0	102.47	-82.62	0	0
India	-60.08	10.62	146.68	-188.11	3.51	-1.92
	-73.41	0	102.47	-125.24	0	0
Japan	46.76	28.00	143.68	-153.81	3.51	-6.47
	48.19	0	102.47	-113.61	0	0
Korea	10.41	24.97	143.68	-135.01	3.51	-5.38
	33.10	0	102.47	-99.50	0	0
Russia	14.23	-1.65	143.68	-139.10	3.51	0.0003

	-39.71	0	102.47	-112.78	0	0

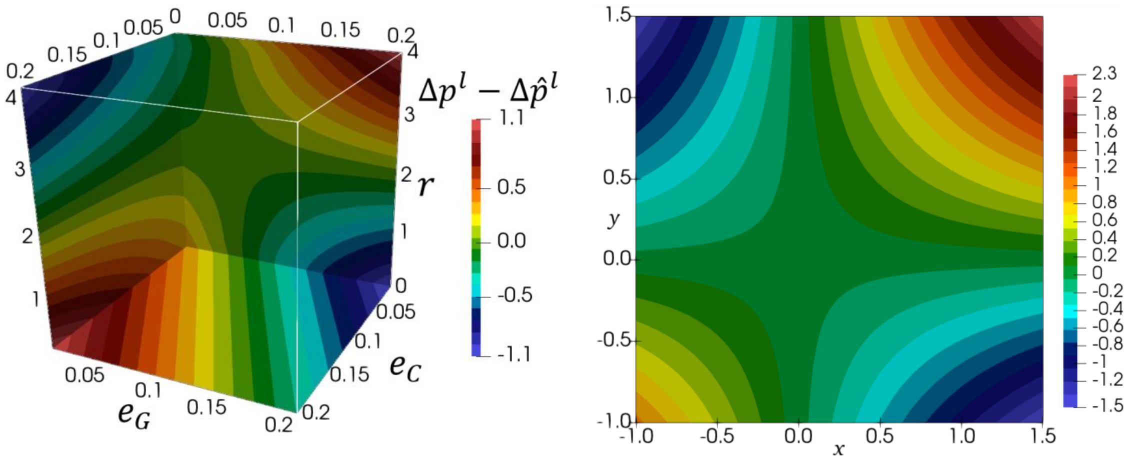
Tab. 2: Coefficients for the meta-model $\Delta\bar{p}^l$ for different competitors, CO_2_0

We validate our meta-model $\Delta\bar{p}^l$ by computing the Normalized Mean Absolute Error (NMEA) of Δp^l with respect to $\Delta\bar{p}^l$. Additionally, we consider der maximum error. The error (Tab. 3) due to replacing Δp^l by $\Delta\bar{p}^l$ is small compared to the range of the data. This justifies $\Delta\bar{p}^l$ as a suitable meta-model of Δp^l.

	Brazil	**China**	**India**	**Japan**	**Korea**	**Russia**
NMEA	0.014	0.014	0.014	0.011	0.010	0.014
Max. err	0.064	0.064	0.064	0.057	0.046	0.064

Tab. 3: NMEA and maximum error for replacing Δp^l by $\Delta\bar{p}^l$, CO_2_0

From now on, we thus identify $\Delta\bar{p}^l$ with Δp^l. The modeling error and model coefficients for CO_2_30 and CO_2_50 are similar (see Appendix).



Remarks: e_G: Improvement in efficiency in Germany compared to 2014, e_G: Improvement in efficiency in competing country compared to 2014, r: changes prices for raw material [1: increase by 100%, 4: increase by 400% compared to 2014], Δp^l: differences in floor prices [$/t], tr: increases in cost for transport

Fig. 6: Left: $\Delta p^l - \Delta\hat{p}^l$ for $r = 0$ fixed, the competing country is India. Right: Plot of $f(x, y) = xy$.

Even carefully selected scenarios involve uncertainties in the exact values of the input parameters. Therefore, we conduct a sensitivity analysis of our model. To first order accuracy, it holds

$$\Delta p^l(x) - \Delta p^l(x') = D\Delta p^l(x) \cdot (x - x'),$$

where $D\Delta p^l(x)$ denotes the gradient of Δp^l in x. By computing upper bounds for the components of $D\Delta p^l(x)$, we obtain upper bounds for the absolute change of Δp^l in $/tonne for a change of the input parameters by 1% (Tab. 4). The results indicate that improving energy efficiency has the most prominent influence on the floor price difference. For the corresponding results for CO_2_30 and CO_2_50, which are similar, we refer to the appendix.

Comp. country	r	tr	e_G	e_C
Brazil	0.442	0.0080	5.803	5.365
China	0.618	0.144	5.676	4.477
India	1.190	0.117	5.676	6.970
Japan	0.914	0.300	5.676	6.341
Korea	0.735	0.268	5.676	5.545
Russia	0.828	0.0236	5.676	5.902

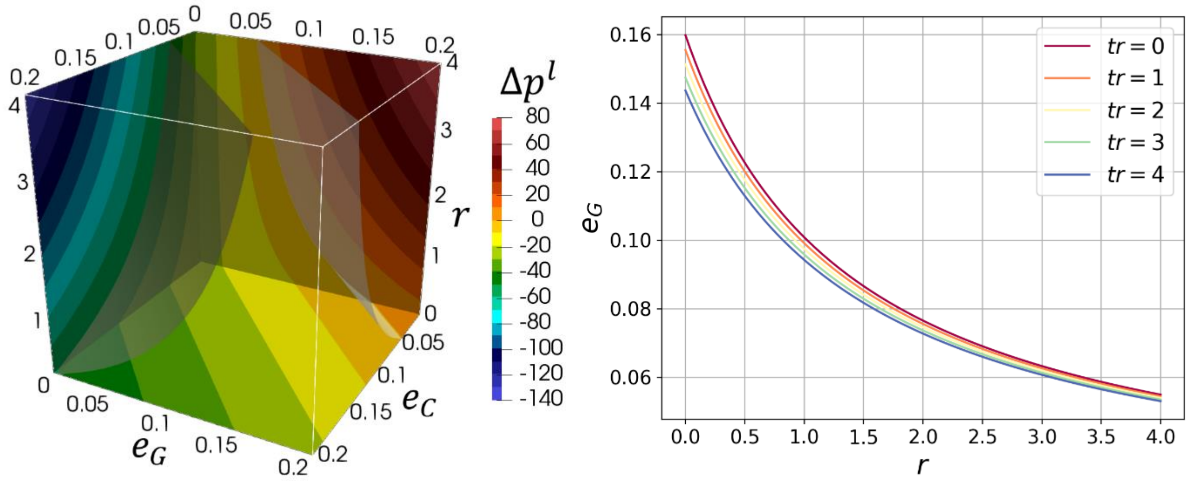
Tab. 4: Sensitivity analysis: Absolute change of Δp^l vs. change of the input variables in %, CO_2_0

4.3 Competition on the European steel market

We analyze the outcome of our floor price model with respect to different competing countries.

4.3.1 Germany – Brazil

For CO_2_0 and $x = (0,0,0,0)$ (current conditions), the floor price advantage for Brazilian steel is \$23.0/tonne (\$409.4/tonne for German steel vs. \$386.4/tonne for Brazilian steel) or relatively 5.6%. Equality of floor prices is reachable under today's conditions, if the German steel industry increases e_G by at least 16.0% provided $e_C = 0$. This is quite ambitious, so it is unclear whether the cost savings due to the increased energy efficiency justify the investment costs. However, raising transport costs slightly mitigate Germany's floor price disadvantage (Fig. 7), albeit the small values of β_2 (Tab. 8) indicate that Δp^l depends only very weakly on tr. Growing r increases Δp^l to Germany's disadvantage (**Fig. 7**, left), however, it takes less efficiency improvements then to close the floor price gap (Fig. 6, right). For CO_2_30, Brazil's floor price advantage rises to \$56.0/tonne (relatively 12.7%) under current conditions, and floor price equality becomes unattainable for $tr = r = e_C = 0$ by increasing e_G. However, significant efficiency improvements in Germany combined with high cost for raw materials still result in floor price equality. The same holds (for even higher r) for CO_2_50.



Remarks: e_G: Improvement in efficiency in Germany compared to 2014, e_G: Improvement in efficiency in competing country compared to 2014, r: changes prices for raw material [1: increase by 100%, 4: increase by 400% compared to 2014], Δp^l: differences in floor prices [\$/t], tr: increases in cost for transport

Fig. 7: Δp^l, Brazil – Germany including level sets for $\Delta p^l = \$0, -\$50$/tonne given $tr = 0$ (left); necessary increase in energy efficiency in Germany for floor price equality depending on r and tr for $e_C = 0$ (right).

4.3.2 Germany – China

Given CO_2_0 and $x = (0,0,0,0)$, Germany's floor price exceeds China's by \$29.8/tonne. Improving e_G by 20% reduces this cost gap to \$1.1/tonne. Germany's steel industry benefits from raising tr whereas China's industry profits from raising r (Fig. 4) such that mainly depending on these input factors, floor prices may or may not be equal.[4]

4.3.3 Germany – India

Under current conditions, Germany's floor price exceeds India's by \$60.0/tonne or relatively 14.7%. For $e_G = 0.2$, that floor price gap is reduced to \$31.3/tonne. Raising tr may improve Germany's competitiveness substantially (Appendix Fig. A-1). Under today's conditions however, even for $tr = 4$, the floor price difference remains at \$17.6/tonne. For $r = e_C = 0$ and $tr = 4$, our model predicts a floor price advantage for Germany for $e_G \geq 11.2\%$ which corresponds to $p^l =$ \$421.1/tonne. It turns out that Δp^l significantly depends on r, with growing r favouring India. Germany's competitiveness for CO_2_0 depends on the cost side on tr and r, which cannot be directly influenced by measures taken by industry. Competiveness with respect to floor prices is completely lost for $C0_2$_30 and $C0_2$_50.

4.3.4 Germany – Russia

Under current conditions, the floor price for Russian steel exceeds Germany's by \$14.2/tonne, and floor price equality given $tr = r = 0$ requires $e_C = 10.2\%$ (Appendix Fig. A-2). The small values of β_2 (Tab. 8) indicate that Δp^l depends only weakly on tr: for $x = (4,0,0,0)$, Russia's floor price disadvantage reduces to \$7.6/tonne ($p^l = \$446.4$/tonne). However, Δp^l strongly depends on r. For CO_2_30, we obtain \$$\Delta p^l(0,0,0,0)$ =\$-18.8/tonne. If Germany increases e_G by 10.6%, floor price equality is regained at $p^l = \$423.7$/tonne. For CO_2_50 and $x = (0,0,0,0)$, Russia's floor price is \$40.8/t below Germany's corresponding to a relative advantage of 8.7%. In this scenario, Germany cannot achieve floor price equality by efficiency improvements. The influence of r on floor price equality is smaller than before. Russia's steel industry suffers from disadvantages in floor prices on the European market unless r or the price of CO_2-emission certificates raises significantly.

4.3.5 Other countries

We additionally analyze the situation for Japan and South Korea, as neither of these countries enjoys a floor price advantage on the US market and may therefore turn to the European market. For CO_2_0, the floor price for Japanese steel exceeds the one for German steel under all conditions considered here. Under current conditions, the cost difference is \$46.8/tonne and thus significant. Given CO_2_30, the Japanese steel industry may achieve floor price equality, if the cost of raw material remains low and Japan increases the efficiency of its steel mills significantly. For CO_2_50, however, Germany's cost advantage is lost. The Japanese steel industry cannot compete with the German steel industry regarding floor price on the European market unless the pricing of CO_2-certificates raises significantly. Under current conditions and CO_2_0, the Korean steel industry has a floor price disadvantage of \$10.4/tonne on the European market (\$409.4/tonne for German steel vs. \$419.8/tonne for Korean steel). The Korean steel industry will not achieve significant floor price advantages under conditions that are foreseeable today in the case of $C0_2$_0. For CO_2_30, however, Germany's steel industry suffers under today's conditions from a floor price disadvantage of \$22.6/tonne steel or 5.1% in relative terms. Given CO_2_50, Germany's steel industry cannot reach floor price equality under today's conditions by improving its energy efficiency alone. According to our calculations, steel producers from the US have and will have a hard time on the European market.

[4] For details and additional analysis, we refer to [64]

4.4 Implications on national, European, and global level

As mentioned above there is a broad range of uncertainties that challenge the iron and steel industry. We showed that a broad range of uncertainties challenge the iron and steel industry sector in the EU. Beside uncertainties regarding the future of the prices for raw material and transportation cost, which fluctuated strongly in the past and are expected to remain fluctuating, there are still uncertainties caused by possible future regulatory action, in particular regarding climate policy and trade rules. (Footnote: We are aware that other factors may influence the cost of steel production as well.) All these factors decide on the future competitiveness of the steel industry in the EU. We cannot predict the long-term development of these factors due to the principal openness of future and due to the at least partial irrationality of human action. In particular changes in the setting of policy priorities on national and international level (e.g. “USA first” – policy, “Green Deal” in Europe, implementation of “Powering Past Coal Alliance” on international level) cannot be reliably forecasted.

However, we do account for these uncertainties and challenges by stating conditions on the main input factors identified to be relevant for the cost of crude steel production, under which the steel industry in the EU is competitive. Based upon this, we develop and analyse corresponding scenarios (Tab. 5). If the identified conditions for competitiveness are not met, relocation to other countries is likely to happen. In this case, we analyse to which countries relocation might occur and its consequences with respect to different aspects of sustainability

Taking the floor price difference as a rough indicator for competitiveness, it is obvious that depending on the scenario chosen relocation of steel production from the EU may take place. We now assess sustainability aspects, in particular effects on climatic change, of such relocations. Based on our findings presented in the previous chapter, we provide in Tab. 5 an overview on the competiveness with respect to floor price for the production of crude steel of Germany’s steel industry for different scenarios. We moreover assess possible impacts on energy demand, CO_2-emissions on national and global level as well as impacts on countries integrated in the value chain. For assessing consequences with respect to sustainability, we include impacts of possible relocations on the overall economy (i.e. employment) due to the relevance of steel as intermediate good for the production of other goods and include feedbacks on other economies.

The results in Tab. 5 indicate that German steel producers will have a competitive disadvantage if the transport cost does not increase significantly and if they are not able to expand their technological lead. Increases in prices for raw material strengthen the position of China, Russia and Brazil as players on the European steel market. Since transporting of steel from China is costlier than from Russia, we expect a cost advantage for Russia if the cost of transport rises. Significantly, higher prices for raw materials can lead to a reduced market share for Germany and also to increased global CO_2-emissions since Russia could gain substantial market share then. We find that in the current situation, producing steel in China enjoys cost advantages. Depending on the scenario, a relocation of steel production from the EU to China or Russia is very possible.

Relocating steel production from the EU will obviously reduce its the CO_2-emissions. However, the specific CO_2-emissions of steel mills in Germany are slightly lower than in China and significantly lower than in Russia (Tab. 5). As more than 3.5 Million tonnes of steel are imported from China and about 9.0 Million tonnes from Russia annually, relocations to these countries may have a considerable impact on global emissions even if the differences in specific CO_2-emissions are small. We thus expect such relocations to result in carbon leakage and increased global emission, in particular in the case of relocating German steel production to countries with less efficient steel production (e.g. Russia). On the other hand, our results indicate that a leadership of Germany in the development of new steel production technologies helps to improve its competitive position and to reduce global specific CO_2-emissions.

Steel production in e.g. Germany and South Korea is linked with economic values generated in countries categorized by a medium HDI (e.g. , South Africa or Indonesia). In contrast to that, the steel production in other countries comprises only activities in high or very high HDI-rated countries. Therefore, certain countries with medium HDI could even benefit from strengthening Germany or South Korea as production locations. According to our calculations, an increase in the cost of raw materials by 400 % will result in a significant increase in the share on the value added of the share of country with medium HDI category (Tab. 5). Thus, since Germany and South Korea obtain mainly raw materials being needed for iron and steel production from medium rated countries they will benefit from increases in prices for raw material.

However, as mentioned above Germany and South Korea may lose market share if the prices for raw materials increase. This may impact the demand of raw material and thus less developed countries.

Tab. 5 reflects the complexity of an assessment of an energy-intensive sector with respect to CO_2-reduction, decreases in specific energy consumption, relocation of employments effects (resulting from cost disadvantages) in combination with impacts on countries with low living standard (incl. e.g. low life expectancy, low gross national income per capita). Information such as presented could help to assess which conditions would be beneficial for the Europe, for the world or for countries with medium HDI.

The results could support selecting and specifying measures for the development of energy and industry policies whereas the weighting of the impacts has to be exploited on political level: The results show that, depending on the development of prices of raw materials, transportation cost and the efficiency improvement, it could be more cost-effective buying steel from countries like China than to produce it in Europe. Taking into consideration that steel is used, as an intermediate good for other goods, from an (pure) economic point of view, increases in steel imports can be beneficial. Regarding national emission reduction targets, a relocation of energy-intensive industries could be beneficial, too. However, according to our calculations, increases in imports could result in higher global CO2 emissions (depending on the technological development in the corresponding country). The results show that a relocation of steel production could also affect countries with low Human Development index. All impacts strongly depend on the developments of the overall framework (including change in prices and trade policies of other countries).

Calculations like ours could help to identify a broader range of implications of developments and can serve as support for appropriate decisions on policy measures.

Efficiency gap	Incr. in transport cost			Increases in prices of raw materials											
				No change (Prices of 2014)				Moderate increase (+100%)				Strong increase (+200%)			
No changes	No changes (Cost level: 2014)	Order with respect to cost		CN	BR	DE	KO	CN	RU	BR	DE	CN	RU	BR	DE
		Cost (DE=1)		0.93	0.94	1.00	1.03	0.9	1.0	1.0	1.0	0.92	0.94	0.97	1.00
		Emis-sions	generated in Europe	0.0	0.0	2.3	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.3
			gen. on global level	2.4	2.3	2.3	2.2	2.4	4.5	2.3	2.3	2.4	4.5	2.3	2.3
		Energy	consumed in Europe	0.0	0.0	20.1	0.0	0.0	0.0	0.0	20.1	0.0	0.0	0.0	20.1
			cons. on global level	21.6	19.0	20.1	20.3	21.6	42.5	19.0	20.1	21.6	42.5	19.0	20.1
		Distribution of value added*		12/87/1	0/100/0	72/25/3	82/9/9	13/86/1	100/0/0	0/100/0	68/28/4	14/85/1	100/0/0	0/100/0	66/30/4
	Moderate increase (+200%)	Order with respect to cost		BR	CN	DE	US	RU	CN	BR	DE	RU	CN	BR	DE
		Cost (DE=1)		0.95	0.99	1.00	1.02	0.96	0.96	0.97	1.00	0.93	0.95	0.97	1.00
		Emis-sions	generated in Europe	0.0	0.0	2.3	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.3
			gen. on global level	2.3	2.4	2.3	2.0	4.5	2.4	2.3	2.3	4.5	2.4	2.3	2.3
		Energy	consumed in Europe	0.0	0.0	20.1	0.0	0.0	0.0	0.0	20.1	0.0	0.0	0.0	20.1
			cons. on global level	19.0	21.6	20.1	18.4	42.5	21.6	19.0	20.1	42.5	21.6	19.0	20.1
		Distribution of value added*		0/100/0	12/87/1	73/24/3	98/2/0	100/0/0	13/86/1	0/100/0	68/28/4	100/0/0	14/85/1	0/100/0	67/29/4
	High increase (+400%)	Order with respect to cost		BR	CN	DE	US	RU	CN	BR	DE	RU	CN	BR	DE
		Cost (DE=1)		0.95	0.99	1.00	1.02	0.96	0.96	0.97	1.00	0.93	0.95	0.97	1.00
		Emissions	generated in Europe	0.0	0.0	2.3	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	2.3
			gen. on global level	2.3	2.4	2.3	2.0	4.5	2.4	2.3	2.3	4.5	2.4	2.3	2.3
		Energy	consumed in Europe	0.0	0.0	20.1	0.0	0.0	0.0	0.0	20.1	0.0	0.0	0.0	20.1
			cons. on global level	19.0	21.6	20.1	18.4	42.5	21.6	19.0	20.1	42.5	21.6	19.0	20.1
		Distribution of value added*		0/100/0	12/87/1	73/24/3	98/2/0	100/0/0	13/86/1	0/100/0	68/28/4	100/0/0	14/85/1	0/100/0	67/29/4
Moderate (Δe=10%)	No changes (Cost level: 2014)	Order with respect to cost		CN	BR	DE	KO	CN	RU	BR	DE	CN	RU	DE	BR
		Cost (DE=1)		0.96	0.98	1.00	1.06	0.96	1.00	1.00	1.00	0.95	0.97	1.00	1.01
		Emissions	generated in Europe	0.0	0.0	2.1	0.0	0.0	0.0	0.0	2.1	0.0	0.0	2.1	0.0
			gen. on global level	2.4	2.3	2.1	2.2	2.4	4.5	2.3	2.1	2.4	4.5	2.1	2.3
		Energy	consumed in Europe	0.0	0.0	17.7	0.0	0.0	0.0	0.0	17.7	0.0	0.0	17.7	0.0
			cons. on global level	21.6	19.0	17.7	20.3	21.6	42.5	19.0	17.7	21.6	42.5	17.7	19.0
		Distribution of value added*		12/87/1	0/100/0	72/25/3	82/9/9	13/86/1	100/0/0	0/100/0	67/29/4	14/85/1	100/0/0	66/30/4	0/100/0
	Moderate increase (+200%)	Order with respect to cost		BR	DE	CN	US	RU	CN	DE	BR	RU	CN	DE	BR
		Cost (DE=1)		0.98	1.00	1.03	1.06	1.00	1.00	1.00	1.00	0.97	0.98	1.00	1.01
		Emissions	generated in Europe	0.0	2.1	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	2.1	0.0
			gen. on global level	2.3	2.1	2.4	2.0	4.5	2.4	2.1	2.3	4.5	2.4	2.1	2.3
		Energy	consumed in Europe	0.0	17.7	0.0	0.0	0.0	0.0	17.7	0.0	0.0	0.0	17.7	0.0
			cons. on global level	19.0	17.7	21.6	18.4	42.5	21.6	17.7	19.0	42.5	21.6	17.7	19.0
		Distribution of value added*		0/100/0	72/25/3	12/87/1	98/2/0	100/0/0	13/86/1	68/28/4	0/100/0	100/0/0	14/85/1	66/30/4	0/100/0
	High increase (+400	Order with respect to cost		BR	DE	RU	US	RU	DE	BR	CN	RU	DE	BR	CN
		Cost (DE=1)		0.98	1.00	1.06	1.06	0.99	1.00	1.00	1.04	0.96	1.00	1.01	1.01
		Emissions	generated in Europe	0.0	2.1	0.0	0.0	0.0	2.1	0.0	0.0	0.0	2.1	0.0	0.0
			gen. on global level	2.3	2.1	4.5	2.0	4.5	2.1	2.3	2.4	4.5	2.1	2.3	2.4
		Energy	consumed in Europe	0.0	17.7	0.0	0.0	0.0	17.7	0.0	0.0	0.0	17.7	0.0	0.0
			cons. on global level	19.0	17.7	42.5	18.4	42.5	17.7	19.0	21.6	42.5	17.7	19.0	21.6
		Distribution of value added*		0/100/0	73/24/3	100/0/0	98/2/0	100/0/0	68/28/4	0/100/0	13/86/1	100/0/0	66/30/4	0/100/0	14/85/1
High (Δe=20%)	No changes (Cost level: 2014)	Order with respect to cost		CN	DE	BR	KO	CN	DE	RU	BR	CN	DE	RU	BR
		Cost (DE=1)		1.00	1.00	1.02	1.10	0.99	1.00	1.04	1.04	0.99	1.00	1.00	1.05
		Emissions	generated in Europe	0.0	1.8	0.0	0.0	0.0	1.8	0.0	0.0	0.0	1.8	0.0	0.0
			gen. on global level	2.4	1.8	2.3	2.2	2.4	1.8	4.5	2.3	2.4	1.8	4.5	2.3
		Energy	consumed in Europe	0.0	15.4	0.0	0.0	0.0	15.4	0.0	0.0	0.0	15.4	0.0	0.0
			cons. on global level	21.6	15.4	19.0	20.3	21.6	15.4	42.5	19.0	21.6	15.4	42.5	19.0
		Distribution of value added*		12/87/1	71/26/3	0/100/0	82/9/9	13/86/1	66/30/4	100/0/0	0/100/0	14/85/1	65/31/4	100/0/0	0/100/0
	Moderate increase (+200%)	Order with respect to cost		DE	BR	CN	US	DE	RU	CN	BR	DE	RU	CN	BR
		Cost (DE=1)		1.00	1.02	1.07	1.10	1.00	1.03	1.03	1.04	1.00	1.00	1.02	1.05
		Emissions	generated in Europe	1.8	0.0	0.0	0.0	1.8	0.0	0.0	0.0	1.8	0.0	0.0	0.0
			gen. on global level	1.8	2.3	2.4	2.0	1.8	4.5	2.4	2.3	1.8	4.5	2.4	2.3
		Energy	consumed in Europe	15.4	0.0	0.0	0.0	15.4	0.0	0.0	0.0	15.4	0.0	0.0	0.0
			cons. on global level	15.4	19.0	21.6	18.4	15.4	42.5	21.6	19.0	15.4	42.5	21.6	19.0
		Low income country		72/25/3	0/100/0	12/87/1	98/2/0	67/29/4	100/0/0	13/86/1	0/100/0	65/31/4	100/0/0	14/85/1	0/100/0
	High increase (+400)	Order with respect to cost		DE	BR	RU	US	DE	RU	BR	CN	DE	RU	BR	CN
		Cost (DE=1)		1.00	1.02	1.10	1.10	1.00	1.03	1.04	1.08	1.00	1.00	1.05	1.05
		Emissions	generated in Europe	1.8	0.0	0.0	0.0	1.8	0.0	0.0	0.0	1.8	0.0	0.0	0.0
			gen. on global level	1.8	2.3	4.5	2.0	1.8	4.5	2.3	2.4	1.8	4.5	2.3	2.4
		Energy	consumed in Europe	15.4	0.0	0.0	0.0	15.4	0.0	0.0	0.0	15.4	0.0	0.0	0.0
			cons. on global level	15.4	19.0	42.5	18.4	15.4	42.5	19.0	21.6	15.4	42.5	19.0	21.6
		Distribution of value added*		72/25/3	0/100/0	100/0/0	98/2/0	67/29/4	100/0/0	0/100/0	13/86/1	65/31/4	100/0/0	0/100/0	14/85/1

Remarks: * Share of country on the overall cost clustered by HDI category (very high/high/medium) in %, BR: Brazil, CN: China, DE: Germany, KO: Korea, RUS: Russia, US: USA

Tab. 5: Cost, emissions, specific energy demand and effects on the distribution of value added related to the production of 1 tonne Crude steel

5 Conclusions

Currently, ambitions of European climate policy to reduce emissions of greenhouse gases, disadvantages in production costs and international disputes about trading rules pose challenges for the European steel industry. The European steel industry supports the vision of a climate-neutral economy and already now the production of steel is linked with low CO2 emissions compared to other countries. However, cost disadvantages increase the likelihood of relocation of production that could bring about higher emission levels globally. Further pressure on the European steel sector results from global excess capacities and trade tariffs by third countries (i.e. USA) that tend to increase the endeavor of countries like China, Brazil or Russia to export more steel to Europe.

In our paper we analyzed under which conditions the EU steel industry will be still competitive. We stress that relocation will not only have ecological impacts but also affects least developed and developing countries since they participate in the value chain. The results underpin arguments for implementing measure to avoid relocation of the European steel industry.

To assess the competiveness of Germany's steel industry (as the most important steel industry in the EU) and resulting impacts on national and international level in an uncertain environment, we concentrated on comparing floor prices under varying circumstances. Since the share of Germany's steel industry on the US market is rather small, we to a large extent focus on secondary effects resulting from the increase of the US tariffs on steel and steel products emerging to the European market. We expect that the implementation of duties for steel products in the US will force steel producing countries to shift their activities towards the European markets besides others. This holds particularly for China, Brazil and Russia.

For that assessment, we applied a novel approach, which can deal with impacts of changes in economics of steel production on the trade of steel, on emissions, energy demand, on the involvement of developing countries in the value chain, and the need for innovations to avoid relocations of production. Based on variations of cost factors, we take uncertainties into consideration and analyzed changes in floor price differences with respect to selected competitors on the European steel market with our technology-based floor price model. That systematic analysis was made possible by a parametric meta-model whose structure was determined based upon visualizations. According to our calculations, preserving the competitiveness of Germany's steel industry with respect to floor price in a free market requires intensive measures to improve energy efficiency. However, even significant improvements in that field do not necessarily lead to equality of floor prices. Raising cost of transport are advantageous for Germany's steel industry when considering differences of floor prices in all cases considered. This implies that for some competitors and scenarios, there is only hope of raising transport cost in order to achieve equality in floor prices. This applies particularly in the case of rising costs for CO_2-emissions. Taking the difference in floor price as rough indicator for competitiveness and thus for the likelihood of relocation of production, we assess consequences of such relocation in terms of sustainability aspects and CO_2-emissions. Relocating steel production from the EU to China increases global emissions slightly, whereas relocating production to Russia leads to notable carbon leakage. Thus, high prices for CO_2-allowances in the EU could result in higher emissions on international level. Therefore, for a successful emission reduction policy it must be taken into account that leakage effects can countervail reductions at national level. We show that relocation of steel production from the EU may indirectly impact countries with a lower HDI and which may still need some support from developed countries to reach a greater standard of life.

The EU is one of the major world steel producers and importers. At the domestic market not only the steel produced in the member states, but also foreign producers are competing for market share. In this context technology choices, efficiency improvements and environmental policies abroad impact the local European producers.

Measures like the safeguard measures for steel that include duty of 25% for imports above fixed tariff-rate quotas (EC 2019) help to stop relocation of production. However, such interventions may entail similar actions by other countries and may affect free trade.
Measures focusing on the support of R&D in the steel sector (like the funds as Horizon 2020, structural funds, and the research fund for coal and steel) may fit better in a world with free trade.

6 References

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Appendix

			Manufacture of basic metals				Manufacture of fabricated metal products, except machinery and equipment				Manufacture of machinery and equipment not elsewhere classified.			
			2013	2014	2015	2016	2013	2014	2015	2016	2013	2014	2015	2016
Number of enterprises	1000	EU28	17.1	17.2	16.6	16.8	17.1	17.2	16.6	16.8	17.1	17.2	16.6	16.8
		Germany	2.8	2.7	2.7	2.6	2.8	2.7	2.7	2.6	2.8	2.7	2.7	2.6
Value added at factor cost	1000 mio. Euro	EU28	57.0	62.0	63.0		57.0	62.0	63.0		57.0	62.0	63.0	
		Germany	18.5	19.0	19.3	19.5	18.5	19.0	19.3	19.5	18.5	19.0	19.3	19.5
Production value		EU28	330.0	330.0	330.0	310.0	330.0	330.0	330.0	310.0	330.0	330.0	330.0	310.0
		Germany	97.4	95.9	96.7	90.6	97.4	95.9	96.7	90.6	97.4	95.9	96.7	90.6

Source: [6]

Tab. A-1: Key indicators: manufacturing of steel and metal products in the EU-28 and Germany

BF/BOF		Germany	China	Japan	United States	India	Russia	South Korea
Iron Ore	tonne	1.53	1.55	1.53	1.52	1.72	1.65	1.40
Coking Coal	tonne	0.83	0.86	0.86	0.62	1.03	1.62	0.79
Steel Scrap	tonne	0.14	0.12	0.15	0.18	0.18	0.18	0.17
Thermal energy	GJ	-6.28	-6.86	-7.57	-4.31	-6.00	-7.04	-7.32
Electricity	kWh	172.34	142.12	171.47	151.68	197.19	209.22	144.62
Labor	hours	0.50	1.89	0.48	0.46	1.88	1.97	0.38
EAF								
Steel Scrap	tonne	1.09	1.23	1.09	1.04	0.23	1.1	1.23
Oxygen	m^3	50	65	16	5	65	14	65
Ferroalloys	tonne	0.011	0.14	0.011	0.023	0.14	0.014	0.14
Fluxes	tonne	0.06	0.025	0.029	0.025	0.025	0.043	0.025
Electrodes	tonne	0.003	0.006	0.002	0.002	0.006	0.002	0,006
Thermal energy	GJ	0.43	0.43	0.58	0.43		0.426	
Electricity	kWh	400	370	360	370	748	250	748
Labor	hours	0.4	0.6	0.55	0.6	0.6	0.34	0.6

Source: [66, 67]

Tab A-2: Technological Parameters (inputs per tonne)

Prices (fob)		Ger-many	China	Japan	Aus-tralia	USA	Brazil	Indo-nesia	South Africa	Can-ada	Russia	South Korea	India	
Coking Coal	$/tone	140	92	120	125.5	137	120	126	27	121	87	235	111	[66]
Iron Ore	$/tone	160	97.6	116	120	97	99	120	79	99	65	111	34	
Steel Scrap	$/tone	229	236	205	418	352	119	418	345	387	200	386	176	

Prices (domestic)		Germany	China	Japan	United States	India	Russia	South Korea	
Thermal energy	$/GJ	14.1	11.7	13.4	9.4	14.8	1.4	16.2	[66]
Electricity	$/kWh	0.16	0.14	0.17	0.12	0.17	0.06	0.18	
Labor	$/hour	37.8	6.44	35.8	54.87	3.35	12.15	22.85	

Transportation cost

Factor	Unit	Capesize	Panamax	
Charter rate	$/day	15 000	8 500	Own calc. based on [68]
Load volume	t	150 000	70 000	
Speed	knt/h	14	14	
MDO* cons.	t/day	15	14	
MDO price	$/t	838	838	
HFO** cons.	t/day	56	27	
HFO price	$/t	558	558	
Docking fee, …	$/visit	161 000	26 000	

Remarks: *MDO: marine diesel oil, **HFO: heavy fuel oil, *** Round trip (days), including congestion and bunkering – Capesize – Iron ore

Tab. A-3: Economic Parameters being relevant for iron and steel production

2011	Unit	Germany	South Korea	Russia	India	United States	Japan	China	*Source*
Iron ore									
Domestic prod.	Mio. metric tons	0.5	5.3	103.8	169.7	54.7		1335.0	[69]
Total Imports		39.7	64.9	0.15	1.3	5.3	128.5	686.7	
Imports from (share in total imports)		BR (57%) CA (15%) SE (13%), ZA (6%), Rest (9%)	AU (68%), BR (25%), ZA (4%), IN (2%), Rest (0%)	(UA 100%)	ML (52%) UA (22%) Rest (26%)	CA (74 %), BR (11 %), ZA (3 %), Rest (12 %)	AU (62%) BR (28%), ZA (4%), IN (3%), Rest (3%)	AU (43%), BR (21%), IN (11%), ZA (5%), Rest (20%)	[70]
Coking coal									
Production	Mio. t	7.3	-	65.4	44.3	81.3	-	510	[71, 72]
Total Imports	Mio. t	8.8	32.2	2.4	33.9	0.2	53.8	44.6	
Imports from (share in total imports)	(%)	US (32%), AU (29%) RU (11%), CA (9%), CO (6%), ZA (6%), PL (6%) Rest (1%)	AU (51%), US (16%), CA (20%), RU (7%), CN (6%)	-	AU (85%), US (10%), CA (1%), Rest (4%)	CA (100%)	AU (55%), ID (21%), CA (10%), USA (9%), RU (4%), Rest (1 %)	AU (30%), US (9%), CA (7%), RU (7%), Rest (46%)	[71, 73]
Scrap									
Production	Million metric tonnes	22.7	24.0	23.8	n.b.	81.1	41.9	115.8	[74, 75]
Exports		9.0	0.4	4.0		24.4	5.4	0	[76]
Imports		6.2	8.6	0	6.2	4.0	0.6	6.8	
Orgins of Imports		PL (19%) NL (29%) CZ (17%) Rest (45%)	JP (34%), US (34%), RU (12%), Rest (20%)		US (15%), GB (15%), AE: (14%), ZA (9%), CN (3%), Rest (44%)	CA (81%), MX (12), Rest (7%)	US (38%) KR (20%) Rest (42%)	US (41%), JP (34%), AU (6%), Rest (19%)	[70]
AE: United Arab Emirates AU: Australia, BR: Brazil, CA: Canada, CN: China, CO: Colombia, CZ:, ID: Indonesia, IN: India, JP: Japan, KR: South Korea, ML: Mali, MX: Mexico, NL: Netherlands, PL: Poland, RU: Russia, SE: Sweden, UA: Ukraine, ZA: South Africa									

Tab. A-4: Domestic production and imports of input factors being relevant for crude steel production

	Germany	Europe	China	Japan	Australia	USA	South America	Indonesia	South Africa	Canada	Russian Federation	Rep. of Korea	India	Central America	Middle East	Africa
Germany			85	92	82	29	36	80	45	25	29	89	79	48	54	39
Europe			83	91	82	29	36	80	45	25	29	88	79	47	52	38
China	81	79	0	19	32	96	77	23	55	97	99	16	35	102	43	78
Japan	88	87	19	0	34	100	81	27	59	100	103	18	39	109	55	85
Australia	80	80	34	36	0	117	56	39	63	39		37	44	55	57	58
USA	29	29	100	104	119	0	31	55	55	18		102	83	19	80	53
South America	38	38	83	87	60	33	0	65	40	57		97	83	14	69	53
Indonesia	82	82	29	33	43	57	65	0	47	53		31	28	69	40	46
South Africa	46	46	54	64	66	56	39	46	0	93		57	38	55	33	22
Canada	25	25	101	104	41	18	55	51	92	0		40	65	28	78	78
Russian Federation	28	28	102	106							0	14				
Rep. of Korea	84	83	15	17	34	97	90	24	51	35	10	0	11	107	53	81
India	77	77	37	41	44	81	79	24	35	63		14	0	76	17	60
Central America	47	46	105	112	56	18	11	66	53	27		111	77	0	58	48
Middle East	53	51	46	58	58	79	66	37	31	77		57	18	58	0	47
Africa	38	37	81	88	59	52	50	43	20	77		85	61	48	47	0

Source: Own calculation, [59]

Tab. A-5: Round trip (days), including congestion and bunkering – Capesize – Iron ore

	Germany	Europe	China	Japan	Australia	USA	South America	Indonesia	South Africa	Kanada	Russian Federation	Rep. of Korea	India	Central America	Middle East	Africa
Germany			75	75	69	28	35	62	44	24	28	88	56	47	46	38
Europe			75	75	69	28	35	62	44	24	28	87	56	46	46	37
China	71	71	0	18	31	72	74	22	54	77	58	15	34	101	48	77
Japan	71	71	18	0	33	65	73	26	58	71	62	17	38	108	54	84
Australia	67	67	33	35	0	116	54	38	62	38		36	43	54	56	57
USA	28	28	76	69	118	0	36	54	54	17		72	68	18	44	50
South America	37	37	80	79	58	38	0	64	39	56		96	82	13	50	52
Indonesia	64	64	28	32	42	56	64	0	46	52		30	27	68	39	45
South Africa	45	45	59	63	65	55	38	45	0	92		56	37	54	32	21
Canada	24	24	81	75	40	17	54	50	91	0		39	64	27	74	70
Russian Federation	27	27	61	65								13				
Rep. of Korea	83	82	14	16	33	67	89	23	50	34	9	0	31	106	52	80
India	54	54	36	40	43	66	78	23	34	62		34	0	75	25	59
Central America	46	45	104	111	55	17	10	65	52	26		110	76	0	57	47
Middle East	45	45	51	57	57	43	47	36	30	73		56	26	57	0	46
Africa	37	36	80	87	58	49	49	42	19	69		84	60	47	46	0

Source: Own calculation based on [59]

Tab. A-6: Round trip (days), including congestion and bunkering –Panamax – Iron ore

	Germany	Europe	China	Japan	Australia	USA	South America	Indonesia	South Africa	Canada	Russian Federation	Rep. of Korea	India	Central America	Middle East	Africa
Germany	0	14	86	93	94	30	37	81	52	98	23	90	49	49	55	40
Europe	14	0	84	92	93	30	37	81	52	98	23	89	48	48	53	39
China	86	84	0	20	36	97	88	24	50	41	19	17	43	103	44	79
Japan	93	92	20	0	36	101	93	28	55	35	17	19	51	110	56	86
Australia	101	100	43	43	0	123	61	45	69	45		43	49	61	63	64
USA	35	35	102	106	121	0	20	57	57	20		104	84	21	82	55
South America	43	43	94	99	60	21	0	66	41	58		98	83	15	70	54
Indonesia	87	87	30	34	44	58	66	0	48	54		32	28	70	41	47
South Africa	59	59	57	62	69	59	42	49	0	96		60	40	58	36	25
Canada	102	102	45	39	42	19	56	52	93	0		41	65	29	79	79
Russian Federation	24	24	20	18							0	17				
Rep. of Korea	90	89	17	19	36	99	92	26	53	37	16	0	12	109	55	83
India	50	49	44	52	43	80	78	23	34	62		13	0	75	16	59
Central America	53	52	107	114	58	20	13	68	55	29		113	78	0	60	50
Middle East	59	57	48	60	60	81	68	39	33	79		59	19	60	0	49
Africa	44	43	83	90	61	54	52	45	22	79		87	62	50	49	0

Source: Own calculation based on [59]

Tab. A-7: Round trip (days), including congestion and bunkering – Capesize – Coal

	Germany	Europe	China	Japan	Australia	USA	South America	Indonesia	South Africa	Kanada	Russian Federation	Rep. of Korea	India	Central America	Middle East	Africa
Germany			76	76	83	29	36	63	51	62	22	89	55	48	47	39
Europe			76	76	83	29	36	63	51	62	22	88	54	47	47	38
China	76	76	0	19	35	73	87	23	49	40	18	16	42	102	49	78
Japan	76	76	19	0	35	66	92	27	54	34	16	18	50	109	55	85
Australia	90	90	42	42	0	122	60	44	68	44		42	48	60	62	63
USA	34	34	78	71	120	0	38	56	56	19		74	69	20	46	52
South America	42	42	93	98	59	39	0	65	40	57		97	82	14	51	53
Indonesia	69	69	29	33	43	57	65	0	47	53		31	27	69	40	46
South Africa	58	58	56	61	68	58	41	48	0	95		59	39	57	35	24
Canada	66	66	44	38	41	18	55	51	92	0		40	64	28	75	71
Russian Federation	23	23	19	17							0	16				
Rep. of Korea	89	88	16	18	35	69	91	25	52	36	15	0	11	108	54	82
India	56	55	43	51	42	65	77	22	33	61		12	0	74	24	58
Central America	52	51	106	113	57	19	12	67	54	28		112	77	0	59	49
Middle East	51	51	53	59	59	45	49	38	32	75		58	27	59	0	48
Africa	43	42	82	89	60	51	51	44	21	71		86	61	49	48	0

Source: Own calculation based on [59]

Tab. A-8: Round trip (days), including congestion and bunkering –Panamax – Coal

		Classification		
	HDI	Very high (0.800 or greater)	High (0.700–0.799)	Medium (0.550–0.699)
Australia	0.939	x		
Germany	0.936	x		
Canada	0.926	x		
USA	0.924	x		
Japan	0.909	x		
Rep. of Korea	0.903	x		
Russia	0.816	x		
China	0.752		x	
Brazil	0.759		x	
South Africa	0.699			x
Indonesia	0.694			x
India	0.640			x

Source: [60]

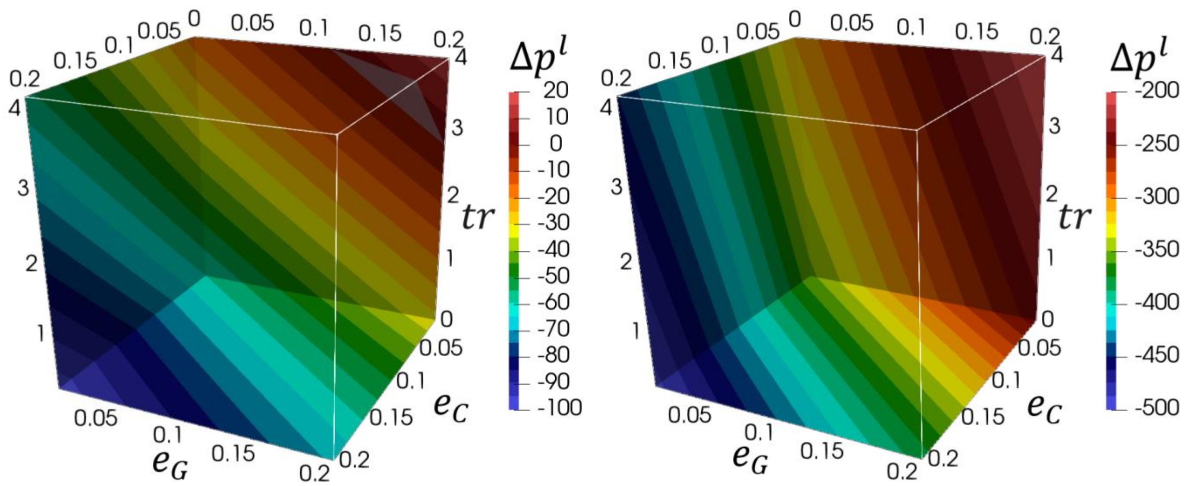
Tab. A-9: Human Development Index (HDI)

	β_1	β_2	β_3	β_4	β_5	β_6
Brazil	-56.00	0.075	176.72	-138.66	3.51	-0.090
	-1.86	0	102.47	-99.34	0	0
China	-62.87	13.68	176.72	-116.55	3.51	-0.16
	-24.78	0	102.47	-82.62	0	0
India	-93.11	10.62	176.72	-188.11	3.51	-1.92
	-73.41	0	102.47	-125.24	0	0
Japan	13.73	28.00	176.72	-153.81	3.51	-6.47
	48.19	0	102.47	-113.61	0	0
Korea	-22.63	24.97	176.72	-135.01	3.51	-5.38
	33.10	0	102.47	-99.50	0	0
Russia	-18.81	-1.65	176.72	-139.10	3.51	0.0003
	-39.71	0	102.47	-112.78	0	0

Tab. A-10: Coefficients for $\Delta\bar{p}^l$ for different competitors, CO_2_30

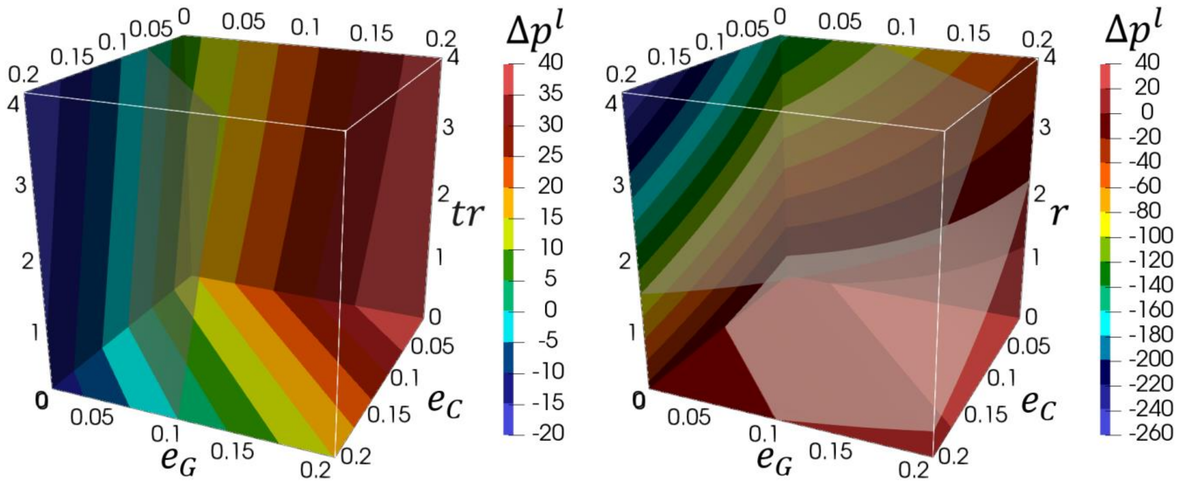
	β_1	β_2	β_3	β_4	β_5	β_6
Brazil	-78.02	0.075	198.74	-138.66	3.51	-0.090
	-1.86	0	102.47	-99.34	0	0
China	-84.89	13.68	198.74	-116.55	3.51	-0.16
	-24.78	0	102.47	-82.62	0	0
India	-115.14	10.62	198.74	-188.11	3.51	-1.92
	-73.41	0	102.47	-125.24	0	0
Japan	-8.30	28.00	198.74	-153.81	3.51	-6.47
	48.19	0	102.47	-113.61	0	0
Korea	-44.65	24.97	198.74	-135.01	3.51	-5.38
	33.10	0	102.47	-99.50	0	0
Russia	-40.83	-1.65	198.72	-139.10	3.51	0.0003
	-39.71	0	102.47	-112.78	0	0

Tab. A-11: Coefficients for $\Delta\bar{p}^l$ for different competitors, CO_2_50



Remarks: e_G: Improvement in efficiency in Germany compared to 2014, e_C: Improvement in efficiency in competing country compared to 2014, r: changes prices for raw material [1: increase by 100%, 4: increase by 400% compared to 2014], Δp^l: differences in floor prices [$/t], tr: increases in cost for transport

Fig. A-1: $\Delta \boldsymbol{p}^l$ for India and Germany, r fixed (left: $r = 0$, right: $r = 4$), CO_2_0.



Remarks: e_G: Improvement in efficiency in Germany compared to 2014, e_C: Improvement in efficiency in competing country compared to 2014, r: changes prices for raw material [1: increase by 100%, 4: increase by 400% compared to 2014], Δp^l: differences in floor prices [$/t], tr: increases in cost for transport

Fig. A-2: Δp^l for Russia and Germany, (left: $r = 0$ fixed, right: $tr = 0$ fixed), CO_2_0 (left: level sets for $\Delta p^l = 0$, right: level sets for $\Delta p^l = 0;\ -100$)