Macroeconomic implications of a 2°C-compatible transition path in the European iron and steel industry

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1. *Introduction*

The Paris Agreement to address climate change entered into force on the 4th of November 2016 demanding a *"fundamental structural transformation"* (Zhengelis, 2016, p. 174) of the currently prevailing social and economic system. According to Rockström et al. (2017), going even "well below" the agreed upon 2°C target would require the inclusion of substantial amounts of anthropogenic CO2 removals (i.e. negative emissions) by land-use changes and bioenergy carbon capture and storage. Hence, climate mitigation action is urgent. The iron and steel sector, accounting for about 25% of global industrial emissions in 2012 (Serrenho et al., 2016), is among the sectors facing particular challenges in decarbonizing future production. Evidently, continuous process improvements and retrofitting measures have led to a decoupling of greenhouse gas (GHG) *combustion* emissions and steel output in the past. However, in steel production another emission category, *process* emissions, accounts for about half of global GHG emissions of the iron and steel sector.

This is due to the currently prevailing technology, the blast furnace-basic oxygen furnace (BF-BOF) route. It is the globally most utilized steel-making technology (with a share of about 90%) (CCC, 2015; WSA, 2016) and uses coke as reducing agent which results in GHG process emissions. These process emissions can only be reduced i) by reducing BF-BOF-steel production or ii) by switching to a different production process (Napp et al., 2014). Today, steel serves as an input in a vast range of downward applications, from plates, bars and stripes to automobile chassis or rotor blades of wind power plants (CCC, 2015; BCG, 2013). In the present analysis we assume a continuous demand for and use of steel in the forthcoming decades, and analyse the macroeconomic implications of switching to carbon-free production technologies.

In Austria, a country with a large iron and steel sector (2.7% of gross value added to GDP in 2014; Statistik Austria, 2016), the major steel producer already anticipates the requirement for such a technological regime shift. Its publicly available firm policy credibly promotes a strategy of net zero GHG emissions by 2050. Within the EU-H2020 project *TRANSrisk*[1] a specific transition path up until mid-century was developed in the course of a comprehensive *´desired futures´* process involving the relevant stakeholders, a path that is in compliance with the Austrian contribution to achieve the global 2°C target. Taking the steel producers' strategy as a piece of a broader transition pathway, we here ask: *What are the macroeconomic implications of a 2°C-compatible transition pathway in the European iron and steel industry?*

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[1] Transitions Pathways and Risk Analysis for Climate Change Mitigation and Adaption Strategies (http://transrisk-project.eu).

2. *Method and Data*

Methodologically we deploy the WEGDYN model based on GTAPv9 data (Aguiar et al., 2016) which is a dynamic-recursive multi-region multi-sector computable general equilibrium (CGE) model (based on the static version specified by Bednar-Friedl et al., 2012). Particularly, we implement a transition path for the iron and steel sector up to mid-century simulating a linear and bidirectional technology switch from BF-BOF-steel to steel derived from either i) direct reduced iron (DRI-H) and electric arc furnace (EAF), or ii) plasma direct steel production (PDSP), both using hydrogen from electrolysis instead of coke implying process emission free production[2]. This switch is integrated in all countries participating in the European Unions' Emission Trading Scheme (EU-ETS). The bottom-up cost assessment of representative European DRI-H and PDSP technologies is based on a stakeholder dialogue and CEPS (2013). The background characteristics of the model are driven by socio-economic pathway assumptions (SSP2) on regional economic growth and labour force development (O'Neill et al., 2014; van Vuuren et al., 2011, IIASA, 2017).

Table 1: Unit costs in €/t of steel (net of taxes) and process emission factor in tCO2/t of steel for different steel production technologies.

Technology-specific cost component	BF-BOF [€/t steel]	DRI-H-EAF [€/t steel]	PDSP [€/t steel]
Refinery products (coke)	84	0	0
Electricity*	0	219	131
Iron pellets	0	84**	
Iron ore	189	189	189
Services	45	40	40
Unskilled labor	5	4	4
Skilled labor	44	40	40
Capital (wear and tear)	48	48	48
Total	**415**	**624**	**452**
Difference to BF-BOF	**-**	**+209**	**+37**
Process emission factor [tCO2/t steel]	**1.50**	**0**	**0**

*electricity costs for hydrogen production (and EAF in the case of DRI-H_2-EAF)
**additional costs due to the intermediate stage of producing iron pellets out of iron ore

Source: Stakeholder dialogue, CEPS (2013), UBA (2017)

For current market prices of intermediate inputs (e.g. coke or electricity) and primary factors (labour and capital) we find that neither carbon-free technology is competitive to the prevalent BF-technology using a conventional unit costs analysis (Table 1). In particular, DRI-H would require a break-even CO2 price of about 140 €/tCO2 to reach cost parity to the BF-BOF technology using an process emission factor of 1.50 tCO2/t steel (UBA, 2017). For PDSP a CO2 price of about 25 €/tCO2 would suffice primarily due to lower unit costs regarding iron ore inputs to production and an assumed industrial electricity price of 3 €cents/kWh (cf. Grossmann et al. 2012 and Steininger et al., 2017).

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[2] Note that the occurring shift from coke to electricity as input to steel production necessitates the simultaneous expansion of renewable electricity generation and phase out of fossil fuel based capacities avoiding a mere shift of mitigated process emissions in the iron and steel sector to additional combustion emissions in the electricity generation sector. This crucial consideration is part of currently ongoing research.

However, including financing costs for new facilities of the carbon-free technologies worsens the competitive disadvantage of carbon-free steel technologies (Table 2) even more.

Table 2: Investment unit costs for DRI-H-EAF (0.05€/kWh electricity price) and PDSP (0.03€/kWh electricity price).

Technology	DRI-H-EAF	PDSP
Electricity price [€/kWh]	0.05	0.03
Gross investment unit costs [€/t]	1,113	1,043
Interest rate [%]	2.00	2.00
Investment phase [y]	12	12
Life time [y]	12	12
Annuity factor	0.09	0.09
Investment unit costs (annuity) [€/t]	105	99

Source: Stakeholder dialogue and CEPS (2013)

This conventional comparison of technologies lacks to incorporate changing market prices of intermediate inputs and primary factors as well as changing climate policies in the prospective course of economic development. Especially endogenous price effects for intermediate inputs and primary factors, by definition not incorporated in conventional bottom-up cost comparisons, might eventually alter the unit cost relations such that the conventionally calculated level of required CO2 prices is too low (or too high) to reach cost parity.

Table 3: CO_2-price and fossil fuel price forecast (based on IEA, 2016).

	CO_2-Price EU-ETS [$€_{2011}/tCO_2$]	CO_2-Price China [$€_{2011}/tCO_2$]	Coal [price index normalized to 2011]	Oil [price index normalized to 2011]	Gas [price index normalized to 2011]
2011	5	0	1.00	1.00	1.00
2015	5	3	1.05	1.19	1.10
2020	14	7	1.11	1.43	1.21
2025	20	12	1.17	1.70	1.33
2030	26	16	1.23	2.04	1.46
2035	30	20	1.29	2.43	1.60
2040	35	25	1.36	2.90	1.76
2045	40	30	1.43	3.47	1.94
2050	46	36	1.51	4.14	2.13

Source: Own calculations based on IEA (2016)

We deploy two specific scenarios in which the current BF-BOF-route is stepwise replaced by either the DRI-H or the PDSP technology. The replacement takes place along a linear path, with investments into new facilities starting in 2035 and DRI-H or PDSP steel production starting two years later (2037).

This means that the old emission intensive steel route is completely replaced by mid century. Regarding the stringency of climate policy we assume that current NDCs are being implemented, but no further mitigation efforts are carried out. In our analysis this means that we follow the IEA's (2016) forecast regarding CO_2 and energy prices (Table 3).

3. *Preliminary Results and Discussion*

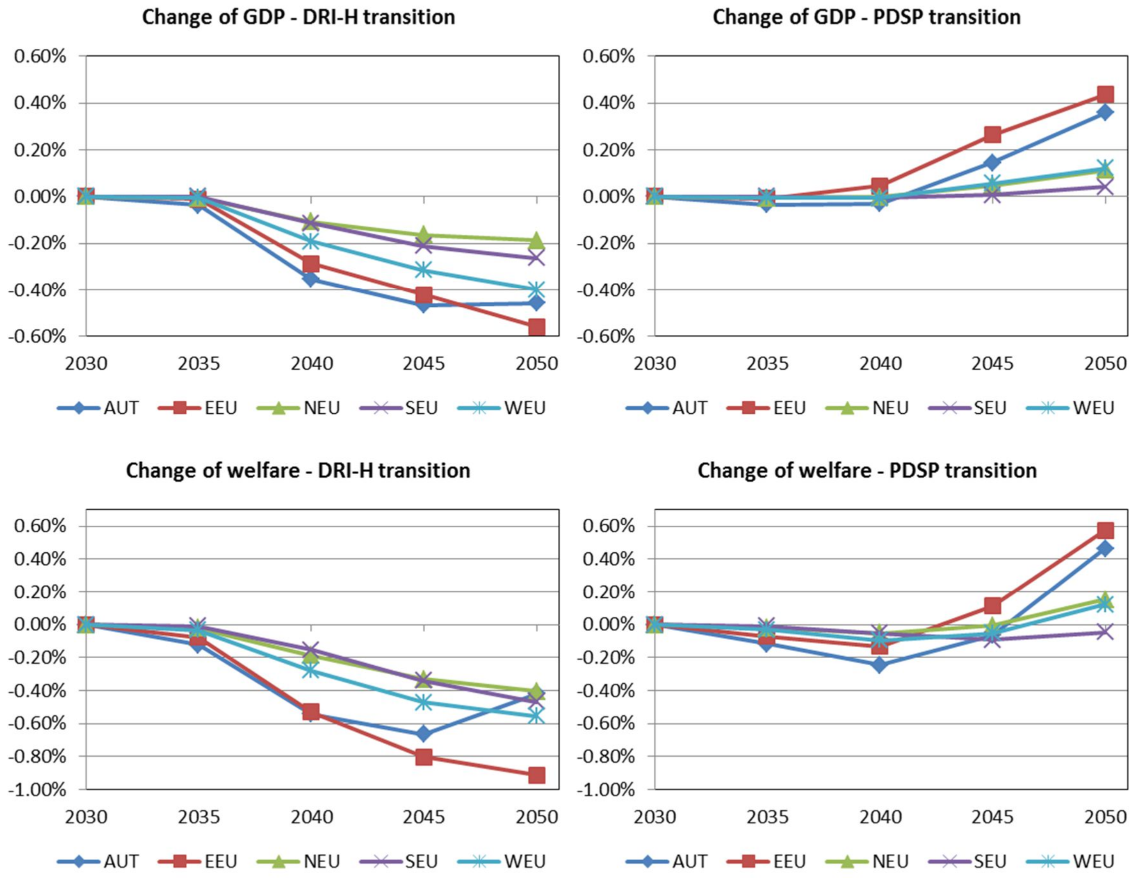

Figure 1: Change of GDP and welfare (Hicks'ian equivalent variation) in percentage relative to the reference case development without technology switch. Left: DRI-H transition. Right: PDSP transition. AUT – Austria. EEU – Eastern Europe. NEU – Northern Europe. SEU – Southern Europe. WEU – Western Europe.

Our simulations show that a competitive (dis)advantage translates into respective GDP and welfare (dis)advantages (Figure 1). The underlying CO2 price development (cf. Table 3) is too low for DRI-H but suffices for PDSP. This is not a surprising outcome for CGE macroeconomic analysis. However, across countries the CO2 process emission factors evaluated by national inventories and reported to the UNFCCC deviate stronger than a technologically meaningful assessment would suggest (cf. IEA, 2007, Figure 5.4, p. 108). Although the attribution of GHG emissions in the iron and steel sector to either combustion or process emissions follows a common accounting method, stoichiometric uncertainties are implemented differently across countries. Process emissions, currently implemented, are between 0.25 tons of CO2 per ton BF-BOF crude steel produced for Southern Europe and 1.50 for Austria (UNFCCC, 2017; WSA, 2012, 2016).

Consequentially, impacts from the introduction of a carbon-free steel technology are strongest in countries with a high BF-BOF CO2 process emission factor (Austria and Eastern Europe). This is true in both directions, e.g. Southern Europe is characterized by the lowest CO2 process emission factor, and experiences lowest gains and losses in GDP and welfare. However, current work aims at harmonizing the accounting of either combustion or process emissions across regions to tackle this deficiency.

4. Outlook

The WEGDYN CGE analysis is able to give a more robust evaluation of unit cost differences of distinct technologies through incorporation of endogenously changing market prices of intermediate inputs and primary factors. This allows deriving an extended comparison of unit costs of technologies and the related break-even CO2 price reaching cost parity. Thus, our analysis of the iron and steel transition in Europe helps to reduce consequential risks of poorly informed climate and related policies. Especially the inquiry of carbon leakage, income distributional (wages and capital rents) as well as labour market effects will allow a more fully-fledged assessment of the implications of such a 2°C-compatible transition.

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