Paying the full price of steel – Perspectives on the cost of reducing carbon dioxide emissions from the steel industry

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Abstract

This study examines the impacts felt downstream of carbon pricing and investments made in CO_2 abatement within the steel industry. Using the supply of steel to a passenger car as a case study, the effects of a steel price increase on cost structures and price at each step of the supply chain were assessed. Since the prices of emission allowances under the European Union Emissions Trading System fall well below those required to unlock investments in low-CO_2 production processes in the integrated steelmaking industry this paper seeks to pave the way for a discussion on complementary policy options. The results of the analysis suggest that that passing on the compliance costs of the steel industry would have only marginal impacts on costs and prices for the end-use sectors (e.g., on the production cost or selling price of the passenger car). Under the assumptions made herein, at a carbon price of 100 €/tCO_2, the retail price of a mid-sized European passenger car would have to be increased by approximately 100–125 €/car (<0.5%) to cover the projected increases in steel production costs.

Keywords: Integrated steelmaking; Carbon dioxide; Emission reduction; Costs; Supply chain; Steel; Car manufacturing; Climate policy

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1 Introduction

The Nordic countries have adopted an offensive stance to addressing the challenge of mitigating global climate change. Nonetheless, the Nordic climate policy targeting the industrial sectors continues to rely almost exclusively on the price signal imposed through the EU Emissions Trading System (EU ETS). However, in the case of carbon-intensive industries, as long as there exists a need to balance competitiveness and environmental effectiveness without additional policy measures, reliance on the trading system alone may lead to under-investment in the high-abatement, long-lead-time measures required to reach the long-term targets for emissions reductions (Vogt-Schilb et al., 2014; Bennett and Heidug, 2014).

In the case of iron and steel production from virgin iron ores, which is the focus of this paper, achieving significant decarbonisation up to Year 2050 will require substantial changes in the steelmaking process (Daniëls, 2002; Fischedick et al., 2014; Wörtler, 2014). While several alternative low-CO_2 processes have been investigated at the laboratory scale, moving from the laboratory or pilot plant to larger-scale operation will involve substantial costs (Birat et al., 2008; IEAGHG, 2013; Ho et al., 2013; Hooye et al., 2013). Given the long investment cycles associated with a capital-intensive industry like the steel industry and the fact that CO_2 emissions have to be reduced by some 80% up to Year 2050, there is an urgent need to find ways to unlock investments in the development and implementation of breakthrough technologies. While the existing literature typically focuses solely on the impacts of cost on primary production and the primary product of investing in high-abatement, long-lead-time measures, the present paper examines how cost increases in the steel industry affect both costs and prices further up the product chain.

Skelton and Allwood (2013) have shown that even in steel-intensive sectors, such as the construction and vehicle-manufacturing industries, the actual expenditure on steel is relatively small compared to the expenditure on other inputs. Their results also indicate that including carbon costs in the steel price would have a limited effect on the cost structure for downstream consumers. There are few other examples of attempts to quantify the impact downstream of CO_2 pricing and abatement in the steel industry. Neuhoff et al. (2014b) used a rough estimate of the carbon cost impact on an average car to report the additional cost as being in the order of 9–221 €/car using different assumptions with regards to the specific emissions from steel manufacturing (1.3–2.3 tCO_2/t steel) and the carbon price (5–100 €/tCO_2). Similarly, PwC (2010) estimated that the Australian vehicle manufacturing industry faced an additional cost, in the absence of government assistance for companies in the supply chain, in the order of 222–412 AUD per vehicle produced, based on a carbon price of 20–30 AUD/tCO_2.

Our investigation differs from these previous studies in that it takes as its point of departure the preconditions and costs of investments in low-CO_2 processes in the steel industry, and, by accounting for changes in reference conditions across the supply chain of steel. Using the supply of steel to a passenger car as a case study, this paper seeks to pave the way for broadening the discussion as to how best to allocate the costs required to develop and deploy new low-carbon steel-making processes.

2 Method

To place the analysis in context, we begin by providing an overview of the material and value flows involved in the supply chain of steel. Then, based on performance data for the Nordic iron ore-based steel industry, we assess how compliance costs, i.e., the combined cost of buying emission allowances and investing in new low-carbon process technology affects the break-even costs for primary production. Finally, we estimate the magnitude of the cost increases that may occur in the auto industry due to increases in the acquisition costs for steel products.

2.1 Material flows and value chains

The study reported herein relies on an approach similar to that used in a previous study by the authors in which the focus was on the cement industry and the supply chain of cement (Rootzén and Johnsson, 2015b). Steel and cement are both intermediates in the supply chain of a large range of final goods, and both our present and previous studies build on the recognition that as these basic materials are transformed and passed along the chain of production their shares of the total input expenditures gradually diminish (Dahlström and Ekins, 2006; Allwood et al., 2011; Skelton and Allwood, 2013). However, the fact that the markets for cement and concrete are mostly regional meant that the material flows involved in the Nordic cement supply chain could be traced with fairly good accuracy. This is not the case for the steel industry, in that steel and semi-finished steel products are traded globally. In addition, there are other characteristics that complicate the mapping of the material and value flows involved in the chain of production, fabrication, and end-uses of steel. These characteristics include: the range and variation of the steel product portfolio with a significant span between low- and high-value-added products; the fact that for many applications, primary and secondary steel are nearly perfect substitutes; and the number of, and in some cases the complex network of, intermediate parties involved (steel service centres, distributors, and components manufacturers) before the steel reaches the end-user. Nevertheless, to provide a context for the subsequent analysis, we give a basic overview of the flows of steel that link the Nordic iron ore-based steel industry with the final consumers of the steel or steel-containing products (Figure 1). Following Dahlström and Ekins (2006) and Cullen et al. (2012), the production chain and the associated material flows can be subdivided into four production steps: (1) iron and steel making (including reduction of the iron ore, steelmaking, and casting); (2) finishing (including rolling, forming, and coating); (3) fabrication and manufacturing (including the intermediate processing of semi-finished steel products by various manufacturing sectors); and (4) eventual consumption (divided into four main sectors and ten subsectors). The flows of steel were traced from the bottom up using the three Nordic integrated iron and steel production plants currently in production (with an overall average annual production capacity of approximately 7.5 Mt crude steel/year), as the point of departure. The classification of the different steel products into categories (1) and (2) were made based on data from SSAB (2005), Rautaruukki (2008), and WSA (2013). Since there are no public records of the subsequent flow of semi-finished steel, the splitting of the flow of intermediate steel products is approximate. Thus, the estimates of the categories of final consumption of primary steel across end-use sectors (4) rely on data that describe European and global conditions (Cullen et al., 2012; Eurofer, 2015).

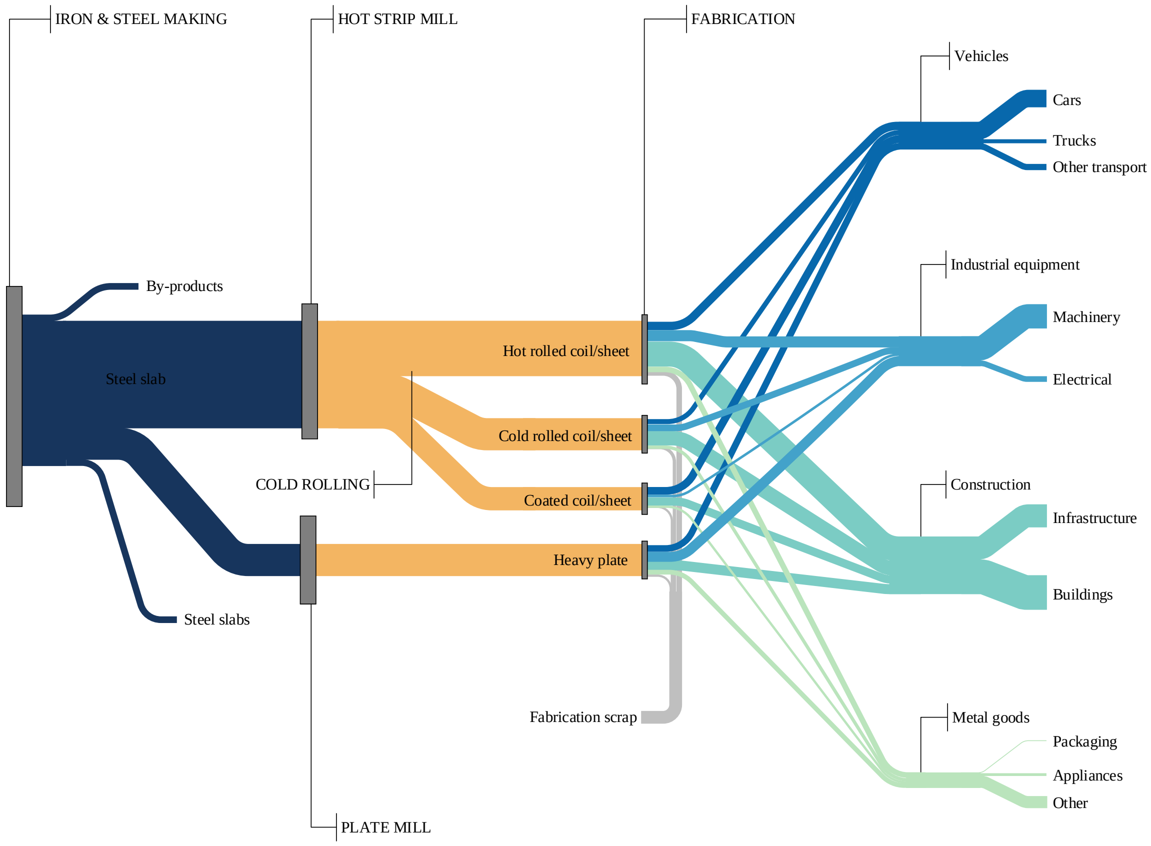

Figure 1. Illustration of the main material flows involved in the supply chain of steel, from primary production in the Nordic integrated steel plants to final consumer products. Whereas the estimates of the composition of the steel used in the respective end-use sectors are rough, the width of each line gives an approximation of the share (% by weight) of the total annual primary steel production in the Nordic countries that enters the respective steel product category and final end-use sector.

2.2 Carbon cost impacts from steel to car manufacturing

In the subsequent analysis, the supply of steel to produce a passenger car was used as a case study. Using a stylised representation, the supply chain can be described as: (1) the production of automotive steel in a hypothetical integrated steel plant; *via* (2) further preparation of steel and steel-containing automotive parts in the components manufacturing industry; to eventual use (3) in the assembly of a mid-sized passenger car. The set-up of the production process (three options) at the steel works and market price for emissions allowances (three price levels) decide the price of the steel. Specifications of the material compositions of the passenger cars considered (four functionally equivalent versions of a European mid-sized passenger car) define the amount and mix of steel required. Based on descriptions of the cost structure in each step of the supply chain, the actual expenditure on steel is compared to the expenditure on other inputs (Figure 2). All flat steel products used in the car are assumed to be sourced from the same hypothetical average Nordic integrated steel plant, and in the reference case, the steel plant is operating with existing units and with the price of emissions allowances under the EU ETS (EUA) set at zero. We assume that industry pass-through of cost is complete, in other words that the intermediate and final consumers of the steel-containing products bear the full costs of CO_2 trading and investments in CO_2 abatement. As in the study conducted by Skelton and Allwood (2013), the analysis of the impact downstream of steel price increases attributable to CO_2 trading and investments in CO_2 abatement measures at the steel plant has been carried out under *ceteris paribus* assumptions. All the additional costs in the steel industry are assumed to be passed through completely along the supply chain. Furthermore, for the components and car manufacturers, it is only the steel acquisition costs that change; all the other costs are kept constant. Finally, whereas the impact of carbon cost on two light-weight versions of the reference car, in which aluminium replaces steel, have been investigated, increases in the selling price of steel are not assumed to lead to substitution effects.

Additional assumptions and limitations applied at each step in the chain are described in Sections 2.2.1–2.2.3.

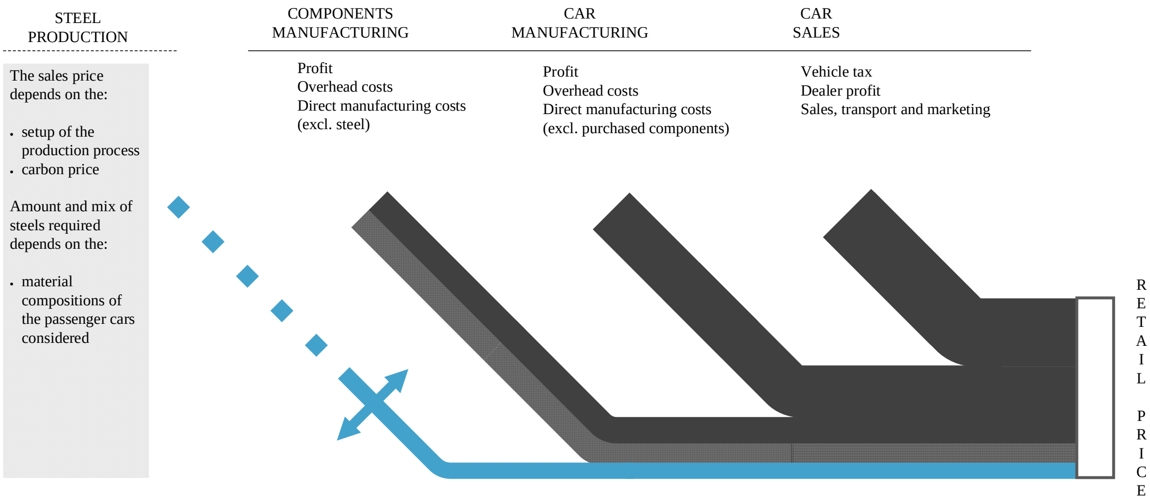

Figure 2. Illustration of the basic analysis approach. The ‘basic steel price’, i.e., the price of the intermediate steel product that exits the steelworks depends on the set-up of the production process and the price of emissions allowances. In the reference case, the steel plant is operated with existing units and with the price of emissions allowances set at zero. By initially determining for the reference case the steel acquisition cost share of overall expenditures for each step of the supply chain, the impacts of changes in steel production costs can be assessed.

2.2.1 Integrated iron and steel production - from iron ore to steel

The unit selling price of steel (€/t) was calculated as the sum of the average production costs, the carbon cost, the delivery costs, and the expected profit margin. The production cost, which is expressed as €/t Hot-Rolled Coil (€/t HRC), depends on the set-up of the production process. Three options with regards to the configuration of the production process were considered:

S0: assumes continued operation with existing units [coke oven, blast furnace(s) (BF), basic oxygen furnace (BOF), rolling mills, and power plant];

S1: in which investments are made to replace the existing BF and supporting units with state-of-the-art process technology; and

S2: in which the existing BF is replaced with BF with top gas recycling (TGR-BF) and fitted for CO_2 capture.

Table 1 presents the breakdown of the production costs, the data sources used for the cost estimates, and the performance data used as the basis for calculating the carbon costs for each option. The current (Year 2010) average production cost (€/t HRC) at the hypothetical Nordic integrated steel plant (S0) was estimated based on the ex-works price of Nordic steel (MEPS, 2015). Average production costs in S1 and S2 are assumed to correspond to average production cost in the 'Reference' and 'OBF with CO_2 capture (Oxy-Blast Furnaces with Top Gas Recycle and CO_2 Capture)' versions of the conceptual newly built Western European Integrated Steel Mill used as a case study by IEAGHG (2013) and Hooye et al. (2013). The proposed production costs are, obviously, sensitive to changes in input costs, especially the prices of iron ore and coke. Similarly, the costs associated with investing and operating new production units are to be regarded as tentative. In particular, this applies to the case in which CCS is assumed to be introduced (S2), since the suggested process, TGR-BF with CO_2 capture (e.g., through chemical absorption or vacuum pressure swing adsorption), has yet to be demonstrated on a commercial scale (Birat et al., 2008; Kuramochi et al., 2011). Nevertheless, the suggested cost range gives an indication of the additional production costs relative to current practices.

The carbon cost is calculated as the sum of the cost of purchasing emissions allowances (S0–S2) and the costs of transporting and storing the captured CO_2 (S2).

The integrated plant is assumed to deliver automotive steel in the form of three categories of flat products. The prices of further-processed, higher-value-added products, i.e., galvanised cold-rolled sheets and high-strength steel sheets are relative to the break-even price of HRC. The mix and relative price of each steel product category used in production of the car used in the subsequent assessment are presented in Section 2.2.3 (Tables 4 and 5).

The delivery costs and profit margin, which are added on top, are assumed to remain fixed and the same, irrespective of the configuration of the production process or steel product category.

Table 1. Indicative production costs and carbon costs for a hypothetical integrated steel plant.

	Current average S0	New BAT S1	TGR-BF w/ CCS S2
Production costs[a] (€/t HRC), of which	430	435	475
Variable operational costs (%)		*55*	*54*
Fixed operational costs (%)		*22*	*21*
Capital costs (%)		*24*	*26*
Carbon costs[b]			
Specific emissions (tCO_2/t HRC)	1.7	1.5	0.6
Captured CO_2 (tCO_2/t HRC)	-	-	0.9
Allowance price[c] (€/tCO_2)	0/50/100	0/50/100	0/50/100
Transport and storage costs[d] (€/t CO_2)	-	-	25
Average delivery costs[e]	30		
Profit per unit sold	25		

[a] Authors' elaboration of data from Birat et al. (2008), Kuramochi et al. (2011), IEAGHG (2013), and Hooye et al. (2013), MEPS (2015).
[b] Performance data used as the basis for calculating the carbon costs for each option are taken from Rootzén and Johnsson, 2015a.
[c] The price range corresponds to the price range expected for EUA for the period 2010–2050 (European Commission, 2011; European Commission, 2014).
[d] Based on first estimates of costs associated with the transport (Kjärstad and Nilsson, 2014) and storage (Skagestad et al., 2014) of CO_2 in the Nordic region.
[e] Transport costs are estimated to 5% to 15% of the selling price of the steel products (Eurofer, 2005; Ecorys, 2008)

2.2.2 Automotive supply industry – from steel to components

The automotive supply industry consists of an array of firms, from large global firms that serve vehicle manufacturers worldwide with a range of components of varying complexity to small specialised firms that service the local vehicle manufacturer. With hundreds of firms involved in the manufacturing of the thousands of parts that ultimately are supplied to the vehicle assembly plant, the material and value flows associated with transforming steel into the final steel-containing components are too complex to be described in detail. Instead, the component manufacturing industry is treated as a black box, with automotive steel as the input and steel or steel-containing parts and components as the outputs. Total revenue is assumed to be equal to 70% of the vehicle manufacturers' material expenses (further elaborated upon in Section 2.2.3) (Vyas et al., 2000; Holweg et al., 2009). Material purchases are assumed to account for approximately half of the revenue, based on estimates made by IBIS (2015) and Allwood et al. (2011). The steel acquisition cost for the component manufacturers was calculated as the product of the quantity of automotive steel used (t per vehicle) in the production of the passenger car used as a case study in the present work (see Section 2.2.3) and the average price of the steel mix demanded (see Section 2.2.1). To compensate for material losses in manufacturing, which are significant (Allwood et al. 2011), the steel input is assumed to 15% higher than the output.

2.2.3 Steel in car-manufacturing – from components to finished car

Steel has been the material of choice for the automobile industry for almost a century, and while the shares of alternative light-weight materials (e.g., plastics, aluminium, and composites) have gradually increased, steel continues to dominate as the main material in the typical car (Taub, 2006; Taub et al, 2007). Nevertheless, the material composition of a car may vary considerably across different brands and models and across different markets. Table 2 outlines the material composition of the European mid-sized passenger cars used as the case study in the present work. The data, obtained from Nemry et al. (2008), describe the material compositions of two car models, a petrol-driven car and a diesel-driven car, corresponding to the average characteristics of new cars sold in Europe. To capture the effects of the increased use of light-weight materials, driven by increasingly stringent fuel efficiency and emissions standards, two light-weight versions of the same cars were also included in the analysis. In these cases, aluminium was assumed to replace steel (Nemry et al., 2008). Whereas there are several commercially available materials that could be used to enhance vehicle weight-reduction, aluminium is typically considered to be the closest competitor to steel (USDOE, 2012).

Table 2. Material compositions of the passenger cars considered. Adapted from (Nemry et al., 2008).

Materials	Gasoline Current average (kg)	Diesel Current average (kg)	Gasoline Light-weight (kg)	Diesel Light-weight (kg)
Steel[a], of which	742	959	184	300
- Primary (BF/BOF) (%)	70	70	50	50
- Secondary (EAF) (%)	30	30	50	50
Aluminium, of which	68	72	254	291
- Primary (%)	60	60	60	60
- Secondary (%)	40	40	40	40
Other materials	429	431	429	439
Total weight	1240	1460	870	1020

[a] The typical car also includes a small amount of cast iron (~50–100 kg), which is primarily used in the engine block and suspension. In the light-weight versions of the cars, aluminium is assumed to replace primarily the flat steel products, e.g., galvanised cold-rolled coil sheet, used to manufacture the body-in-white and closings.
[b] Including plastics, glass, paints, other metals (Mg, Cu, Pt, Pl, Rh), rubber, and other materials and fluids.

Table 3 shows the assumed retail prices of the respective versions of the reference car model and the breakdown of the retail price and manufacturing costs applied in the analysis. Estimates of the costs associated with manufacturing and selling a car are relatively coherent (see for example, Vyas et al., 2000; Smokers et al., 2006; Rogozhin et al., 2009; Holweg et al., 2009). Here, based on these previous assessments, direct manufacturing costs are assumed to account for approximately 40% of the price offered to the passenger car buyer. The car manufacturers' material expenses, including purchases of components and raw materials, are assumed to account for approximately 85% of the direct manufacturing costs. As described in Section 2.2.2, acquisitions of parts and components from suppliers in the component manufacturing industry are assumed to account for approximately 70% of the material costs.

Table 3. Suggested breakdown of the retail price and manufacturing costs.

Materials	Gasoline Current average	Diesel Current average	Gasoline Light-weight	Diesel Light-weight
Retail price (€/car), of which	20,000	27,500	21,700	29,700
Cost components[b]	Share of the retail price (%)			
- Vehicle tax[c]	20			
- Dealer profit	2			
- Sales, transport and marketing	15			
- Manufacturers profit	3			
- Manufacturers overhead costs	20			
- Direct manufacturing costs	40			
Breakdown of the direct manufacturing costs[d]	Share of the retail price (%)			
- Material costs	35			
- Assembly labour and other cost	5			

[a] Current (Year 2010) retail prices for medium-sized gasoline and diesel cars from ICCT, 2013. Suggested retail prices for the light-weight version of the respective car model reflect the added manufacturing cost as estimated by Nemry et al. (2008).
[b] Suggested average retail price break-down based on estimates reported in Smokers et al. (2006); Rogozhin et al. (2009) and Skelton and Allwood (2013).
[c] Based on the average vehicle tax level in the EU, including value added tax and registration tax (Smokers et al., 2006).
[d] Based on estimates reported in Vyas et al. (2000) and Holweg et al. (2009) and Skelton and Allwood (2013).

The impacts of changes in steel production costs were assessed separately for the component manufacturing industry and the auto industry. However, as cost pass-through is assumed to be complete across the entire supply chain, changes in the basic cost of steel acquisition (i.e., before further processing in the component industry) was used to estimate the cost impact in both cases (see also Section 2.2.2). As the composition of the steel used and the cost of the respective product category can vary significantly, assigning a price to the product mix of steels used is not a trivial task. Automotive steel includes an array of products, ranging from nuts and bolts to advanced high-strength sheet steels (all with different price tags). Furthermore, steel can be classified along several different dimensions depending on its physical, chemical, and mechanical properties, and the product range constantly evolves. To reflect some of the differences in production costs and prices, the steel used in the considered cars were grouped in three broad categories (and one subcategory). Table 4 presents the product mix of steels used in the analysis. Table 5 gives the price of each steel product category relative to the price of HRC. The additional costs linked to purchasing emissions allowances and investing and operating new low-CO_2 steel processes are assumed to be distributed evenly across the product portfolio. Table 5 also shows the relative cost of aluminium and the specific emissions from the primary production of steel and aluminium.

Table 4. Proposed automotive steel mix.

Product type	Origin	Product category	Share of total steel use[a] (%)	Examples of applications
Flat products	BF/BOF route	Hot rolled sheets	20	Exhaust system, fuel tank, radiator
		Galvanised cold-rolled sheets[b]	50	Body-in-white and closures
Long products	EAF route	Wire rod and beams	30	Bumpers, transmission, tyres and seats

[a] Based on previous estimates of the material composition of an average car (MCI, 2015; Das, 2014; USDOE, 2012).
[b] Approximately 10% high-strength steel sheet (Taub, 2006; USDOE; 2012)

Table 5. Relative costs and specific emissions from the production of steel and aluminium.

Product category	Relative cost[a] (weight)	Emissions[b] (tCO_2/t material)
Hot-rolled sheets	1	0.6–1.7
Galvanised cold-rolled sheets	1.3	0.6–1.7
High-strength steel	2	0.6–1.7
Wire rod and beams	1.2	0.3
Aluminium primary/secondary (cast an sheet)	5	1.6/0.2

[a] Relative prices estimated based on current average prices of intermediate steel and aluminium products (Lutsey, 2010; USDOE, 2012; MEPS, 2015).
[b] Specific emissions (direct emissions) from primary steel production, corresponding to the average emissions from the Nordic iron ore-based steel industry (cf. Table 1). Specific emissions (direct and indirect emissions) from the manufacturing of secondary steel and primary and secondary aluminium are assumed to be equal to the benchmark values for the respective industries (Ecofys, 2009; European Commission, 2011b).

3 Results and Discussion

3.1 Iron ore-based steel production

Figure 3 shows the average production cost at the steelworks, including the costs linked to purchasing emissions allowances and investing and operating new process units. With ready access to high-quality iron ores and with blast furnaces already operating at close to BAT levels, specific CO_2 emissions from Nordic iron ore-based steel plants are low relative to comparable plants elsewhere (Larsson et al., 2006; Rootzén and Johnsson, 2015a). Thus, investments in conventional state-of-the-art process technology (S1) would result in relatively small reductions in emissions and do little to dampen the carbon cost impact. Under the assumptions made above, investing in a TGR-BF with CCS (C2) would first become profitable at an allowance price of approximately 60 €/tCO_2. At a carbon price of 50 €/tCO_2, the unit selling price (€/t HRC) required to cover the production costs, including the carbon costs, would have to be 15% (S0 and S1) to 20% (S2) higher than the reference selling price (485 €/tCO_2). The corresponding increase in the selling price of steel, at a carbon price of 100 €/tCO_2, would be approximately 25% (S2) to 35% (S0).

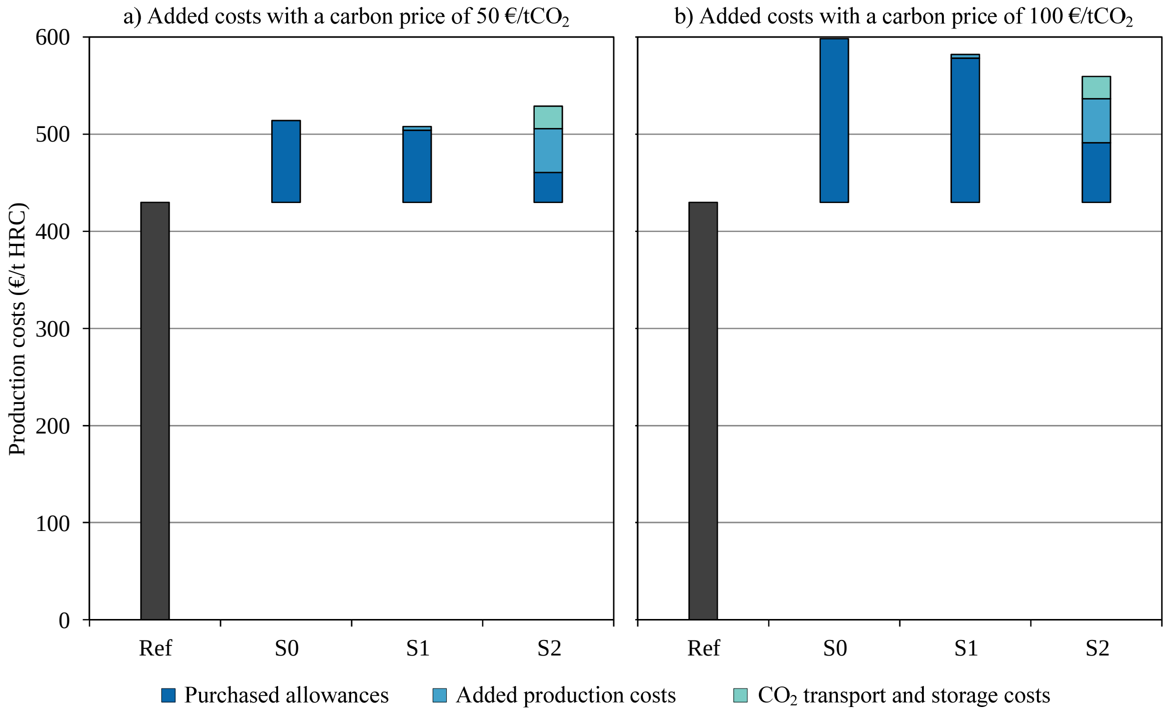

Figure 3. Average steel production costs, including the cost of purchasing emissions allowances (S0–S2), the added costs associated with investing and operating new process units (S1 and S2), and, in the case where CCS is applied (S2), the cost of transporting and storing the captured CO_2. In the reference case, the steel plant is operated with existing units and with the price of emissions allowances set to zero.

3.2 Car manufacturing

Figure 4 illustrates the impacts of increases in the cost of automotive steel as a result of CO_2 trading and investments in CO_2 abatement at the integrated steel plant, given full cost pass-through throughout the supply chain. In addition to the absolute price increase, the figure shows the relative increases in the steel acquisition costs, total material cost, and manufacturing costs for the car manufacturer, as well as the increases in retail prices facing consumers. It must be emphasised that the cost increase shown for each step in Figure 4 is based on the assumption that the entire increase in cost attributable to increased automotive steel prices (a consequence, in turn, of carbon trading and investments in CO_2 abatement at the steelworks) is allocated to that step. The impacts on the manufacturing costs and the selling prices of the light-weight versions, with considerably less steel in the car (~180–300 kg), are obviously significantly lower than for the versions representing current European mid-sized passenger cars. However, even for the diesel version of the current average car, which contains 950 kg of steel, the cost impact would be relatively low. As shown in Figure 4f, at a carbon price of 100 €/tCO_2, the retail price would have to be increased by approximately 100–125 €/car to cover the increases in automotive steel costs. With the reference retail price set at €27,500, this would correspond to an increase in the retail price of less than 0.5%.

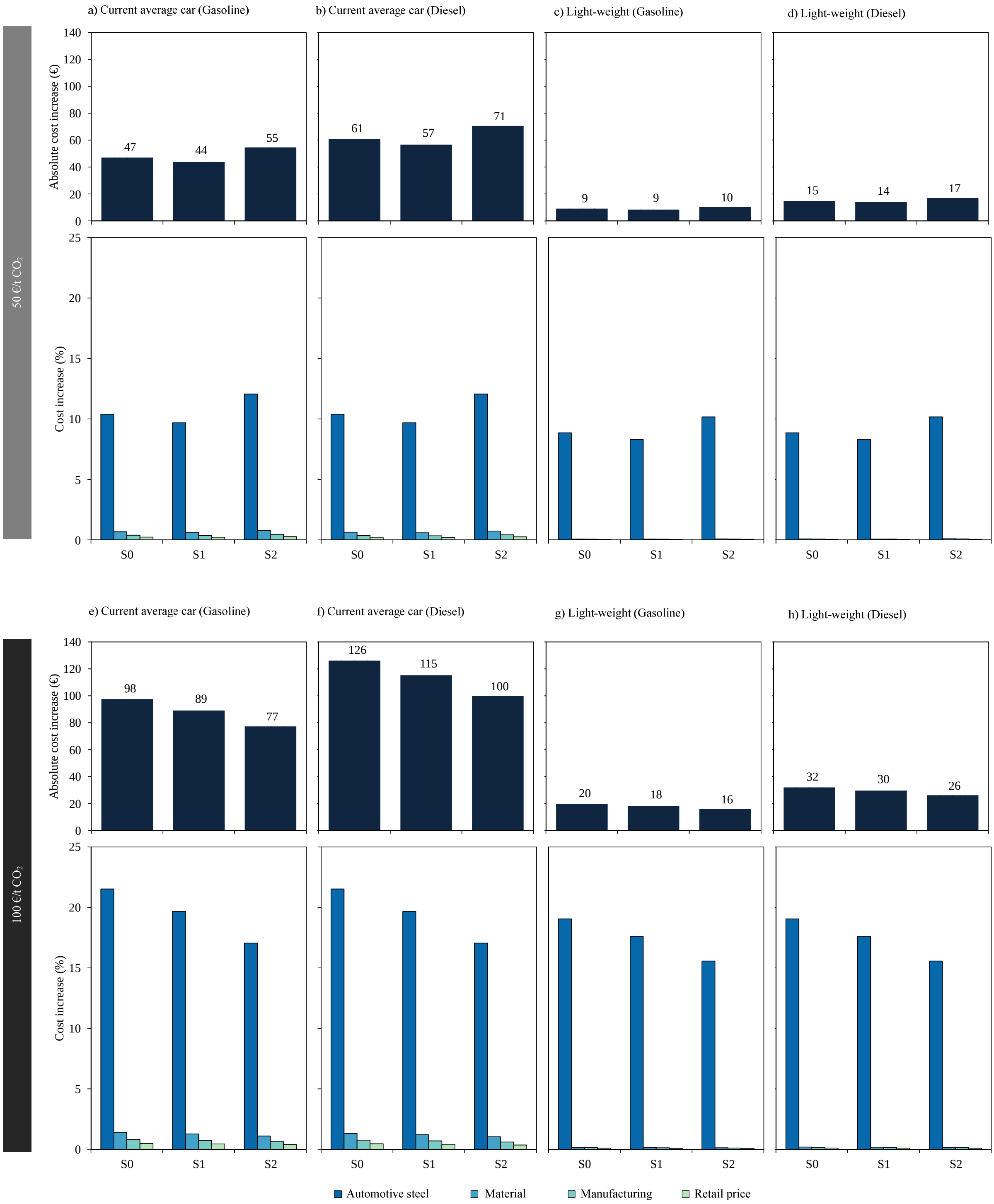

Figure 4. Impacts on the manufacturing cost and price of a mid-sized passenger car associated with increased automotive steel prices, given full pass-through of the costs of CO_2 trading and investments in CO_2 abatement. The charts (a–h) show the absolute cost increases (top row) and the relative cost increases (bottom row) per cost category for each version of the car used as a case study. The steel price increase, in turn, is driven by internal abatement costs, i.e., investments in BAT and CCS process units (S1–S2), and the purchasing of emissions allowances (S0–S2) at 50 €/tCO_2 (a–d) or 100 €/tCO_2 (e–h) in the steel industry.

3.3 Summary and Discussions

From this and previous studies, it is clear that the cost impact on primary production and the primary product of investing in the high-abatement measures required to achieve significant decarbonisation in the integrated steelmaking route will be substantial. However, based on the above description of the material and value flows involved in the supply of automotive steel, the impacts on downstream costs and prices appear to be manageable. Figure 5 provides an overview of the impacts on cost and prices along the supply chain: from the selling of the basic steel products (1), subsequent use as the input in the components manufacturing industry (2–3), to eventual use in the manufacturing (4–5) and sales (6) of mid-sized passenger car.

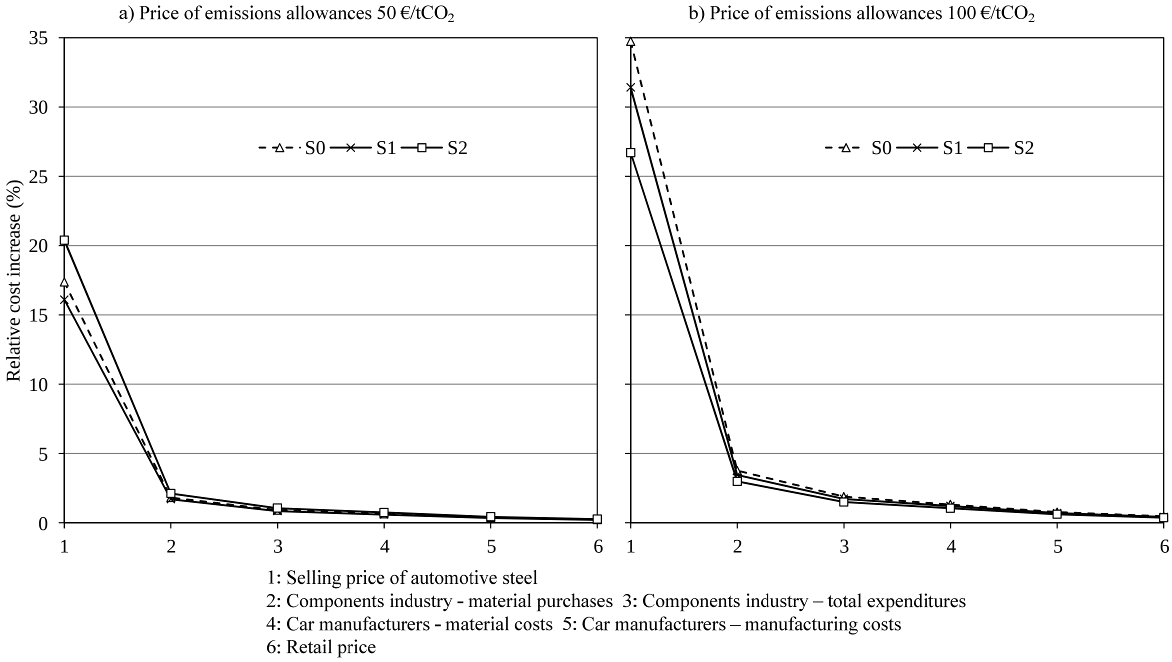

Figure 5. Cost impacts along the supply chain of automotive steel linked to increases in the steel production cost (S0-S2) given full pass-through of the costs of carbon trading and investments in CO_2 abatement. The estimates are for the supply of steel for the construction of the current average mid-sized diesel car at an allowance price of 50 €/tCO_2 (a) or 100 €/tCO_2 (b). Cost increases are estimated relative to the reference case, in which steel is sourced from a steel plant operating with existing units and with EUA price set at zero.

Increasingly, stringent CO_2 and fuel economy standards and the shift towards alternative powertrains are ensuring that weight reduction remains a key priority for car manufacturers. The inclusion in the analysis of two light-weight versions of the reference car was not to compare the relative merits of steel- and aluminium-intensive car designs, but rather to illustrate how changing preferences in the end-use sectors will also affect the conditions for and effects of passing on carbon costs. To avoid product choice distortions, any policy measure that is designed to pass on the compliance costs of the steel industry to customers would require that a similar measure be applied to alternative materials (Neuhoff, 2014b). Figures 6 and 7 demonstrate how the inclusion of carbon costs in the price of both steel and aluminium would affect car manufacturing costs. Figure 6 shows the estimated costs for automotive steel and aluminium in the current average and light-weight diesel version of the reference car, assuming different CO_2 prices. While the overall spending on automotive steel and aluminium is higher for the light-weight version, the impact of carbon cost increases is somewhat lower. As secondary production of both metals is considerably less CO_2-intensive than primary production, the figure also illustrates how assumptions made with regards to the material compositions of the respective versions of the car (Table 2) affect the magnitude of the carbon cost impact. Figure 7, in turn, shows the costs of automotive steel and aluminium relative to other costs in the respective steps of the supply chain. Whereas the breakdown between expenditure on steel and aluminium differs depending on the choice of car design, it is again clear that, as actual expenditure on metals is relatively low compared to expenditure on other inputs, passing on the carbon costs, even with a high price for CO_2, is likely to have limited effects on the cost structure across the automotive supply chain.

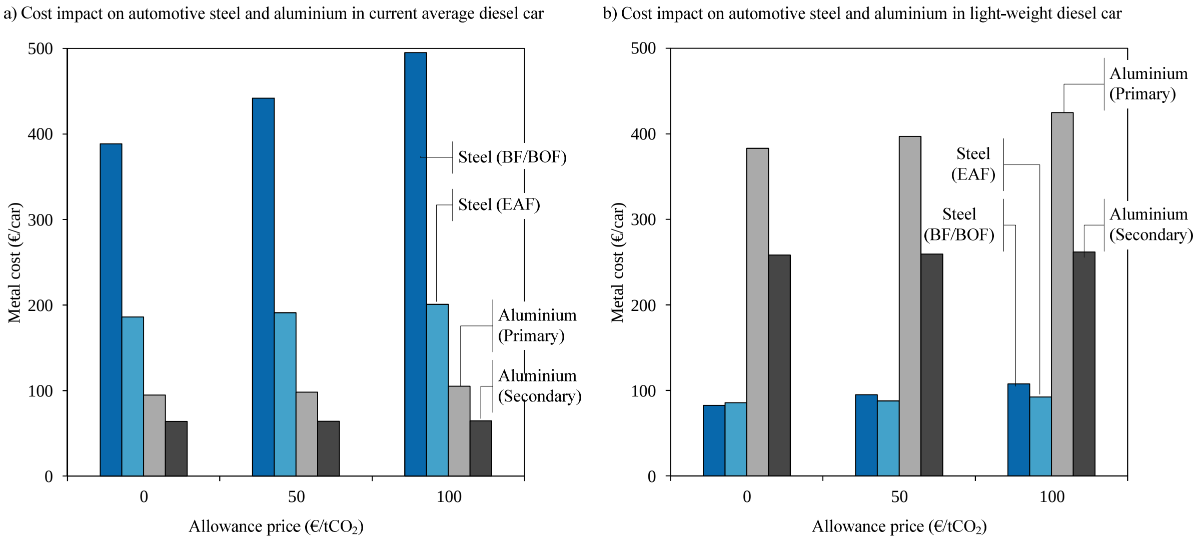

Figure 6. Steel and aluminium acquisition costs in the automotive industry with the prices of emissions allowances set at 0, 50, and 100 €/tCO_2. a) Costs of the steel and aluminium used in the current average diesel car. b) Costs of the steel and aluminium used in the light-weight diesel car.

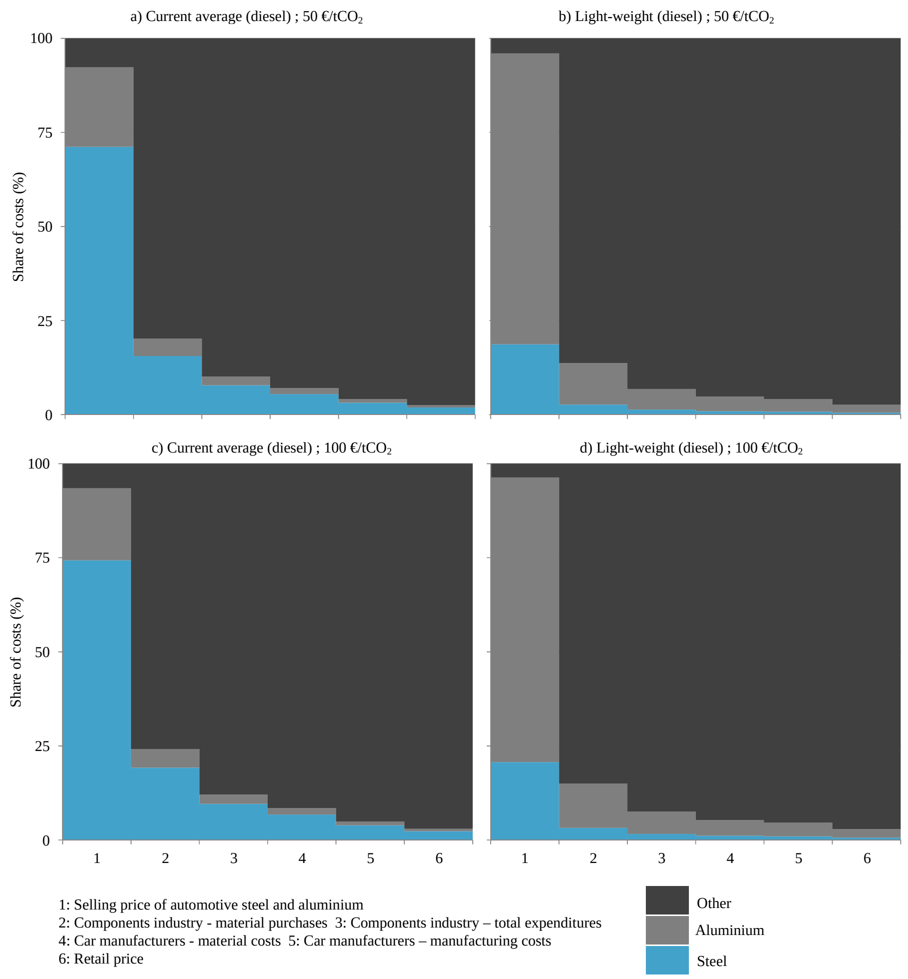

Figure 7. The cost of automotive steel and aluminium relative to the cost of all other inputs across the automotive supply chain.

Finally, as discussed in Section 2.1, the use of steel in the car manufacturing industry accounts only for a small fraction of the total use of primary steel, and the market structure and demand for steel are constantly evolving. As a consequence, the results derived here may not be generalisable to other sectors or situations. However, as noted above, results from Skelton and Allwood (2013) suggest that even in the most steel-intensive sectors, the steel share of input expenditure is less than 5%. Examination of the cost structure in a sample of typical Swedish building and civil engineering projects suggests that the costs of steel products as shares of the total construction costs vary from approximately 5%–10% in residential building projects to 25%–40% in more-steel-intensive constructions (e.g., industrial buildings and bridges) (SCF, 2011). Given that most of the steel products go through at least one fabrication stage before delivery to the construction site and that the total project cost typically, on top of the direct construction costs, includes additional overhead costs (including costs related to land procurement and parcelling and taxes), it seems reasonable to accept that the estimates of ‘the true expenditure on steel’ provided by Skelton and Allwood (2013) accurately reflect the situation in many Swedish construction projects. This implies that passing on the carbon cost of the steel industry will have a limited impact on the total cost facing a procurer of, for example, a new building, as is shown to be the case for the car used as the case study in the present work.

4 Conclusions

Covering the costs of investing in new low-CO_2 steelmaking processes would require substantial increases in the selling price of steel. However, the results presented herein suggest that such price increases would have limited impacts on costs and prices across the supply chain for automotive steel, even though the compliance costs of the steel industry are assumed to be passed-through perfectly. This is because the basic price of steel, i.e., the price of the intermediate steel product that exits the steelworks, accounts for a relatively small share of the total expenditures in the automotive supply and car manufacturing industries. Whereas the proposed steel production costs, the estimates of the production cost increases due to CO_2 trading and investments in CO_2 abatement, and the representation of the supply chain for automotive steel are to be regarded as tentative, the results give good indications of the approximate cost increases that occur across the different steps of the supply chain.

As mentioned above, the fact that the price of steel represents a relatively small fraction of the total cost to the end-user is not a characteristic that is unique to the automotive industry; instead it seems that this is also the case in other steel-intensive end-use sectors (Skelton and Allwood 2013). Thus, there are reasons to believe that passing on the compliance costs of the steel industry would have limited impacts on costs and prices also in other end-use sectors.

Taken together, these findings have implications for the possibility to develop complementary policy options aimed at allocating the costs required to develop and deploy new low-carbon steelmaking processes, as well as for corporate strategies related to the procurement of low-CO_2 materials.

References

Allwood J.M., Cullen J.M., McBrien M., Milford R.L., Carruth M.A., Patel A.C.H, Cooper D.R., Moynihan M., 2011. Sustainable Materials: with both eyes open. UIT Cambridge, England. ISBN 978-1-906860-05-9

Bennett, S. and Heidug, W., 2014. CCS for Trade-exposed Sectors: An Evaluation of Incentive Policies. Energy Procedia, 63, pp.6887–6902.

Birat J-P., Lorrain J-P. and de Lassat Y, 2008. The "CO_2 Tool": CO_2 Emissions & Energy Consumption of Existing & Breakthrough Steelmaking Routes. Proceedings of the 4th Ulcos seminar, 1-2 October, 2008.

Branger, F. and Quirion, P., 2014. Climate policy and the "carbon haven" effect. Wiley Interdisciplinary Reviews: Climate Change, 5(1), pp.53–71.

Cullen, J.M., Allwood, J.M. and Bambach, M.D., 2012. Mapping the global flow of steel: from steelmaking to end-use goods. Environmental science & technology, 46(24), pp.13048–55.

Daniëls, B., 2002. Transition paths towards CO_2 emission reduction in the steel industry. [Ph.D.thesis] Rijksuniversteit Groningen:Universal Press Veenendaal; 2002.

Dahlström, K. and Ekins, P., 2006. Combining economic and environmental dimensions: Value chain analysis of UK iron and steel flows. Ecological Economics, 58(3), pp.507–519.

Das, S., 2014. Life Cycle Energy and Environmental Assessment of Aluminum-Intensive Vehicle Design," SAE Int. J. Mater. Manf. 7(3):588-595.

Ecofys, 2009. Methodology for the free allocation of emission allowances in the EU ETS post 2012 – Sector report for the aluminium industry- Ecofys (project leader) By order of the European Commission

Ecofys, 2013. Support to the Commission for the determination of the list of sectors and subsectors deemed to be exposed to a significant risk of carbon leakage for the years 2015-2019 (EU Emission Trading System). Final report

Ecorys, 2008. Study on the Competitiveness of the European Steel Sector. Report prepared on behalf of Directorate-General Enterprise & Industry, Within the Framework Contract of Sectoral Competitiveness Studies – ENTR/06/054 Final report, August 2008. Ecorys, Rotterdam, The Netherlands.

Ellerman, D., Marcantonini, C. and Zaklan, A., 2014. The EU ETS: Eight Years and Counting. EUI Working Paper RSCAS 2014/04, Climate Policy Research Unit, Robert Schuman Centre for Advanced Studies, European University Institute, Badia Fiesolana, Italy.

Eurofer, 2005. Steel on the move – Transport of Steel in the European Union 2005 Edition. European Confederation of Iron and Steel Industries (EUROFER), Brussels, Belgium.

Eurofer, 2015. Economic and Steel Market Outlook 2015-2016, Q1-2015 Report from EUROFER's Economic Committee. The European Steel Association (EUROFER), Brussels, Belgium.

European Commission, 2006. EU ETS Review Report on International Competitiveness, Report compiled by McKinsey & Company and Ecofys on behalf of the European Commission, Directorate General for Environment, December 2006.

European Commission, 2011b. Commission Decision – Determining Transitional Union-wide Rules for Harmonised Free Allocation of Emission Allowances Pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council, Decision 2011/278/EU, Official Journal of the European Union, L130/1.

Fischedick, M., Marzinkowski, J.,Winzer, P. and Weigel, M., 2014. Techno-economic evaluation of innovative steel production technologies. Journal of Cleaner Production, 84, pp.563–580.

Holweg, M., Davies, P. and Podpolny, D., 2009. The Competitive Status of the UK Automotive Industry. New Automotive Innovation and Growth Team, PICSIE Books, Buckingham, U.K..

Ho, M.T., Bustamante, A. and Wiley, D.E., 2013. Comparison of CO_2 capture economics for iron and steel mills. International Journal of Greenhouse Gas Control, 19, pp.145–159.

Hooey, L., Tobiesen, A., Johns, J. Santos, S., 2013. Techno-economic Study of an Integrated Steelworks Equipped with Oxygen Blast Furnace and CO_2 Capture. Energy Procedia, 37, pp.7139–7151.

ICCT, 2013. European Vehicle Market Statistics – Pocketbook 2013. International Council on Clean Transportation (ICCT), Berlin, Germany.

Ishinabe, N., 2011. Analyses of Japanese Business & Environmental Policies – From Interviews to Top Securities Analysts. Research Report 2011/02, Institute for Global Environmental Strategies, Hayama, Japan.

IEAGHG, 2013. Iron and Steel CCS Study (Techno-Economics Integrated Steel Mill). IEA Greenhouse Gas R&D Programme (IEAGHG), 2013/04, July, 2013.

Kuramochi, T., Ramírez, A., Turkenburg, W. and Faaij, A., 2011. Comparative assessment of CO_2 capture technologies for carbon-intensive industrial processes. Progress in Energy and Combustion Science, 38(1), pp.112–87.

Kjärstad, J. and Nilsson, P-A., 2014. CCS in the Baltic Sea region (Bastor 2) – Infrastructure for CO_2 transport in the Baltic Sea Region (Work Package 5), Elforsk report 14:49

Laing, T., Sato, M., Grubb, M. and Comberti, C., 2013. Assessing the effectiveness of the EU Emissions Trading Scheme, Working Paper No. 126 Centre for Climate Change Economics and Policy.

Laing, T., Sato, M., Grubb, M. and Comberti, C., 2014. The effects and side-effects of the EU emissions trading scheme. Wiley Interdisciplinary Reviews: Climate Change, 5(4), pp.509–519.

Laitner, J. A. (S.), Worrell, E., Galitsky, C., and Hanson, D. A. (2003). Characterizing emerging industrial technologies in energy models. Sustainability and Industry: Increasing Energy Efficiency. Washington, DC: ACEEE.

Larsson, M., Grip, C-E, Ohlsson, H., Rutqvist, S., Wikström, J-O., Ångström, S., 2006. Comprehensive Study Regarding Greenhouse Gas Emission from Iron Ore Based Production at the Integrated Steel Plant SSAB Tunnplåt AB. International Journal of Green Energy, 3(2), pp.171–183.

Lutsey, N., 2010. Review of Technical Literature and Trends Related to Automobile Mass-Reduction Technology. Research Report UCD-ITS-RR-10-10, Institute of Transportation Studies, University of California, Davis, U.S.

MEPS, 2015. MEPS- Nordic steel Price. MEPS (International) LTD, Sheffield, U.K.. URL: < http://www.meps.co.uk/NordicPrice.html>

McKibbin, W., Wilcoxen, P., 1999. The theoretical and empirical structure of the G-cubed model. Economic Modelling 16(1), 123-148.

MCI, 2015. Auto weight analysis - passenger vehicle steel content. Metals Consulting International Limited (MCI), Essex, U.K.. URL: < http://www.steelonthenet.com/files/automotive.html>

Nemry, F., Leduc, G, Mongelli, I. and Uihlein. A., 2008. Environmental Improvement of Passenger Cars (IMPRO-car). European Commission Joint Research Centre – Institute for Prospective Technological Studies, Luxembourg: Office for Official Publications of the European Communities.

Neuhoff, K., 2008. Tackling Carbon: How to Price Carbon for Climate Policy, Report 29/9/2008, Climate Strategies, London, UK.

Neuhoff, K., Vanderborght, B., Ancygier, A., Tugba Atasoy, A., Haussner, M., Ismer, R., Mack, B., Ponssard, J-P., Quirion, P., van Rooij, A., Sabio, N., Sartor, O., Sato, M. and Schopp, A., 2014a. Carbon Control and Competitiveness Post 2020: The Cement Report. Final report, February 2014. Climate Strategies, London, UK.

Neuhoff, K., Acworth, W., Ancygier, A., Branger, F., Christmas, I., Haussner, M., Ismer, R., van Rooij, A., Sartor, O., Sato, M. and Schopp, A., 2014b. Carbon Control and Competitiveness Post 2020: The Steel Report. Final report, October 2014. Climate Strategies, London, UK.

PwC, 2011. Potential impact of a carbon price on the Australian automotive industry. Report commissioned by the Federal Chamber of Automotive Industries and prepared by PricewaterhouseCoopers Australia (PwC), May 2011.

Rautaruukki, 2008. Raahe Works Environmental Report 2007. Helsinki, Finland: Rautaruukki Corporation, Raahe, Finland.

Rogozhin, A., Gallaher, M. and McManus, W., 2009. Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. Prepared for U.S. Environmental Protection Agency (US-EPA) by RTI International and Transportation Research Institute University of Michigan, US-EPA, Ann Arbor, U.S..

Rootzén, J. and Johnsson, F., 2015a. CO_2 emissions abatement in the Nordic carbon-intensive industry – An end-game in sight? Energy, 80, pp.715–730.

Rootzén, J. and Johnsson, F., 2015b. Perspectives on the costs of reducing CO2 emissions from industry – the case of the Nordic cement industry. Submitted for publication (2015).

SCF, 2011. Entreprenadindex husbyggnads- och anläggningsverksamhet – tillämpningsföreskrifter för indexberäkning av kostnadsändringar. (Building and civil engineering works – rules of application for index-bound calculation of cost changes). The Swedish Construction Federation (SCF). URL: < http://www.byggindex.scb.se>

Schmidt, M., 2008. The Sankey Diagram in Energy and Material Flow Management: Part II. Journal of Industrial Ecology, 12(2), pp.173–185.

Skagestad, R., Onarheim, K. and Mathisen, A., 2014. Carbon Capture and Storage (CCS) in Industry Sectors – Focus on Nordic Countries. Energy Procedia, 63, pp.6611–6622.

Skelton, A. and Allwood, J., 2013. The incentives for supply chain collaboration to improve material efficiency in the use of steel: An analysis using input output techniques. Ecological Economics, 89, pp.33–42.

Smokers, R., Vermeulen, R., van Mieghem, R., Gense, R., 2006. Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars. Report compiled by TNO on behalf of the European Commission (DG-ENTR), TNO, Delft, The Netherlands

SSAB, 2005. SSAB Annual Report 2004. Svenskt Stål AB (SSAB), Stockholm, Sweden.

Taub, A.I., 2006. Automotive Materials: Technology Trends and Challenges in the 21st Century MRS Bulletin, 31 (4), pp.336-343.

Taub, A.I., Krajewski, P.E., Luo, A.A., Owens, J.N.2007. The evolution of technology for materials processing over the last 50 years: The automotive example. JOM, 59(2), pp.48–57.

USDOE, 2012. Report on the First Quadrennial Technology Review: Technology Assessments U.S. Department of Energy (USDOE). Report on the First Quadrennial Technology Review: Technology Assessments. DOE/S-0002. Washington, DC.

USDOL, 2013. International Comparisons of Hourly Compensation Costs in Manufacturing, 1996–2012. Bureau of Labor Statistics, United States Department of Labor.URL: <bls.gov/fls/ichccindustry.htm>

Vogt-Schilb, A., Hallegatte, S. and de Gouvello, C., 2014. Long-Term Mitigation Strategies and Marginal Abatement Cost Curves : A Case Study on Brazil. World Bank Policy Research Working Papers (2014) 6808, pp.1–20.

WSA, 2013. Steel Statistical Yearbook 2013. World Steel Association (WSA); 2013. World Steel Committee on Economic Studies, Brussels, Belgium.

Vyas, A., Santini, D and Cuenca, R, 2000. Comparison of indirect cost multipliers for vehicle manufacturing. Technical Memorandum in support of Electric and Hybrid Electric Vehicle Cost Estimation Studies. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, Argonne, U.S.

Wörtler, M., Schuler, F., Voigt, N. Schmidt, T. Dahlmann, P., Lüngen, H.B., Ghenda J.-T., 2013. Steel's Contribution to a Low-Carbon Europe 2050: Technical and Economic Analysis of the Sector's CO_2 Abatement Potential, The Boston Consulting Group and the Steel Institute VDEh.