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Impact and Repercussions of Regional Industrial and Environmental Regulation on Austria's Steel Industry in the& Context of an Inhomogenous Global Economy and Policy& Suggestions for a Profitable Green Transition

A Master&s Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **STELLA MITSCHE, BSC MSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "IMPACT AND REPERCUSSIONS OF REGIONAL INDUSTRIAL AND ENVIRONMENTAL REGULATION ON AUSTRIA'S STEEL INDUSTRY IN THE CONTEXT OF AN INHOMOGENOUS GLOBAL ECONOMY AND POLICY SUGGESTIONS FOR A PROFITABLE GREEN TRATSITION", 122 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 13.06.2024

Signature

Abstract

A comprehensive analysis, aimed at understanding the evolution of the Austrian steel sector and thereby deriving future policy suggestions, suggests that the apparent decline in international competitiveness of the European steel sector can only be explained by incorporating the interconnection of many interdependent industrial and environmental regulatory acts as well as globally asymmetrical capital market exposure and various country specific factors. This decline has been particularly noticeable since the turn of the century, with Austria being disproportionally affected. Furthermore, multiple factors have been identified that are in support of policy intervention to assist the steel sector in its transition towards a decarbonized industry. Through an interdisciplinary approach, taking into account both technological feasibility and research on addressing market failures, policy recommendations for both the EU and Austria have been formulated.

These conclusions stem from a comprehensive evaluation of various sources aggregated in a holistic assessment of the impact and repercussions of regional industrial and environmental regulations on an industry that is competing globally. This includes in-depth analyses on the EU-policy landscape and public policy research as well as country level macroeconomic data. Additionally, particular focus has been directed to an international comparison of present-day technology dominance and transitionary potential across countries and regions, in light of available steel production methods and their environmental impact.

Concludingly it is suggested that EU-policy should focus on (1) promoting research, development and industrialization (R&D&I) focused on both carbon capture and storage/utilization (CCS/U) and carbon direct avoidance (CDA) technologies as well as knowledge sharing, (2) constructing and coupling hydrogen and renewable energy infrastructure, (3) building recycling markets, (4) ensuring green public procurement, (5) advancing financial incentive setting, (6) aligning global approximations and improving projections, (7) increasing public awareness and finally (8) creating a global level playing field through international agreements. Additionally for Austria (A) an even stronger focus on public awareness as well as (B) the introduction of earmarked CO_2 taxes to finance (C) an increase in government R&D expenditure focused on advancing CCS/U technologies and recycling metallurgy and (D) national recycling infrastructure have been identified as additive policy measures.

Table of Contents

List of Abbreviations

AIT .... Austrian Institute of Technology

BAU .... Business-As-Usual

BCAs .... Border Carbon Adjustments

BFI ....Blast Furnace Iron

BF-BOF .... Blast Furnace – Basic Oxygen Furnace

BMK .... Bundesministerium für .... Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

BMNT .... Bundesministerium für Nachhaltigkeit und Tourismus

CAPEX .... Capital Expenditure

CBAM .... EU's Carbon Border Adjustment Mechanism

CCS/U .... carbon capture and storage/utilization

CDA .... Carbon Direct Avoidance

DRI .... Direct Reduced Iron

EAR .... Electric Arc Furnace

EC .... European Commission

EITE .... emissions-intensive, trade-exposed

EU .... European Union

EU-ETS .... EU's Emission Trading System

EUROFER .... European Steeal Assicoaition AISLB

FDI .... Foreign Direct Investment

H-DRI .... Hydrogen – Direct Reduced Iron

IEA .... International Energy Agency

IEEFA .... Institute for Energy Economics and Financial Analysis

IETA .... International Emmission Trading Association

IED .... Industrial Emissions Directive

IMF .... International Monetary Fund

JRC .... Joint Research Centre

MNEs .... Multinational Enterprises

MMT / mmt .... million metric tonnes

NDCs .... Nationally Determined Contributions

NG-DRI .... Natural Gas – Direct Reduced Iron

OECD .... Organisation for Economic Co-operation and Development

PPP 2015 .... Purchasing Power Parity at US 2015 Levels

R&D .... Research and Development

R&D&I .... Research, Development and Industrialization

…………………………..…………...………………… (also R&D&C for Commercialization)
RTO……………………………………………… Research and Technology Organisation
RRF ………………………………………………………… Recovery and Resilience Fund
t …………………………………………………………………………………… metric tonne
TCTF ………………………………………… Temporary Crisis and Transition Framework
TWh ………………………………………………………………………… Terra Watt Hours
UNIDO …………………………… United Nations Industrial Development Organization
UNFCC …………………… United Nations Framework Convention on Climate Change
VDEh ………………… Verein Deutscher Eisenhüttenleute, German Steel Association
CO …………………………………………………… Carbon Monoxide (Molecular Name)
CO_2 …………………………………………………… Carbon Dioxide (Molecular Name)
Fe ……………………………………………………………………… Iron (Chemical Symbol)

Abbreviations for Regions (Country List included in Annex 2)
ATA …………………………………………………………………… Anglo-Transatlantic Allies
EEA ………………………………………………………………… European Economic Area
ROW ……………………………………………………………………… Rest of the World

1 Introduction

As economies grow and develop, consumption of steel is generally expected to rise. Over the past decades, moreover steel consumption in developed countries was constant or even decreasing and could increasingly be met with the surging availability of steel scrap while the significantly increasing steel demand in developing countries was predominantly met through the installation of primary steel plants. The associated increased global steel demand, moreover, arose in a context where, globally speaking, the steel industry was able to benefit from relatively low costs for primary resources and, if applicable, only minimal costs for carbon emissions. In turn, while the output of steel industry increased by 190 per cent over the 2000 to 2015 time period CO_2 emissions associated with global steel production increase by 250 per cent over the same time period. This corresponds to an increase in global average emission intensity from 2.1 t CO_2 per tonne steel in 2000 to 2.8 t CO_2 per tonne steel in 2015 (P. Wang et al. 2022). In turn we have reached a historic high of total CO_2 emissions directly attributable to the iron and steel sector that amount to 7 to 8 per cent of global CO_2 emissions. These developments serve as the backdrop to investigate an industry that is characterized by low profit margins and therefore low economic incentives to innovate and move away from a highly efficient, but highly emitting BF-BOF based steelmaking process (Medarac, Moya, and Somers 2020).

The landmark international environmental legislation acts of 1992 the UNFCC and the Rio Declaration, emphasised the concept of common but differentiated obligations, which was first introduced in the Montreal Protocol, as it differentiated between environmental obligations of developed, so called Annex 1 countries, vs. developing countries. Having provided that, in the following decades developed countries adopted environmental industrial policy focused on pricing in local emissions with the aim to provide an economic incentive towards investing in green technologies and thereby facilitate a transition (United Nations 2024). Such ambitions were the strongest within the EU in the form of the EU-ETS, though other developed economies followed similar policy strategies. Over the past decade these local emission pricing policies did however not curb global emissions but rather provided an opportunity for environmental arbitrage in the form of carbon leakage as the production location shifted away from regulated areas (Branger and Quirion 2014; Keen, Parry, and Roaf 2022; Lim et al. 2021; Rossetto 2023b; Zachmann and McWilliams 2020) .

The fact that curbing global emission levels can only be dealt with at a global level, was pointed out as early as 1991 by Michael Hoel in his paper *Global environmental problems: The effects of unilateral actions taken by one country,* stating that "In global environmental problems, each country's own contribution to worldwide emissions is small, so there is little a country can do by itself. To solve global environmental problems, one needs coordinated actions between countries" (Hoel 1991). Moreover, the aspect of globality has been found to be particularly relevant for EITE industries, among which is steel manufacturing (Ramseur, Murrill, and Casey 2023; OECD 2002). New EU-regulations, therefore, now aim to correct the international imbalance through facilitating a shift towards re-shoring and transforming steel production (Branger and Quirion 2014; Keen, Parry, and Roaf 2022; Lim et al. 2021; Rossetto 2023b; Zachmann and McWilliams 2020).

This thesis tries to investigate how policy actions have shaped an industry that faces global competition and thereby tries to develop a balanced policy approach that is not only fit to correct a carbon leakage caused by earlier policy, but will rather promote a transition towards a wholly new and fully decarbonized industry.

1.1 Relevance & Importance of the Topic

As economic development is dependent on the steel sector, having a vital national steel industry has long been a political goal, hence every economy desires to support domestic steel production. With regards to the relevance of analysing the evolution of the Austrian steel sector five distinct factors highlight the relevance and importance of the thesis topic:

I. The global steel industry in its current form is one of the largest emitters globally.
II. Steel is necessary to sustain economic activities within developed economies and to enable further global economic development.
III. Commercialization of green steelmaking technologies so far has been slow being limited by a lack of marketability of carbon-neutral steel and high price sensitivity.
IV. Facilitation of the transformation of the global steel industry towards a decarbonized industry is inevitable to meet NDCs, which will require environmental industrial policy.
V. Historically Austria's economy has had a comparatively high dependency on the national steel industry. Targeted policy measures are therefore needed to facilitate

the pending transition of Austria's steel industry and reverse comparative disadvantages.

From this it follows that, the EU now particularly seeks to implement policy measures to re-shore steel production back. This case is even more serious as Austria has a relatively high resource demand for metals comparatively to its European peer group (Federal Ministry of Climate Action, 2020) which already indicates a comparatively high economic dependence on the steel industry.

1.2 Scope of Thesis

Both policy measures and their impact as well as technological advancements and their adoption are within the scope of this thesis. From a time-scale perspective this thesis focusses on this millennia though references to earlier developments are also within the scope of this thesis. Similarly, while the thesis' focus lies on the European and Austrian steel industry global references are included where necessary.

From a life cycle perspective, all aspects starting from ironmaking up until re-consumption are considered. Mining and raw material processing are however predominately excluded for several reasons. For one, Austria's domestic iron ore demand exhibits an import dependency of 86 per cent, suggesting that domestic mining activities are of minor importance. The embedded emissions of raw materials, including iron ore, processed into marketable steel products in Austria hence effectively depend on respective imports. Meanwhile local CO_2 emissions attributable to the Austrian iron- and steel sector primarily stem from production activities (BMK 2020). Secondly, the Austrian government has identified metals, and steel in particular, as one of the key enabling materials towards moving to a circular economy (BMK 2020). This thesis therefore predominately focusses on recirculation opportunities of steel stock instead.

Finally, iron and steel are globally marketable products, though industrial as well as environmental policies covering their production vary greatly, hence they form part of the EITE-industries. To this end all environmental implications off shipping, both of raw materials as well as end products to be used within the EEA are excluded from this thesis. This delimitation has been made due to inconsistent boundary definitions for the steel industry and its respective impacts. Nevertheless, the implication of disregarding emissions liked to global trade and international shipping with regards to policy enforceability are considered (Hasanbeigi 2022).

2 Literature Review

While this master thesis tries to find answers applicable for the Austrian steel industry, the following literature review provides a global perspective, as steel production constitutes part of EITE-industries. EITE-industries, such as steel, aluminium, and cement, "face an elevated risk of carbon leakage" (IETA 2023) necessitating the consideration of global market structures when evaluating national and regional policies. Given this context the literature review can be divided into two distinct sections. Firstly, the economics of the global steel industry will be reviewed, turning to different production methods of iron and steel thereafter. Secondly, the most important economic principles of industrial policy making are summarized and finally a noncomprehensive overview of environmental industrial policy is provided, with a focus on those policies that have or are believed to have a significant impact on the iron and steel industry.

2.1 Overview of the Steel Industry

To analyse implications of industrial and environmental policies on the iron and steel industry, this section provides a general overview of market dynamics and industry specifies of the steel sector. It has been pointed out by many that economic development has, up until now, been coupled to material stock increases that can be quantitative measured through material flow accounting (MFA) (Krausmann et al. 2009; Olasehinde-Williams, Balcilar, and Wandebori 2023). What is more steel has been identified as a particularly relevant stock material, as quantitative research suggests, that up to a certain level of economic development "steel stock plays a vital role, almost equivalent to labour and non-steel capital stock, in economic growth" (Ding et al. 2021).

2.1.1 Global Capacity, Production and Demand

A decade ago, in 2014, the OECD was reporting that global steel capacity had been increasing since the early 2000s, which can be seen in Figure 1 (OECD Steel Committee 2014). Overcapacity, which refers to the gap between production capacity and actual steel production, in turn had reached record highs by 2014, comparable to those levels experienced in the aftermath of the financial crisis in 2008. Up until 2021 overcapacity has been steadily decreasing (Figure 2), however "a total of 313 steel investment projects are either currently underway or in the planning stages around the world" (OECD 2023) and believed to be in operation by 2026. These new projects are assumed to add further 46.0 mmt of capacity, tallying the global overcapacity that is estimated to stand at 610.8 mmt at the end of 2023 (OECD 2023).

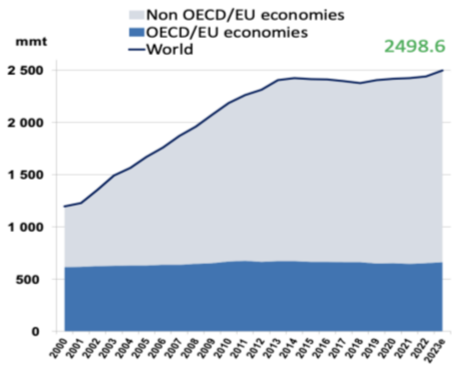


Figure 2.1: Evolution of crude steelmaking capacity in OECD economies and non-OECD economies.

Source: OECD Capacity Database (Mercier et al. 2023).

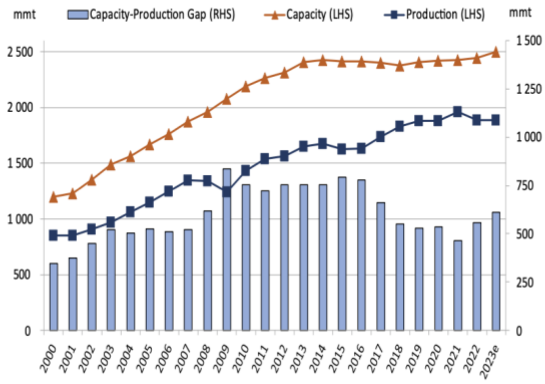


Figure 2.2: Global crude steelmaking capacity, crude steel production and capacity utilisation rate.

Source: (OECD 2023)

Steel demand is described as "Apparent steel consumption […] (which) is the total of all steel delivered to the steel market, including steel products that are being stocked rather than consumed immediately by the steel-using sectors."(EUROFER 2023a). Figure 3 shows the evolution of global steel demand, that on average has been increasing since the turn of the century, though it has not done so at fluctuating compound annual growth rates (CAGR).

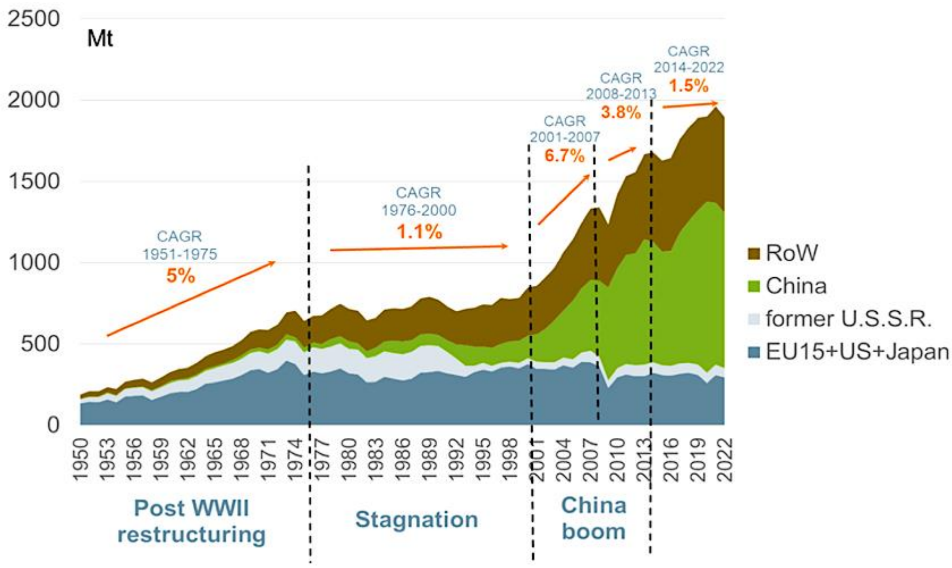


Figure 2.3: Evolution of global steel demand, 1950 – 2022, steel demand in crude steel equivalent terms

Source: OECD with data worldsteel.org

Figure 3 additionally shows that the growth over the 2000 to 2020 period can predominantly be attributed to China while annual steel demand of further developed economies remained fairly constant, increasing only sightly. It has been argued that Chinese demand may have peeked already, however global annual demand for steel is believed to continue to increase and by 2050 reach levels 1,4 times as high as the demand of steel today. This increase is assumed be primarily driven by countries who's economies are developing (World Economic Forum 2023). This supported by research concluding that the "stock of steel in society tends to increase markedly until it reaches a level of 8-16 tonnes per capita" (Pauliuk and Müller 2014) and thereafter requires annual reinvestments amounting to 400kg per capita per annum on average (International Energy Agency 2020), which gives an average useful life of 20 to 40 years for end-user steel product. Dividing apparent steel consumption by sector helps understand the increase in steel demand as economies develop, as the construction sector, comprised of both buildings and infrastructure, makes up for 50% of steel demand globally (worldsteel Association 2024). In comparison, in the EU the construction sector is still the biggest consumer but made up only 35% of total demand in 2023 (Mercier et al. 2023). The two second largest consumer sectors globally, and within the EU, are the mechanical engineering and the automotive sector, respectively, that each make up around 15% of the respective demand (worldsteel Association 2024; Mercier et al. 2023). Having said that, the recent slack in the CAGR, as seen in Figure 3, that started in 2016, can to a large extend be attributed to the Chinese real estate crisis, as the crisis emerged from the largest consumer measured by both, country and sector, which has visibly weight down global steel demand (Mercier et al. 2023).

2.1.2 Cost Structure and Financials

Production costs of steel can vary greatly both between countries and regions as well as within them, as seen in Figures 4 and 5. Furthermore, European facilities face some of the highest production costs irrespective of the production methods explained in the succeeding chapter. For one tonne steel they stood at an average of 458 € for the BF-BOF process and 486 € for the EAF process for the year 2019 (Medarac, Moya, and Somers 2020). While it should be noted that the recent crisis in energy costs in Europe is not reflected in these prices, there are two distinctly European price factors worth pointing out.

For one, "other costs" in the BF-BOF process are one of the highest in the EU. As this cost category does not only include CAPEX but also cost for CO_2, this may be nonsurprising, as costs for CO_2 account for 2% of the EU27 average total production cost. In comparison, "other costs" in the EFA process are fairly aligned for all countries across the globe, especially as CO_2 costs are considered negligible (Medarac, Moya, and Somers 2020).

Secondly, while BF-BOF facilities in all analysed countries can decrease production costs via credits, European BF-BOF facilities are "among world leaders in creating credits […] decreasing the costs of hot rolled coil by 83 EUR/t on average" (Medarac, Moya, and Somers 2020). To this end "credits" refer to negative costs, similar to revenues, "generated from savings when raw materials are recycled inside the facility instead of purchased from external sources, or when energy is self-generated" (Medarac, Moya, and Somers 2020). The associated whisker in Figure 4 nevertheless also highlights that the ability to generate such credits equally exhibits the greatest variation among EU member states. Finally, when comparing the negative costs from the well-established BF-BOF credit structure, to the same cost category for the EAF-production, the disadvantage of such credit structures not being readily available yet to drive down costs, becomes apparent, though it is particularly pronounced in Europe.

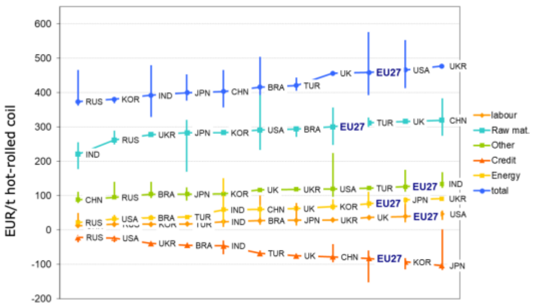


Figure 2.4: Hot rolled coil production costs in the BF-BOF process in 2019

Source: JRC based on data from (CRU, 2020).

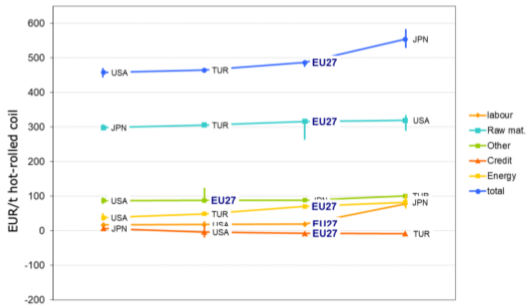


Figure 2.5: Hot rolled coil production costs in the EAF process in 2019

Source: JRC based on data from (CRU, 2020).

While the sudden and significant increase in demand form 2000 up until the financial crisis in 2007/08 pushed profitability to a constant high, the abovementioned overcapacity subsequently limited steel industry's profitability over the past two decades as can be seen in Figure 6.

To gain a deeper understanding of the current position of the steel industry, one must also factor in R&D expenditure, as the advancement of new technologies heavily relies on such long-term investments though short-term expenses. To this end Figure 5 shows that the iron & steel industry, which is summarized under industrials together with Aluminium; Containers & Packaging; Diversified Industrials; Industrial Machinery;

Nonferrous Metals and Transportation Services has faced one of the lowest levels of R&D expenditure over the 2009 to 2019 period in comparison to all other industries, with the notable exception of the chemical industry, that is however equally considered one of the most notable climate offenders (EC: JRC/DG RTD 2019).

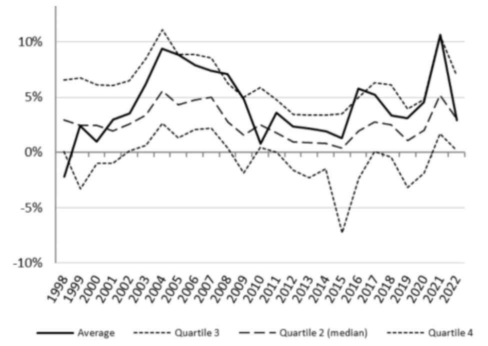


Figure 2.6: Evolution of net profit margin between 1998 and 2022

Source: OECD Steel Market Developments Q4 2023.

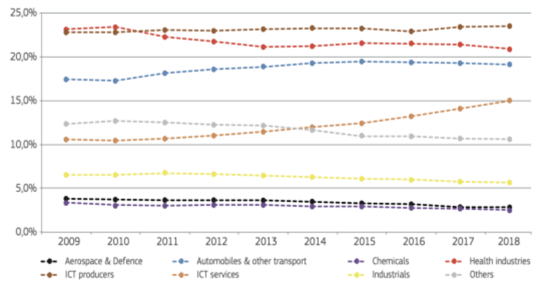


Figure 2.7: Evolution of global R&D shares for industrial sectors

Source: The 2019 EU Industrial R&D Investment Scoreboard (EC: JRC/DG RTD 2019).

2.1.3 Environmental Burden

It has been estimated that each tonne of steel produced on average has an embedded emission value of 1.85 tonnes of CO_2 (Hoffmann, Van Hoey, and Zeumer 2020). The IEA more precisely estimates it to be "1.4 t of direct CO_2 emissions and 0.6 t of indirect CO_2 emissions" (International Energy Agency 2020), which equates to about 8 percent of annual global carbon dioxide emissions (Hoffmann, Van Hoey, and Zeumer 2020). This average value does however not reflect that actual steel-to-emission ratios do vary between countries and the respective prevailing technologies and methods used to produce steel (World Economic Forum 2023). Figure 8 shows that emissions are predominantly related to coal used in the BF-BOF process. Furthermore, the ratio of emissions (blue line) to ton of steel produced (dashed line) stayed fairly constant up until 2016, when production increased while total emissions remained constant, an effect referred to as decoupling (Wen et al. 2019).

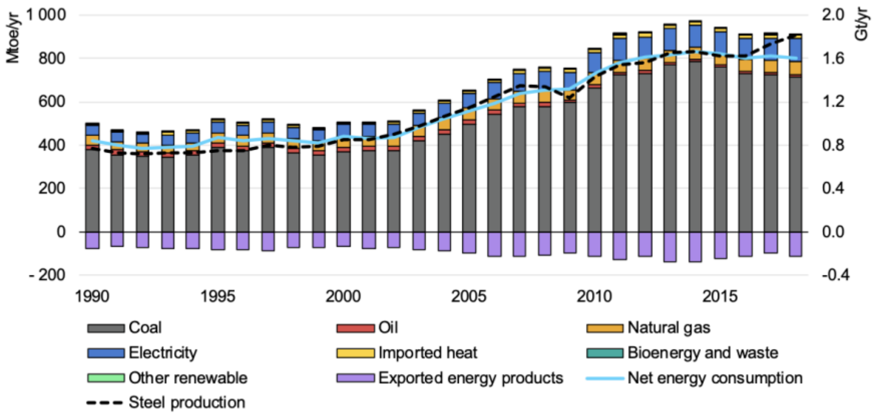


Figure 2.8: Final energy consumption in the steel industry

Notes: Gt = gigatonne; Mtoe = million tonnes of oil equivalent.
Source: IEA analysis based on IEA (2020a), World Energy Balances, and multiple editions of the World Steel Association Steel Statistical Yearbook.

As data shows that on a global level decoupling has only started less than 10 years ago it is worth looking at Industry reports from this period, where the change in sentiment regarding the inalienability of CO_2 emissions linked to steel production over the past decade becomes eminent. In its 2013 Roadmap, that included research carried out by BCG and the Steel Institute VDEh as well as the JRC, the European Steel association EUROFER concluded that the 2050 emission reduction targets aimed at by the EC were not economically feasible. Furthermore, the report points out estimations, that an emission reduction beyond 15% per produced ton of steel would not be economically viable and anything beyond that would only be possible through the large-scale implementation of technologies far beyond those know at the time (The European Steel Association | EUROFER AISBL 2013). Contrary to this, in 2019 EUROFER already describes "Pathways to a CO_2 neutral European steel industry" (The European Steel Association | EUROFER AISBL 2019). What is more, in its most recent publication, named Manifesto 2024-2029, EUROFER points out the importance of the European Steel industry as "it is not just adapting to the transition, it's leading it" (EUROFER 2024a).

2.2 Steel Production Technologies

As briefly touched upon there are various methods to produce steel that each have specific input requirements, namely a combination of iron ore, energy (mainly coal, natural gas, and electricity), limestone and steel scrap, and equipment to turn these inputs into steel as well as associated costs and emissions. Figure 9 provides a simplified overview regarding the key production routes in the steel industry, from raw material production to steelmaking. As a general distinction, there are two main elements dividing the various steelmaking methods. On the one hand steelmaking is divided according to the furnace being used, which traditionally is either a Blast Furnace – Basic Oxygen Furnace, short BF-BOF or an Electric Arc Furnace, short EAR. A second distinction is made according to which raw material is used as the iron component in the production, differentiating between steel made from iron ore, referred to as primary production and steel made from steel scrap, which is referred to as secondary production, though the two iron sources nowadays are increasingly combined at the steelmaking stage (International Energy Agency 2020).

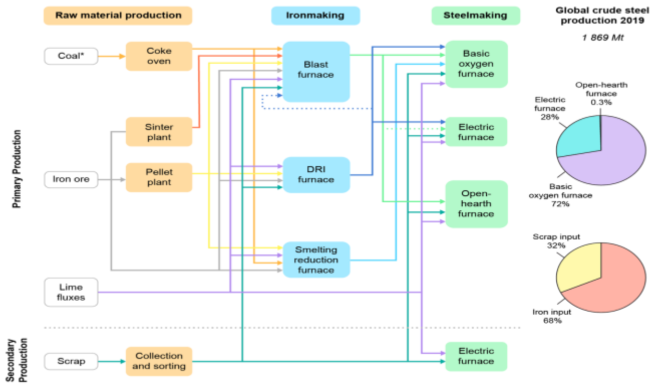


Figure 2.9: Main steel production pathways and material flows in 2019

Notes: "open-hearth furnace is an outdated alternative to the BOF and has largely been phased out given its inferior energy performance" (International Energy Agency 2020)*; Smelting reduction is an alternative class of processes for ironmaking which is currently at a commercial development stage.*

Source: Crude steel production quantities based on World Steel Association (2020b), World Steel in Figures 2020. Graph from (International Energy Agency 2020)

While Figure 9 depicts the various combinations of technologies, also covering raw material processing which has been excluded from the scope, in practice the key differentiation is made between BF-BOF and EAF production, while EAF production is then further divided into primary and secondary steel, denoted as DRI-EAF and Scrap-EAF. To this end Figure 10 provides an overview of the global average of the respective energy and emission intensities of each of these production routes and their respective global share.

Technology process	Emission intensity CO_2 (t)/ Crude steel (t)		Energy Consumption (GJ/t)		Share of global steel production (%)
	Direct	Direct + Indirect	IEA	Worldsteel	
BF-BOF	1.2	2.2	21.4	22.7	73.2
DRI-EAF	1.0	1.4	17.1	21.8	4.8
Scrap-EAF	0.04	0.3	2.1	5.2	21.5

Figure 2.10: Key production metrics of main steel production routes.

Note: worldsteel reference values are adjusted to match the IEA "crude steel boundary". Differences between IEA and worldsteel values are mainly attributable to the treatment of electricity.

Data Source: (IEEFA 2022)

The following sub-chapters will provide a concise overview of the technologies used in each production step today as well as the technological advancements currently under way. While an in-depth technical description is spared, this section will primarily highlight the greening potential found in each production step and, to the extent that they are available, also looking at associated cost and economic feasibility. As the distinction between primary and secondary steel is ever more fluid, this section will first provide an overview of the different iron ore processing steps and the focus on each of the prevailing processes in the steel production individually rather than looking at greening opportunities on an aggregated level.

2.2.1 Blast Furnace Iron (BFI) vs Direct Reduced Iron (DRI)

"The major share of energy consumption during steel manufacturing is spent on iron making" (S, Gowd, and Rajendran 2024). Iron (Fe) is one of the most abundant elements in the earth's crust making up about 5,6% only overtaken by Silicon and Aluminium as well as Oxygen that makes up almost half of the earth's crust (worldatlas 2024). In its natural form iron usually comes as a mineral in the form of iron oxides known as rocks, magnetite (Fe_3O_4), hematite (Fe_2O_3), siderites ($FeCO_3$), and limonite ($2Fe2O_3 \cdot 3H_2O$) (Fisher and Barron 2019).

Since the 18th century, the chemical method used to reduce iron oxides to elemental iron, needed as a raw material in the steel making, is the combustion of iron oxides together with carbon-rich substances such as coal or coke in a blast furnace which provides carbon (C) and carbon monoxide (CO) that act as reducing agents to produce the stable end products Fe in the form of hot molten metal and CO_2 in its gaseous state. While for centuries the gaseous CO_2 produced in this combustion process was released into the atmosphere more recent literature highlights the opportunities to capture carbon and for example use carbon mineralization technology to transform CO_2 "into a thermodynamically stable solid carbonate material" (Moon et al. 2024).

Additionally, to the reduction itself, lime fluxes are also introduced during the blast furnace combustion process whereby lime combines with waste products apparent in the ore enabling their reduction through the formation of molten slag (Fisher and Barron 2019). The thereby produced off-product slag is one notable source for credits in the BF-BOF process, as it is sold to the cement industry, where it can be used as a primary raw material, enabling emission reduction (International Energy Agency 2020; Medarac, Moya, and Somers 2020).

Alternatively, to BFI, where carbon-rich substances are introduced as a reducing agent, much attention has recently been directed at the environmental potential of direct reduced iron, short DRI. In this process iron is reduced below its melting point as syngas is introduced, either composed of the natural gas methane (CH_4) or hydrogen (H), to reduce the oxygen in the iron ore. This process achieves 90–95% metallization as the stable end-products Fe, H_2O and, depending on the amount of methane being introduced, some CO_2 is formed. As CO_2 is only one of the end-products, next to H_2O, when methane is used in the DRI-production, this process does emit much less CO_2 (Boretti 2023) and is even believed to cut CO_2 emissions by more than half, compared to the BF-process. However, production of DRI that primarily depends on the use of coal, does not garner equal emission reduction (S, Gowd, and Rajendran 2024).

Using green hydrogen, referred to as H-DR, is suitable to eliminate practically all emissions (Trinca et al. 2023). While some H-DR plants have been installed, "Industrial-scale hydrogen ironmaking is still in the development and early deployment stage" (Boretti 2023). To this end one of the key processes limiting mass implementation is the production of hydrogen itself. What is more, "scalability of the process, and the integration of hydrogen-ironmaking with existing steelmaking infrastructure" (Boretti 2023) are both additionally constraining large-scale industrial uptake. As hydrogen production through electrolysis requires large amounts of electricity and the DR process itself is more endogenetic than the BF process, the overall energy efficiency of the DR process is estimated to be fairly similar to that of the BF process (International Energy Agency 2020).

Furthermore, "to have an environmental benefit compared with the methane-based direct reduced iron process, the green hydrogen plant must operate for at least 5136 h per year (64.2% of the plant's annual operating hours) on renewable energy." (Trinca et al. 2023). Researchers have also argued that using green hydrogen alone, referred to as H-DR, would actually become cost efficient beyond a certain level of carbon price (Vogl, Åhman, and Nilsson 2018) and may also be a means to balance energy systems that are more reliant on renewable energy though sector coupling (Vogl, Åhman, and Nilsson 2018; Elsheikh and Eveloy 2022; Trinca et al. 2023).

2.2.2 BF-BOF vs. DRI-EAF Steelmaking

One of the key differences between the earlier explained BFI and DRI process and hence also the steelmaking that follows each specific ironmaking, is the state of the iron that is being produced. DRI is usually further converted in EFAs while BFI is primarily turned into steel in a BOF.

To this end, the BF-BOF process is often described as an integrated process where the BOF part of the BF-BOF steelmaking process is habitually referred to as a converter. This comes from the fact that, both steps are usually carried out in proximity of each other because the earlier produced BFI comes in the form of molten iron, that is then directly oxidized to remove the excess carbon to around 1% turning iron into steel (Hamadeh, Mirgaux, and Patisson 2018). As pointed out in Chapter 2.1.2, the BF-BOF method profits greatly from credits that this process generates. At an aggregated level these credits come from using the residual energy in flue gas (Blast furnace gas credit, Basic oxygen furnace gas credit, Corex gas credit, Custom iron gas credit, Custom steel gas credit, Steam credit), the use of recycled scrap (scrap reverts, Fe reverts, and sale of off-products) which illustrates the maturity of both the technology and the market, giving it a clear advantage to incumbents (Tar, Benzole and Slag).

On the contrary, an integrated nature is not present in the DRI. While the reduction in the DRI process occurs at up to 950 °C, which is still below the melting point of iron at 1,538 °C, the solid DRI, also called sponge iron, is then cooled down to approximately 50 °C in the lower part of the furnace and only being discharged thereafter (Hamadeh, Mirgaux, and Patisson 2018). These lower discharging temperatures hence allow for the transport of sponge iron over larger distances which permits the DRI process to be removed from the following EAF process (Hamadeh, Mirgaux, and Patisson 2018). At the stage of steelmaking in the EFA, sponge iron is then being heated up beyond its melting point and is then often also combined with scrap metal. Regardless of the possibility of introducing scrap, the DRI-EAF production method does receive much well-deserved attention, as this method can be used to produce primary steel and doing so as mentioned while producing only half the amount of CO_2 emissions when NG-DRI is used compared to the traditional unabated, emission intensive integrated BF-BOF method (S, Gowd, and Rajendran 2024). This method also enables the potential of emission free steel if H-DHI is used in combination with biomass which is then referred to as CDA. This is of particular interest because primary steel with its limited and closely controlled alloy components, is sometimes preferred over secondary steel. This preference arises from an aversion towards impurities that stem from accumulated alloy during scrap reprocessing, because they could negatively impact the quality of the steel and thereby end products (Panasiuk et al. 2022).

2.2.3 Steelmaking form Scrap

As shown in Figure 1 and Figure 3 both global steel production and demand have increased multifold since the end of World War 2 (Dworak, Rechberger, and Fellner 2022). Given an average lifetime of steel of 20-40 years, this has by now resulted in vast amount of steel scrap (Kermeli et al. 2021). As the former section has just highlighted the emission intensity of processing iron ore into elemental iron, the desire to reuse steel scrap as a source for iron is eminent and has been highlighted in literature numerous times. The way how steel scrap is being collected is heavily dependent on the specific industry and vastly expansible hence relevant potentials to increase scrap collection and recycling rates are covered in Chapter 5. Nevertheless, the processes by which steel is recycled back into the steel process and the limitations of using secondary steel are universal. Though the EFA method was initially designed to produce secondary steel, steel scrap can be used to substitute both BFI as well as DRI in either the BOF or the EFA steelmaking processes. Regardless of the steelmaking technology, the tramp elements, however, significantly limit the use of steel scrap. As steel almost always comes in the form of alloy steel, purity of steel scrap itself, and thereby the usability of the scrap, differs both from industry to industry as well as between countries and regions (Panasiuk et al. 2022).

To this end it has been argued that the amount of low purity scrap that cannot be recycled in Austria annually is believed to double by 2050, reaching an annual surplus of 43 Mt/yr (Dworak, Rechberger, and Fellner 2022). Furthermore, research on steel produced from scrap in different parts of the world found "that the recycling technology, the presence of a market for recovered metals, the quality of the material input, steelmaking practices, and the management of by-products derived from a legislative or economic context played a role in the impurities content (Panasiuk et al. 2022)". What is more, multiple researchers have highlighted the importance of "communicating on scrap chemical content, (as to enhance) the collaboration between the recycling and steel industries […] in terms of matching the demand and supply and facilitating an increase in the scrap share in steelmaking" (Panasiuk et al. 2022) , (Dworak et al. 2023). Finally, analysis on the energy efficiency of EAFs that additionally considered the amount of DRI added into scrap mixture during the steel production found that energy efficiency of EFAs heavily depends on the knowledge of the input materials as well as on the management of the entire steel making process including slag handling (Kirschen, Badr, and Pfeifer 2011).

2.3 Framework for Understanding Industrial and Environmental Policy

Following an approach to prosperity established as the Neoclassical Growth Model also known as the Solow Growth Model "every government, throughout history, has been practicing some form of industrial policy – public policies aimed at stimulating industrial growth and, ultimately, the transformation of the economy from low-productivity agriculture (referred to as the Malthusian Age) to high-productivity manufacturing and services" (Devarajan 2016). In this context the term 'industrial policy' must be understood broadly encompassing any set of measures that might be employed by governments to influence a country's economic structure and in turn ensure that political goals are being implemented (Devarajan 2016).

When considering Europe and North America during the time following WW2 and at a later stage also China, the desired objective of those respective governments was first and foremost to enhance productivity that would increase economic competitiveness so that the resulting economic growth would in turn ensure higher incomes and prosperity for the general population in the form of a welfare state. This neoclassical approach has however been under scrutiny, initially due to the lack of productivity gains since the 1970s referred to as the productivity paradigm and more recently due to a lack of consideration given to the consequences of economic growth, including exploitation of both humans and nature (Kufenko, Prettner, and Geloso 2020). To this end research has coined the term 'wicked trinity' which refers to the three present day issues of stagnation, surplus humanity, and environmental breakdown that traditional shareholder capitalism is accused of (Alami, Copley, and Moraitis 2023). While some argue that a shift towards a capitalistic economic structure that includes all stakeholders of a society might be sufficient to counterbalance these inequalities (Beck and Ferasso 2023) much research has been carried out looking at the role policy is supposed to play (Alami, Copley, and Moraitis 2023).

A comprehensive analysis of the consequences of capitalism considering global economic market dynamics and the interplay with national or respective regional policy is beyond the scope of this thesis, especially as the merit of industrial policy itself, aiming at ultimately altering business decisions away from pure market-based economics has been under scrutiny for many decades (Ilyina, Pazarbasioglu, and Ruta 2024). Nevertheless, to provide a comprehensive explanation for the evolution of the global steel industry, this sub-chapter introduces key economic mechanisms. These mechanisms are essential for understanding the significant shortcomings associated with neoclassical welfare economics and the pivotal role that policy should play in addressing them today.

2.3.1 Economics of Capitalism, Market Failures and Climate Change

Extensive research has been carried out to provide both theoretical as well as empirical evidence that many of the economic systems that modern day capitalistic societies and the business therein rely on, cause environmental degradation (Gilbert et al. 2024) and limit large scale industrial transformations (Kufenko, Prettner, and Geloso 2020). One tangible example of a mechanism that has such an effect is the universal use of accounting itself, as this practice has been found to exacerbate issues in times of crisis due to its back looking nature (Gallhofer and Haslam 1991).

One of the key economic concepts trying to explain corporate innovation, business transformation and the common lack thereof focuses on loss aversion and myopic behaviours, which have been empirically proven to be present in most chief executives of listed companies (Bellemare et al. 2005). On a macroeconomic level, the concept referred to as the Kuznets curve which prescribes that as economies develop their per capita emissions increase up to a certain point when regulation counterbalances economic expansion and the per capita ratio of emissions to income decreases again. Combining these microeconomic behavioural with this macroeconomic concept explains the FDI trend of EITE industries. In recent decades these industries have to a large share pursued expansive FDI strategies to evade domestic environmental policies and therewith associated costs, which however came at the cost of increasing overall global emissions (Shahnazi, Jamshidi, and Shafiei 2024).

On a national or respectively regional policy level, it has been found that countries or respective regions that focus on short-term welfare goals, referred to as myopic farsighted policy, consciously limit the implementation of environmental policies. This can be explained as foresighted policy that focus on welfare of future generations by limiting present pollution, has been found to aversely effect present day national welfare because transboundary emissions move elsewhere while economic gains are lost to farsighted countries with lower environmental standards (Benchekroun and Martín-Herrán 2015). What is more, most basic economic models equally provide evidence, that once environmental damages are considered in economic output models, steady state income per capita may be up to three times higher for a 'no damage' scenario compared to an 'all damages' scenario by in 2200 (Tsigaris and Wood 2016).

While research is inconclusive on the relation of economic freedom and emission intensity of a country, it is generally believed that developed countries exhibit higher levels of economic freedom (Acevedo, Lorca-Susino, and Mora 2024). What is more, researchers found that historically countries with a high level of economic freedom were able to decrease their per capita income to emissions ratio compared to countries with a low level of economic freedom. In the context of industrial policy these are important economic findings as regulated industries usually argue that increasing regulation would limit economic growth, cost jobs and hence in turn decrease welfare, as it has been described for the steel industry. Conversely research has in fact shown that regulation may be both growth-enhancing and diminishing and that there is a level of regulation that is in fact growth-enhancing (Heckelman and Wilson 2019).

Having provided these general societal goals and associated conflicts of interest between individual stakeholders the final aspect that needs to be considered is our understanding of welfare and the resulting obligation of policy makers. Traditionally "welfare economics explains regulation as justified in response to market failure due to ill-defined property rights, market power, or asymmetric information. In this view, regulation compensates for market failure and is a policy tool intended to reduce deadweight losses which would otherwise occur" (Heckelman and Wilson 2019). While for the majority of the 20th century, corresponding policies focused on social security such as pension and health care systems, the core of the argument for policy intervention started to be redefined when in 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United

Nations 2024). Following this definition, 20th century policy was primarily concerned with market failures regarding the first part of this sustainability definition while the political and societal discourse now focuses on ensuring the second part of the sustainability equation (Gowdy 2005). This shift in priorities equally reflects academic developments concerning the definition of welfare economics, that demand a dynamic understanding of welfare that can be adopted according to novel knowledge (Dolfsma 2005).

2.3.2 Industrial Policy Measures for an Environmental Transformation

As described in the preceding chapters, the steel industry does not only form part of EITE industries but to enact the low-carbon transition will also require innovation of technologies yet unseen, at least at large scale. With respect to green industrial transformations, much research has been carried out to investigate different policy options and their suitability to enable the fastest transition at the lowest costs for the public. While the outcome of specific policy choices and their effectiveness to transform domestic steel industries will be discussed in the country case analysis in Chapter 5.5 the following paragraphs introduce some key concepts regarding environmental industrial policy.

With regards to regulation, taxes on emissions and subsidies on green R&D or green investments have been described as two sides of the same coin and have both been identified as necessary in one of the landmark publications by Acemoglu et al. 2012. Succeeding research has found that the correct policy choice is dependent on a variety of factors such as knowledge spillovers, public influence through ownership (Lee and Park 2020), influence of large corporations on policy makers (Niu, Ruan, and Zeng 2022), elasticity of substitution between clean and dirty inputs (Wiskich 2021), and many more (Wiskich 2024).

While it has been found that policy instruments focusing on green firm R&D either in the form of subsidies or tax rebate policies are suitable policy instruments to promote the green transition (Chang et al. 2022) "carbon tax and a clean production subsidy should (be) apply(ed) if research instruments are unavailable" (Wiskich 2024). Furthermore, there is evidence suggesting that green subsidies have a greater effect to start off the green transition while emission taxes seem to be more suitable at a later stage of the transition process (Z. Li et al. 2022). Moreover, while "government subsidies to a certain extent will help encourage companies to choose low-carbon innovative production strategies, […] more subsidies are not always better"(D. Liu et al. 2024) as an increase in subsidies is directly reflected in the cost of government regulation (D. Liu et al. 2024).

With regards to taxation, it has been suggested that emission taxes may even pose an alternative to profit taxes in the long run (Pang 2019). What is more, it has been found that even the choice of abatement tax positively effects the likelihood of achieving long-term environmental ambitions as taxation on local air pollution and carbon emissions alone, each come at higher costs for the overall economy compared to a balanced combination of both taxation options as “technology-specific emission profiles and technological substitutability” (Mier, Adelowo, and Weissbart 2024) can be exploited to achieve a more efficient taxation system (Mier, Adelowo, and Weissbart 2024). Finally, policy analysis suggests that implementing dynamic subsidies and tax structures are better suited to quickly reach a steady state corporate low-carbon innovation. Simultaneous public intervention and supervision is meanwhile necessary to prevent both corporate misconduct in the form of over-emitting as well as government misconduct in the form of over-spending or under-regulating (D. Liu et al. 2024).

2.4 Industrial and Environmental Policies in Practice

While the preceding section provided an economic overview upon which policy evaluation can follow, this sub-chapter provides a non-comprehensive summary of the most significant existing industrial policy measures that are either already in place or have been announced. While the focus of this regulatory overview lies on the European Union, to provide a level headed overview global comparisons are added where suitable. As a general introduction it needs to be mentioned that industrial policy has been found to be on the rise, having doubled over the ten-year-period from 2009 to 2019. Over this period, developed economies were taking the lead, implementing five times as many measures as developing countries, and were primarily using industrial policy to set off and further back the green transition. What is more, 6% of all industrial policies in developed countries and 11% for developing countries were specifically targeted at the steel industry (Juhász et al. 2023; Ilyina, Pazarbasioglu, and Ruta 2024; IMF 2024).

2.4.1 Framework and Developments of the EU's Industrial Policy Approach

According to Article 173 TFEU industrial policy is a competence of the EU which means that member states must adhere to industrial policies agreed upon at EU level but may be tasked to implement additional, industrial measures at national level within the scope of EU policies. In 2023, the objective of European industrial policy provided for by the European Parliament has been restated to read that "industrial policy is cross-cutting in nature and aims to secure framework conditions favourable to industrial competitiveness. It is well integrated into several other EU policies such as those relating to trade, the internal market, research and innovation, employment, environmental protection, defence and public health. EU industrial policy is specifically aimed at: (1) 'speeding up the adjustment of industry to structural changes'; (2) 'encouraging an environment favourable to initiative and to the development of undertakings throughout the Union, particularly small and medium-sized undertakings'; (3) 'encouraging an environment favourable to cooperation between undertakings'; and (4) 'fostering better exploitation of the industrial potential of policies of innovation, research and technological development' (Article 173 TFEU)" (Corinne Cordina 2023). Furthermore the EU's industrial strategy, that was published in May 2021, claims that "Europe is embarking on a transition towards climate neutrality and digital leadership"(EC 2021a) and hence proclaims the three focus areas for industrial policy "(1) strengthening the resilience of the single market (2) dealing with the EU's strategic dependencies (and) (3) accelerating the green and digital transitions" (EC 2021a).

These recent statements and policy objectives must be understood in light of recent geopolitical events including COVID-supply chain issues, the US-China trade war and the US Green Deal of the Biden administration, that was announced in 2020. They can however also be seen as a response to the constant decline of domestic industrial output that resulted from the stringent policy approach of the EU in the 2010s. This approach was flanked by the Industrial Emissions Directive, short IED, published in 2010, that introduced the first EU-wide regulation of pollutant emissions from industrial installations, including steel, by introducing emission limit values based on Best Available Technologies (Official Journal of the European Union 2010). Furthermore, the EU-ETS, an emission regulation system that follows a 'cap and trade' principle with the aim of regulating and taxing carbon emissions put further pressure on EITE industries from 2012 onwards. In that year the EU-ETS entered its third phase that eliminated grandfathering terms, which refers to emission allocations according to past production that were introduced in Phase 1 and 2, make auctioning the default method for allocating allowances. To limit carbon leakage, some industries, most notably the iron and steel industry, are to this day being treated more leniently, receiving emission allocations based on historical production of a company multiplied by the average emissions of each sub-sector's 10% best-performing facilities (Sartor, Pallière, and Lecourt 2014). While there has been criticism because the iron and steel industry continue to receive emission allowances according to the earlier described product benchmarks, the EU-ETS remains the only ETS effectively covering the iron and steel industry to date (Frank 2023). The effective decline in European steel production since 2012 can therefore be considered a result of the economic pressure put on EITE industries stemming from these policies (Rossetto 2023a).

2.4.2 EU's Recent Regulatory Acts

Following the earlier mentioned objectives and to counteract the above stated 2010s developments the EC has published various legislative acts as well as political strategies over the last four years in order to achieve the above-stated objectives. Amongst the recent regulation that aims to translate these goals into action is the Ecodesign Regulation that is setting out product standards aiming to enable and promote a circular economy (Council of the European Union 2023). Additionally, the EC has also set up new subsidies frameworks including the Net-Zero Industry Act that aims to facilitate and speed up implementation of large-scale net-zero technologies that have not yet been implemented at large or industrial scale (EC 2024a), and the TCTF as well as provided new subsidies schemes to member states via the RRF (Council of the EU and European Council 2024). Among the member states that have already established national subsidies schemes targeted at enabling the green transition of the iron and steel industry are France and Belgium (International Energy Agency 2024).

As described in Chapter 2.3 the underlying assumption of both free trade and capitalism is that most business decisions should be left for financial markets to decide. This decision is simply taken by providing access to finance for one project, company, or industry over another, based on profit predictions. It has however been argued, that, as earlier mentioned, financial markets have so far been slow at best in provisioning for an environmental transition, as profit predictions do not yet reflect environmental risks appropriately. In part, this has also caused domestic industries to produce elsewhere in order to continue realizing profits. In light of this mismatch, the EC has developed countless legislative acts targeted at financial institutions that are aimed to bring the environmental effect of economic activities to the centre of financial decisions. The centrepiece of these legislative acts is *Regulation (EU) 2020/852 of the*

European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088, better known as the EU-Taxonomy Regulation that comprises a list of all economic activities capable of affecting the environment. The corresponding reporting directives require both financial institutions as well as relevant industries to disclose if the economic activities they undertake or invest in are covered by the EU-taxonomy and if so whether they are carried out in a taxonomy compliant way. As a result, this disclosure requirement should shift investment preferences of financial institutions and in turn corporations towards producing domestically and in a taxonomy compliant way. As steel manufacturing is one of the listed activities, the taxonomy regulation defines certain production criteria listed in Annex 1 that must be met for the activity to be taxonomy compliant. (EC 2021c)

2.4.3 Extraterritorial EU Regulation on Embedded Emissions

As shown in previous chapters, steel produced within the EU is, in general terms, less environmental derogating than steel produced elsewhere, though it has a competitive price disadvantage, especially since the introduction of the abovementioned EU-ETS (Cludius et al. 2020), which explains why EU's industrial strategy shifted towards focusing on increasing competitiveness of the EITE industry. A cornerstone towards making this political goal more attainable was reached in 2019, when the EC announced to commit itself to set up a BCAs mechanism to help reduce carbon leakages and counteract the pollution haven hypothesis. Border Carbon Adjustments, in short BCAs, are a trade-related policy measure, similar in effect to import fees or tariffs, that put a price on the amount of carbon that was emitted during the production of the imported good, with the EU specific policy measure being referred to as the CBAM (Rossetto 2023a).

In December 2022, the European Parliament and the Council of the EU reached a provisional agreement on the CBAM which was then agreed upon and published as *Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 establishing a carbon border adjustment mechanism* (Official Journal of the European Union 2023), and has been in effect since October 2023. This regulation followed previous commitments as stated in EU's NDC under the Paris agreement and the corresponding *Fit-for-55 legislative-package* and hopes to reverse the recent rise in carbon leakage as the "Union has substantially reduced its domestic greenhouse gas emissions, [while] the greenhouse gas emissions embedded in imports to the Union have been increasing" (Official Journal of the European Union 2023) as well as in effect reduce global greenhouse gas emissions, by substituting import consumption with less environmentally burdensome consumption of domestically produced goods (M. Wang and Kuusi 2024). With this mechanism the EC aims to "put a fair price on the carbon emitted during the production of carbon intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries" (EC 2023).

The payment obligations related to the CBAM will resemble certificate trading, similar to the EU-ETS and only be obligatory if the country of origin has not yet implemented an ETS which is considered to be equivalent in effect to the EU-ETS. Moreover, the CBAM payment obligations will be based on weekly average EU-ETS certificate prices and not be pursuant to direct auctions in order to better reflect the equivalent pricing of carbon for both imported and domestically produced goods and hence stipulate a level playing field for imports and exports counterbalancing the EU-ETS (Official Journal of the European Union 2023).

This trade-related policy has recently received much international traction as it is "intended to mitigate adverse competitiveness effects and other concerns when one or more countries establish more ambitious policies to reduce GHG emissions than others" (Ramseur, Murrill, and Casey 2023). What is more this new policy is especially of relevance for the EITE industry since the EU turned from a net steel exporter to a net importer in the 2012-2021 period which may be attributed to the implementation of the EU-ETS (Rossetto 2023a). While WTO-conformity of this system is yet to be determined, the establishment of such a system has already sparked international discussion especially with regards to the iron and steel industry.

With the CBAM entering into its transitional phase on 1 October 2023, importers of CBAM goods have been required to submit two quarterly reports by now, that included data on the quantity of imported products and their embedded carbon emissions. This has, as intended by the EU, put pressure on countries with no or more lenient carbon emission regulation as it also will shed light on global discrepancies of carbon emission intensity. As shown in Figure 12, the emission intensity of iron and steel exports from the vast majority of countries is higher than the EU standard which will translate to compensation payments through the CBAM (IETA 2024).

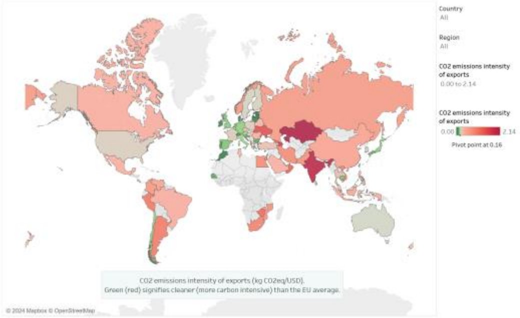


Figure 2.11: CO_2 emission intensity of exports for iron & steel industry, for units see blue box.

Source: Worldbank.org

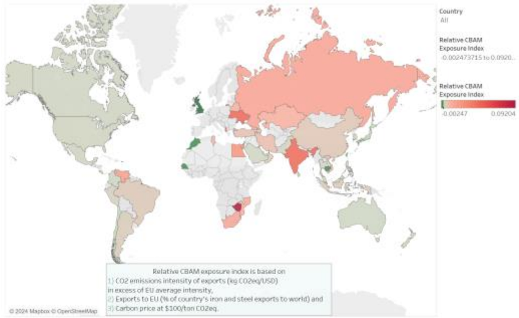


Figure 2.12: Relative CBAM exposure index for iron & steel, for calculation and units see blue box.

Source: Worldbank.org

For this reason, iron and steel exporting countries have been amongst the most strident opponents of the CBAM (IETA 2024). To this end Brazil's steel industry is considered to be the most affected in Latin America, hence its government requested broader discussions on the equitability of such unilateral actions. India on the other hand, where "as much as 40% of the roughly 4 million tons of steel India exports annually to Europe would be exposed to CBAM" (Srivastava 2024) and producers could see the cost of their steel exports increase by 56% by 2034, has engaged in many rounds of negotiations with the EU aiming to receive recognition of their national policy measures and thereby circumvent the CBAM (Srivastava 2024). Chinese producers could equally see the cost of their steel exports rise by 49% by 2034, hence posing a serious threat on Chinese competitiveness and global leadership. While the Chinese government therefore also considers the measure discriminatory, the country does however also consider this greening push coming from the CBAM as an opportunity as China does already have a clear focus on green industrial policies and has an ETS in place. While the existing ETS system does only cover energy the new round of emissions compliance period is announced to also cover aluminium, steel, and cement. This is especially notable given that Chinese steel production emits above global average values of CO_2. Finally, countries close to the EU, including Turkie, the UK and Ukraine, are in the process of aligning their ETS system to the EU-ETS so that the large share of their respective relevant exports covered by the CBAM will already align and no adjustments will be required (IETA 2024).

2.4.4 Global Emission Regulation and Other Global Industrial Policy Measures

As of the end of 2023, around 23% of global GHG emissions are covered by ETSs and carbon taxes in operation in the countries shown in Figure 11 (Worldbank 2023). As mentioned earlier the EU-ETS is so far the only ETS covering the iron and steel industry, with China and India having announced steps to follow (IETA 2024). Furthermore, while ETSs are increasing around the world they are far from reaching their full potential as most systems so far are primarily allocation emissions and not yet effectively implementing sufficient caps (IETA and pwc 2023). Research has for example found that "restrictive strength of the Korean ETS policy remains relatively low"(Jang et al. 2024).

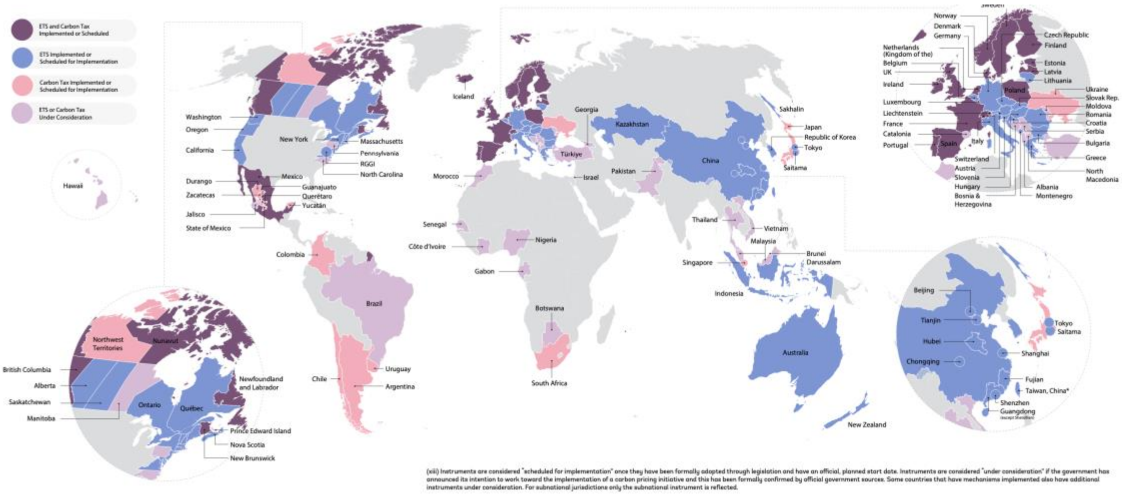


Figure 2.13: Carbon taxes and ETSs across the world.

Source Worldbank Report on Carbon Pricing 2023

Beyond emission regulation, coordinated policies aimed at easing an industrial green transition have been limited. While the US and the EU "launched historic negotiations aimed at landing an agreement to increase trade in "green" steel and aluminium – that is, steel and aluminium produced in a way that emits lower greenhouse gas emissions than when steel is produced using conventional manufacturing practices […] that has the potential to reshape global supply chains toward greater sustainability"(Sutton and Williams 2023) back in 2021, known as the Global Arrangement on Sustainable Steel and Aluminium (GASSA), negotiations have stalled which means risking the target conclusion date of October 2024 (Sutton and Williams 2023).

3 Research Approach and Goals

Having provided this non-comprehensive yet extensive overview of the dynamics fundamental to understand both the iron and steel industry and the foundations of industrial and environmental policy making, the following sections will now build upon this groundwork. More precisely, a further much more in-depth review of academic literature, industry reports and publicly available statistical data will be used to investigate why the iron and steel industry reached its current state and use these findings to derive suggestions for future policy advances. Having said that, the research aim of this thesis is not to evaluate different technological advancements with regards to their suitability to minimize emissions but rather to conclude with an evaluation of measures necessary to transform the steel industry towards net-zero targets while regaining international competitiveness that has recently been lost and divide these necessary actions into regional and Austria specific policy measures.

3.1 Research Goals

The primary goal is to comprise a comprehensive yet concise list of policy measures that, after thorough analysis of geopolitical trends, technological advancements, and the political capabilities of Austria as an EU member state as well as considerations regarding country specific location factors, can be found to be a the most suitable to advance the Austrian steel industry and make it fit for a net-zero future. As an additional outcome, this thesis will in effect also highlight areas where compelling actions are needed to transform the industry, but where rather that policy measures available to Austrian authorities, alternative approaches such as engaging in international cooperation and furthering European regulation would be necessary to facilitate desired actions form Austria's steel industry.

Finally, this thesis also tries to propose a structured approach regarding the identification of nationally tailored industrial policy proposals. To this regard the research approach laid out in the preceding section and its application in the succeeding ones, tries to offer a scientific methodology as to how the analysis of macroeconomic market dynamics, technological advancements, country specific production factors and global academic research can be combined to produce tailored policy suggestions suitable to enable the greening potential of any national EITE-industry.

hence implications of these policies on an industry that faces global competition will be at the centre of the analysis and serve as the baseline upon which policy recommendations are complied.

3.2 Research Questions and Outline

The research carried out in the course of this thesis is targeted at compiling answers to the following three very general and broadly formulated questions "How did we get here?", "Why should policy makers care?" and "What needs to be done now?". While these three questions already provide some indication regarding the research aim of this thesis, more concrete questions have been formulated and split up into corresponding sections.

With this objective in view, the first question aims to provide an analytical understanding and a non-denominated analysis of the interplay between both economic as well as market dynamics and distinctive policy measures that have prevailed in different parts of the world in the past. While the preceding literature review already offers some insights regarding this question, Chapter 4 provides an in-depth discernment of the technological and economic foundations that we saw today's European iron and steel industry emerge from. Furthermore, this chapter also provides a first indication of Austria's specific economic factors and their development in comparison to other EU member states. As such the key questions this section tries to answer are:

Q1: Which economic drivers and which policy measures influenced the development of the European steel market and in which way?

Q2: How do the drivers and corresponding developments in Austria compare to the industry's overall evolution within Europe?

In furtherance of these aspects, the second question namely "Why should policy makers care?" subsequently develops this non-denominated analysis into an evaluative assessment of the global status-quo. For this purpose, the later section of Chapter 4 provides insights regarding the implications of certain global trends within the steel industry, on the economy at large, as well as the environmental and multinational implications. To accomplish this, the questions this second section is focused on are:

Q3: What are the direct economic implications of the above-described developments?

Q4: What are incidental implications of the above-described developments with regards to climate change and international relations?

The third topic question relates to the core of what this thesis aims to research. In order to conclude with an assessment on "What needs to be done now?" the known options, both from a technical as well as a policy perspective are first assessed and then evaluated under consideration of EU industrial policy restraints and Austria specific location factors. With respect to the first half of this question, Chapter 5 assess different technical opportunities with regards to their effectiveness and implementability, highlighting different areas along the life cycle of steel. Chapter 6 thereafter provides an assessment of global industrial policy and highlights differences across discrete regions around the world. As the industrial landscape in Austria is deeply interlinked and dependent on European policies, Chapter 7 provides an aggregation of policy measures that have been identified as necessary to be tackled at EU level. The final research Chapter 8 then investigates how the findings from all earlier chapters can be combined in order to derive policy suggestions relevant for the steel industry in Austria. To realise this, the questions this final section tries to answer are:

Q5: Which of the existing technological innovations and advancements could best optimise current impacts of the steel industry, both environmental and economic?

Q6: Which industrial policy measures do already exist around the world and how well do they facilitate greening efforts of the steel industry?

Q7: Which of the identified opportunities to transform the steel industry should be facilitated through industrial policy at EU policy level?

Q8: Which additional national policy measures should be implemented to assist Austria's steel industry to emerge from this global and industry wide transformation victoriously?

Q9: What actions are needed form Austrian policy makers that go beyond legislation?

3.3 Methodology

While the objective of the introductory literature review is to provide an overview of the research topic and introduce key concepts the succeeding sections aim to contextualise and answer the above introduced research questions. The methodology used to derive answers to the research questions is a systematic review of diverse literature sources, completed with a comparative analysis of publicly available economic data sets.

Existing academic research is used to provide the baseline upon which further sources are introduced and evaluated upon. Further sources include economic reports from the OECD, the IEA, the World Economic Forum and alike, industry reports from reputable Associations such as Worldsteel, the European Steel Association (EUROFER), the IETA and alike, as well as policy reports form the AIT, the IMF, UNDIO and alike, policy strategies as well as legal documents and press releases from European institutions. Finally, country level data is drawn from indices such as the Index of Economic Freedom and the Environmental Performance Index (EPI) as well as statistical data bases including Eurostat and Statistic Austria.

4 Regional Peculiarities in the Context of Global Competition

While Chapter 2.1 provides an overview of the genesis of today's steel industry from a global perspective, this chapter focuses on identifying respective causes and underlying market structures. Furthermore, focus is directed towards understanding how global developments comparatively played out within the EEA and especially in Austria. Regional discrepancies can not only be found with regards to the prevailing production methods but are equally present at the macroeconomic level which can be seen in further-reaching economic indicators. Analysing global discrepancies regarding deployment of furnaces as well as innovation spending, tax burden and capital market exposure therefore provides an indication regarding the environmental consciousness as well as the ability to undergo a transformation of certain countries and regions.

In order to provide a regional comparison, five distinct regional groups have been identified, namely the EEA, the Anglo-Transatlantic Allies (ATA) group, India and China as individual countries and finally Rest of the World (ROW) group, whereas a list of all countries and their respective allocation to each group can be found in Annex 2.

4.1 Variation in Prevailing Production Technologies

Environmental friendliness does not only depend on the share of EAF implementation alone, as they may be almost as environmentally detrimental as their BOF counterpart (IEA 2023b). EAF would however be the most environmentally friendly option if operated with renewable energy and feed with steel scrap or H-DRI (Trinca et al. 2023). An analysis of prevailing furnace technologies measured in mmt of available production capacity, therefore can be considered as an indication regarding the transformation readiness of certain regions or countries (Marlene Arens, Åhman, and Vogl 2021).

To this end China is not only home to approximately half of global steel production capacity but also has the highest share of BOF capacity globally, which stands at 85 %. Global capacity meanwhile is split two thirds in BOF and one third in EAF production, which coincides with the distribution in India. Amid mounting global pressure to transition towards environmentally friendlier practices, particularly to increase EAF capacity, China has long declared plans to raise its proportion of EAF-based steelmaking, though as described in Chapter 6.3 only had limited success so far

(Hill 2024). Beyond China it is worth mentioning that the US and thereby the ATA group in total, is the only group with a majority share of EAF plants, which are however primarily using NG-DRI as a feedstock, while the production capacity of the ROW-group is split in half.

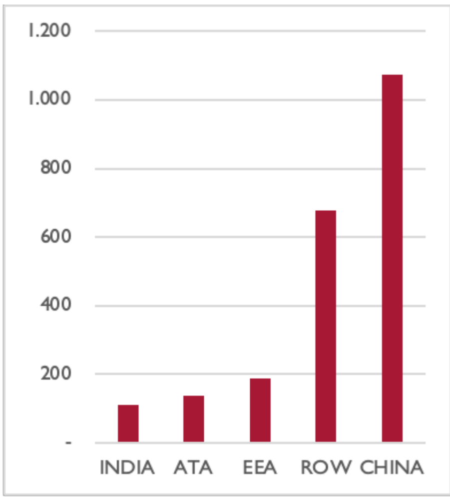


Figure 4.1: Global Steel Production in mmt.

Source: Data from Global Energy Monitor © 2024

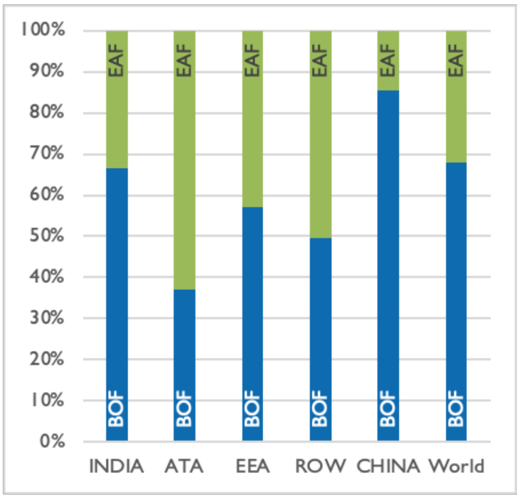


Figure 4.2: Share of BOF vs EAF capacity.

Source: Data from Global Energy Monitor © 2024

While the share of BOF to EAF production capacity sits between the global average and the leading ATA group, there are distinctive differences in the respective share of EEA countries. As before mentioned one country to point out is Luxembourg. This country has an even higher dependence on the steel industry and experienced an even more significant relative loss of jobs than Austria. While the steel industry of Luxembourg has an equally long-standing tradition, the country today, as Figure 16 shows the country now solely operates EAFs. Furthermore, its largest national player ArcelorMittal has announced to invest another € 67 million to further expand EAF production capacity to be sufficient to cover the total demand of the region (Capta 2024). The national government did however not only support this shift towards becoming a pioneer by offering significant state subsidies, but rather by identifying the transition itself as one of its key issues. Ultimately, this shift was led by clear national strategies including the establishment of a *Digital Innovation Hub*, in an attempt "to support companies in this evolution, by providing expertise in the field of digital and innovative technologies and fostering networking at national and European level" (Industry in Luxembourg 2024).

On the contrary Figure 16 equally highlights the inertia prevailing within Austrian steelmakers. While Global Energy Monitor Data claims that Austria solely offers BOF-capacity, EUROFER data does list a capacity of 0.845 mmt of EAF in Austria which would account for less than 10% of national capacity, nevertheless. To counteract this status, Voestalpine has announced a € 1.5 billion investment plan to construct two EAF production facilities in March of last year (Voestalpine 2023). Regardless of the exact data Austria must be regarded as inert, especially when considering that other significant steel producing countries such as Italy and Spain have equally already boosted their EAF share over past decades.

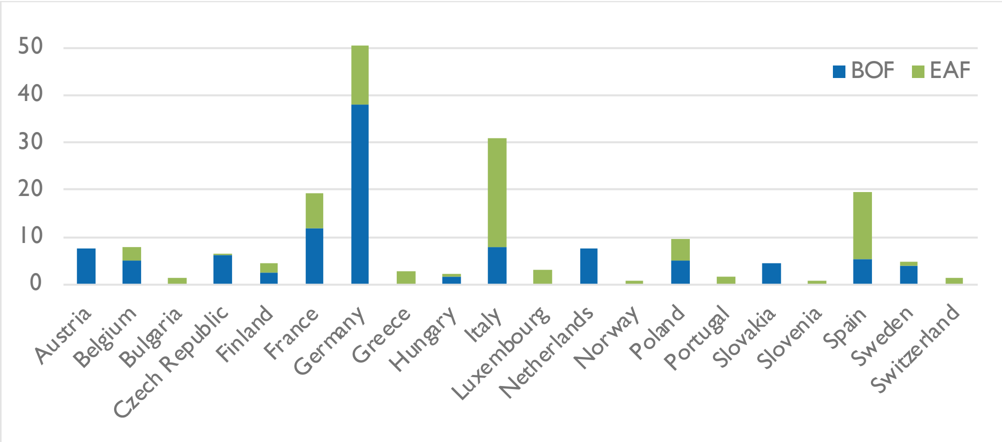


Figure 4.3: BOF vs EAF in mmt for EEA countries.

Source: Data from Global Energy Monitor © 2024

4.2 Implications between Economic Indicators and Policy

One country that stands out in Figure 16 is Italy, which has the highest EAF capacity, both in absolute and in relative terms, among EU countries at 23.136 mmt/y. To provide reasoning regarding the development of EAF capacity in Italy two distinct sector specific indicators have been identified and a designated number of countries have been selected to provide a sound comparison and trend analysis. Having provided this intention Figure 17 shows environmental tax revenue generated by the "manufacture of basic metals" sector while Figure 18 provides the sector-specific carbon intensity per value added over the same time.

Combining the data of these graphs clearly indicates that while the EU-ETS was able to reduce carbon intensity overall, the addition of environmental taxes that was much greater for this sector in Italy did induce a much greater emission reduction. Furthermore, with regards to the change of carbon intensity per value added over the 2012 to 2022 time period Austria can be considered a special case. As the EU-ETS for the steel industry is based on average BAT levels, Austria's industry already served as a baseline in 2012 and correspondingly carbon intensity per value added remained almost constant over the analysed period while all other countries saw a decreas in carbon intensity as they were approaching Austrian values.

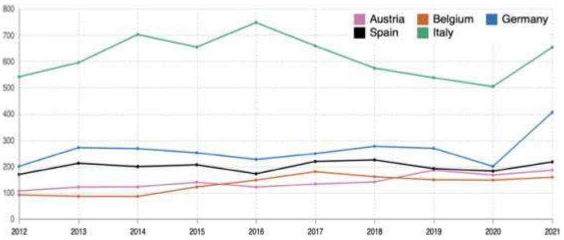


Figure 4.4: Environmental taxes for "Manufacture of basic metals" (NACE Rev. 2) in Million Euro

Source: Eurostat, full graph included in Annex 5

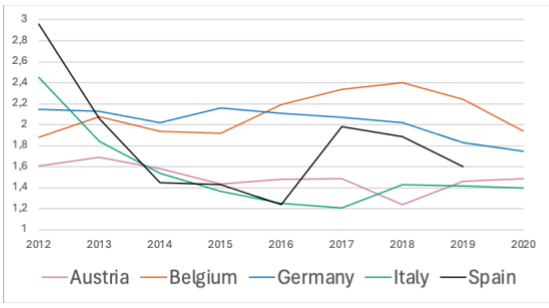


Figure 4.5: Carbon Intensity per value added for "Manufacture of basic metals" (NACE Rev. 2) in kgCO_2/USD at PPP 2015

Source: Data from IEA included in Annex 3

While sector decumulated data regarding innovation spending could not be identified, a comparison of overall R&D expenditure coming from the government vs business enterprise sector does nevertheless provide some insights as well. Firstly, as we have seen that Italy has by far highest environmental tax revenue it is of interest that this did not translate to an increase in government R&D expenditure. Secondly, while the share of government R&D expenditure does show a range of expenditure levels the country difference is much more pronounced for business enterprise expenditure. Thirdly, the designated number of countries splits up into two distinct groups with regards to business enterprise R&D expenditure, one where expenditure is around 2% and one where average expenditure sits bellow 1%. Finally, relating R&D expenditures to domestic tax relief for R&D expenditures does offer further insights as Austria and Belgium are ranked places 3 and 4 regarding their domestic tax relief for R&D and both exhibit high business enterprise R&D expenditure. Italy however ranks third place regarding tax relief but exhibit low business enterprise R&D expenditure (EC 2021b). Combining this data would therefore suggest that comparatively high sector specific emission taxes did provide a greater incentive for the "manufacture of basic metals" to decrease carbon intensity than a comparatively extensive cross-sector tax relief over the 2012 to 2020 period. These findings are further underlined by the fact that innovation expenditure within the heavy industry sector is considered to having been fairly low over the analysed time period (EC: JRC/DG RTD 2019).

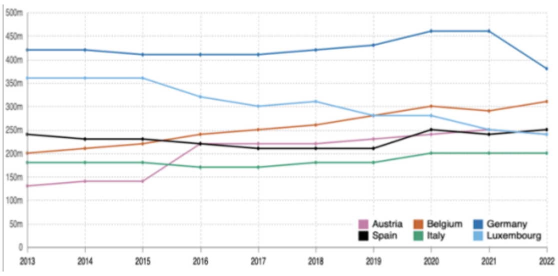


Figure 4.6: Gross Domestic R&D Expenditure of Government Sector in ‰ of GDP.

Source: Eurostat, full graph included in Annex 5

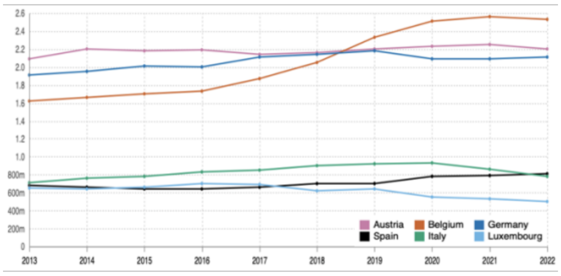
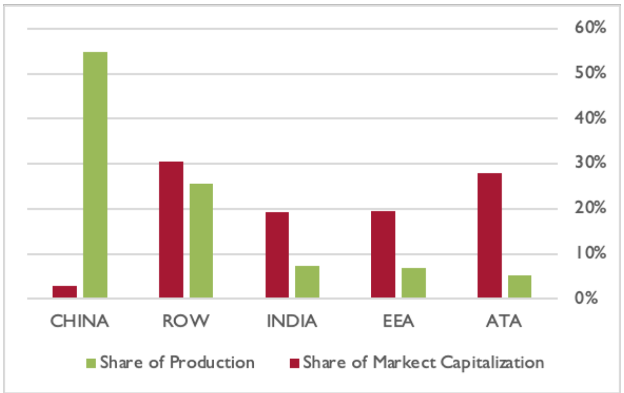


Figure 4.7: Gross Domestic R&D Expenditure of Business enterprise sector in % of GDP.

Source: Eurostat, full graph included in Annex 5

4.3 Exposure to Capital Market Dynamics

As previously stated, the dynamics inherent to capital markets tend to limit large scale industry transformations as they are costly in the short run and potential future profits are valuated at a large risk-discount (Perri et al. 2023; Bellemare et al. 2005). While this is a universal problem the exposure of steel manufacturers around the globe to capital markets varies greatly, as seen in Figures 14 and 15 that compare the share of production with the share of market cap. From these figures we see that while Chinese steel producers can act almost independently of capital markets at a factor of 0.05, the producers among the ATA group are facing highest exposure at a factor of 5.34. Figure 14 furthermore shows that production and market cap in the EEA and India are very similar, however only half as high compared to the ATA-group, standing at 2.86 and 2.58 respectively. While Austria is only responsible for 0.04% of global production hence being excluded form Figure 14, it is worth noting that because Voestalpine is the 24th largest steel producer globally according to its market cap, Austria is faced with an exposure to capital markets that is above the EEA average amounting to 3.18. Finally, the ROW-group appears to be the group with the most balanced exposure rate at a factor of 1.19, which must however most likely be attributed to the aggregation of many different countries around the world that each stand at different levels of economic development and maturity.



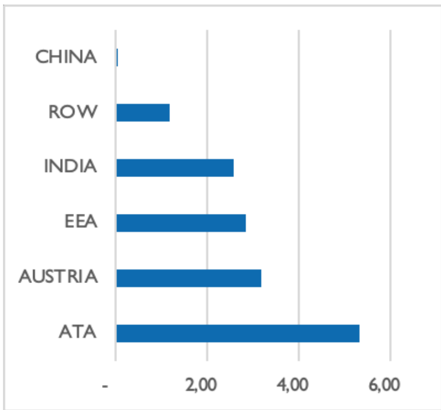


Figure 4.8: Comparison of Production and Market Cap.

Figure 4.9: Exposure to Capital Markets.

Source for both Figures: Data from Worldsteel and CompaniesMarketCap included in Annex 3.

The values shown for "Share of Production" correspond to the respective regional or national steel production as a share of total steel production measured in mmt for the year 2023 according to Worldsteel Data. In comparison the "Share of Market Capitalization" has been computed from stock price and trading value measured in USD that have been derived from CompaniesMarketCap for the 61 largest steel companies around the world as of April 2024. While there may be more than 61 listed steel producing companies, especially considering those that might be traded at smaller stock exchanges, due to the fact that the largest market cap included in the sample is more than 2000 times higher than the smallest one, adding further smaller companies to the sample was disregarded. The factors shown in Figure 15 have been computed by dividing the two respective shares.

As the numbers prove that Chinese companies are least dependent on international capital markets it comes as no surprise that supply-side regulation has been dominating green industrial policies in China (C. Song et al. 2024). From a European viewpoint regulating capital market dynamics and educating the public on the importance of a green industrial transition to ensure public intervention, is of higher relative importance (D. Liu et al. 2024). This is however equally already reflected with consideration of the extensive efforts that went towards the establishment of the EU-Taxonomy Regulation (EC 2021c).

Diverting from the macro- to the microeconomic level, as economic development to some extent depends on steel, affordability is of importance. Having said that, econometric results imply that the steel industry is among those industries was passing through of carbon costs that result from the EU-ETS into final product prices is most significant, which in turn makes their products less affordable and less price competitive (Cludius et al. 2020). While these factors are true for all of EEA countries, the severance of these results is further underlined by Eurostat data showing that "Apparent Labour Productivity" of the steel sector in Austria has just been at EU average, while "Investment per Employee in tangible non-current assets" has in fact even been below the EU average in 2021. These datapoints underline the trend of a declining production cluster in Austria which has been outlined before.

4.4 Effects on Direct Employment

As the above-introduced indicators suggest a decline in economic sentiment, it is of relevance that "worse economic sentiment in an EU member state motivates an MNE in that country to invest abroad" (Cieślik and Ghodsi 2021). From this it follows that without policy intervention and as long as EU-ETS can be circumvented, MNEs emigrate, and a loss of jobs would follow (De Beule et al. 2022). OECD data introduced earlier in fact shows that steel produced in OECD countries, as a share of global production, has been declining for two decades. A differentiated analysis of all EU member states does however provide further insights shown in Figure 23. Combining Worldsteel figures with general Economic data from Eurostat indicates a moderate correlation of 0.57 between the share of steel employment in relation to GDP per capita and a loss of jobs over the four-year-time-period from 2018 to 2022. These results suggest that while employment decreased EU wide those economies that have a relatively high GDP per capital and a relatively high rate of employment within the steel sector have been experiencing most significant losses of jobs. In this ranking Austria holds the second place after Luxembourg, which means that it is the second most affected country from these economic developments. This again points towards the relevance of ensuring a future for the Austrian steel industry. Finally, the importance of recognising these trends also has been pointed out by the European Steel Association in the recent *Clean Transition Dialogue on Steel* as they call for "Urgent Action (…) to Preserve EU Steel Production and Millions of Quality Jobs While Fostering Decarbonisation" (EUROFER 2024b)

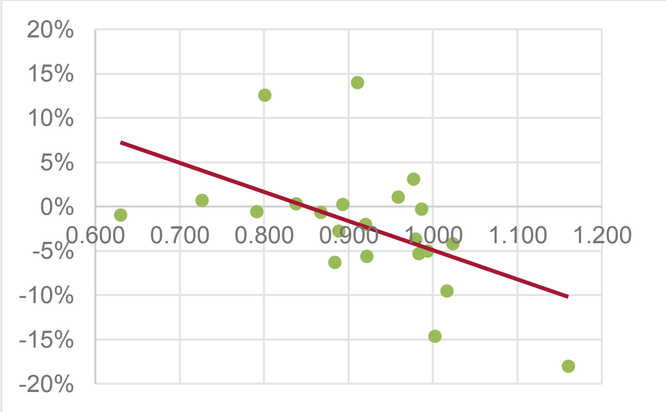


Figure 4.10: Correlation Between Relative Importance of Steel Industry and Change in Direct Employment

Source: Data from Worldsteel and Eurostat, Calculations included in Annex 3

The relative importance of the steel industry has been computed by multiplying direct employment in the steel industry with GDP per capita using 2022 values and correlating it to the relative change in direct employment within the steel industry over the four-year-time-period from 2018 to 2022. To better visualise data on relative importance of the steel industry, data points are displayed with logarithmic application of the x-axis while the change in employment is expressed in percentage.

4.5 Feedback Effects on Connected Industries

Finally, a study carried out by Oxford Economics pointed out that developments in the steel sector are of even higher importance as the industry "has an unusually large global supply chain. This study calculates that, for every $1 of value that is added by work within the steel industry itself, a further $2.50 of value-added activity is supported across other sectors of the global economy" (Godden 2019). EUROFER further reports that for the EU direct GVA € 24 bn that was created by the steel industry in 2023 related to an additional indirect GVA of € 83 bn. This means that value add factor of the EU stands at 3,5. which is almost 40% higher than the global average (EUROFER 2023a).

With regards to job creation, while "there have been substantial cuts to (direct employment) numbers since the 1970s" (Stroud, Antonazzo, and Weinel 2024) the steel industry still employs over 300,000 people and is believed to be responsible for the creation of over 1.5 mio jobs indirectly providing a job multiplier of 5 (Stroud, Antonazzo, and Weinel 2024) compared to the global estimate of 6,5 (EUROFER 2023a). The much higher multiplier for GVA compared to jobs can be explained by the fact that as the EU generally has a further developed economy than the global average apparent labour productivity throughout the economy is greater, though as shown above regional differences within the EU do exist.

5 Transition Potential of Production and Consumption

As described in Chapter 2.2, the emission intensity of steel varies greatly depending on the specific production method used in iron- and steelmaking. Furthermore, the development of DRI and other environmentally preferential methods including readily available yet underutilised energy efficiency and emission reduction technologies dates back decades (Parisi and Laborde 2004; Tien and Turkdogan 1972; Valipour, Motamed Hashemi, and Saboohi 2006; M. Arens and Worrell 2014). The question of how to green the industry, therefore, cannot be answered by comparing production technology and driving for further advancements but is rather found when considering a multitude of aspects in the light of potential barriers to their implementation. Such a macroeconomic evaluation can be divided into a supply side and demand side where steel producers are referred to as suppliers and downstream industries, such as building and construction, compose the demand side. Having said that, the supply side has already been extensively analysed in Chapter 4, hence this chapter will on the one hand look at supply side measures, and on the other hand demand side measures concerned with the consumption and utilisation of consumed steel and steel products.

5.1 Supply Side Measures

The environmental potential of a technological shift highlighted in Chapter 2 and an increasing awareness are both reflected with regards to overall industry trends, measured for the year 2022 as "the new [2023] report from Global Energy Monitor (GEM) shows that 43% of planned steelmaking capacity is now based on electric arc furnace (EAF) technology (…) versus 33% of EAF in planning and 32% of EAF in operation" (Lempriere 2023). This follows estimations from Germany stating that "according to the present scenario analysis, chances are that with rising prices for coal and CO_2 allowances BF-BOF and even BF-CCS become unprofitable by mid-century. With a high share of renewable energy sources and high prices for CO_2 allowances, H-DR and EW become economically attractive in the second half of the current century, when BF-based routes are long unprofitable." (Fischedick et al. 2014).

Nevertheless, it has been extensively argued that the actual emission intensity does not only depend on the type of furnace and feedstock being used but a multitude of factors including fuel mix, electricity grid CO_2 emissions factor and cost of energy and raw materials as well as the age of steel manufacturing facilities, the level of penetration of energy-efficient technologies, and capacity utilisation (Hasanbeigi

2022). An appropriate decarbonisation strategy will therefor need to be country specific and among other things, consider availability of renewable energy sources and water which would favour green steel production against availability of fossil energy and carbon capture techniques creating a more favourable environment for blue steel production. Advancements for both technologies will therefore be needed to facilitate a global transition (Bararzadeh Ledari et al. 2023).

5.1.1 Reduction of Excess Capacity

As explained in Chapter 2.1 the steel industry is characterised by an inherent overcapacity. This overcapacity is most prevailing in China, where CO_2 emission intensity of the steel industry additionally also exceeds the global average standing at 2.33 tonne CO_2 per tonne steel (Song et al. 2023). For this reason, it has been argued that limiting excess capacity, and particularly Chinese, could have two significant effects. One the one hand it could help curbing the high price pressure inherent to the steel industry which in part has been attributed to overcapacity. On the other hand, higher prices would make lower-emitting higher-cost countries more competitive hence steel demanding industries would be incentivised to shift their supply source away from China and in turn decrease overall emissions (OECD 2023). Furthermore, many have argued that a stronger focus on regional procurement would also constitute an important step as this could also present a suitable measure to shift supply to lower-emitting higher-cost countries (Delasalle et al. 2022; Hasanbeigi 2022; Guevara Opinska et al. 2021).

5.1.2 Update Existing BF-BOF

While green steel produced via H-DRI-EFA would be the optimal scenario, commercial spread of GH in the steel industry will most likely only be achieved once GH supply has become more mature (C. Li et al. 2024). Much research has therefore investigated energy-efficiency technologies and emission management through use of CCS units for existing BF-BOF technology which again have been found to be capable of saving up to 66% of emissions and such solutions could be retrofitted to existing BF-BOF facilities (Trinca et al. 2023). Steel produced in such a way is commonly referred to as blue steel (Bararzadeh Ledari et al. 2023). One clear advantage of these technologies is that once the technology becomes more readily available relevant furnace parts could be retrofitted hence infrastructure requirements should not pose a significant barrier towards large scale implementation of such technologies (Marlene Arens, Åhman, and Vogl 2021; Quader et al. 2015). Additionally, it has been argued that implementing CCS/U in combination with using biomass as carbon feedstock could unlock net-negative emission opportunities as carbon steel could effectively act as a storage for carbon from biomass (Andrade, Desport, and Selosse 2024).

Weighing blue steel technology measures against each other according to their environmental potential, economic costs and rate of implementation though presents a problem. For one many cost-efficient energy conservation and emission reduction technologies that would be readily available today remain underutilised (Ma et al. 2016; M. Arens and Worrell 2014; Wu et al. 2016). Furthermore, weighting of more advanced technologies is not yet sensible, because none of these technologies have reached TRL 9. Top gas recycling stands at a TRL of 7 (Guevara Opinska et al. 2021) while pre-combustion configurations (Gazzani, Romano, and Manzolini 2015) as well as carbon capture and sequestration and/or use are estimated to be at a TRL of 5-6 (Guevara Opinska et al. 2021). Moreover, it has been argued that further technology advancements that are either yet unknown or currently at an ever-lower TRL will likely become of high relevance towards reaching decarbonisation even as soon as 2025 (Griffin and Hammond 2019). Concludingly research agrees that a mixture of all technologies to produce blue steel will enable greatest emission savings at lowest economic costs (Luh et al. 2018; Griffin and Hammond 2019).

As briefly introduced carbon-rich blast furnace gas (BFG) and other steel mill off-gases produced at large-scale integrated BF-BOF plants are further sold on to be burned at a power plant "to produce electricity by means of a steam cycle or a gas-steam combined cycle" (Gazzani, Romano, and Manzolini 2015). Such a recovery and utilisation of residual energy and heat system is integrated in 90% of steel plants in advanced countries(Onwuemezie and Darabkhani 2024). Carbon capture therefore becomes "a trade-off between decreased electricity production and decreased emissions" (Tsupari et al. 2015).

Research carried out on the potential of carbon capture initially focused primarily on post-combustion top-gas CO_2 capture methods, looking into absorption capacity of different chemical solvents (Cormos 2016). Furthermore, pre-combustion configurations such as the Sorption Enhanced Water Gas Shift (SEWGS) were also investigated (Gazzani, Romano, and Manzolini 2015). Novel research also focused on synthetisation to produce synthetic natural gas and further methanol. On the one hand this process could close the carbon when natural gas is reintroduced in the process hence reducing coal consumption (Perpiñán et al. 2023), while on the other hand producing both methanol and electricity has been considered also result "in greater economic and environmental gains than solely producing electricity" (Deng and li 2019).

Finally, regarding the status quo, first post-combustion carbon capture and utilisation projects have started to be implemented such as the pilot project by Thyssenkrupp known as Carbon2Chem, where captured carbon is used as feedstock in chemical processes (Held et al. 2020). Nevertheless, large scale implementation of these technologies will highly depend on the carbon intensity of the local electricity grid (Deng and li 2019) as well as CO_2 price and electricity price development (Tsupari et al. 2015). Concludingly, it has been argued that such update-technologies should only be considered as one part of a much more diverse decarbonisation approach (Luh et al. 2018) and "is unlikely to become a long-term mitigation solution in line with the Paris Agreement" (Marlene Arens, Åhman, and Vogl 2021).

5.1.3 Infrastructure to Facilitate Hydrogen Steelmaking

As explained above carbon capture technologies for blue steel production do not yet stand at a TRL level 9 yet, which would correspond to having been system proven in an operational environment, though infrastructure requirements do not pose further limitations. Evaluation on the implementability of green hydrogen steelmaking however tells a different story. At the same time H-DRI technologies currently stand at a similar TRL level of 5-6 (Shahabuddin, Brooks, and Rhamdhani 2023), though infrastructure requirements that ensure continuous sufficient supply of green energy as well as green hydrogen have been identified as one of the key barriers to large scale implementation globally, additionally to technological viability (Marlene Arens, Åhman, and Vogl 2021). What is more, while green hydrogen has been at the core of much decarbonisation research, a study found that when considering the "true cost of hydrogen production routes using life cycle monetisation" (Al-Qahtani et al. 2021) steam methane reforming coupled with carbon capture and storage emerges as the cheapest option at less than 5€ per kg while green hydrogen from wind based electrolysis seems to be the most cost efficient electrolysis-based option (Al-Qahtani et al. 2021). This must be compared with other research that finds that "commercial spread of GH in the steel industry can be achieved after 2035 when the GH production decreases to around 2.5$/kg" (C. Li et al. 2024). Finally, it is unclear if mature electrolysis technology will in fact become cost-competitive though "a potentially more efficient solid oxide electrolysis (SOEL) […] offers lower production cost when technological maturity is reached"(Jacobasch et al. 2021).

As shown in Figure 15 the share of BOF to EAF capacity varies greatly between countries. To this extent, it has been argued that this discrepancy will lead to trickle-down effects with regards to the transition capability of domestic steel industries. High-EAF-countries, albeit they have so far primarily focused on gas-based and secondary steel production, have been able to acquire an expertise with regards to the operation of direct reduction shaft furnaces as well as EAFs. It can hence be expected that while infrastructure limitations will indifferently have to be overcome, High-EAF-countries should have an easier time transitioning their steel industry as they should be able to profit from continued use of existing iron- and steelmaking equipment as well as from their existing expertise (Marlene Arens, Åhman, and Vogl 2021).

5.1.4 Improvements Regarding Recycling Opportunities

EFA with scrap steel as a feedstock is by far the most environmental steel production method and increasing the share of scrap steel has also been identified as one of the key solutions towards decarbonisation. While the technology is readily available and promises an abatement potential of up to 58% (Guevara Opinska et al. 2021) the prospect of using scrap steel at large scale is currently still limited by the availability of scrap both in terms of quantity as well as quality.

With regards to the quantity of available steel, one needs to consider available steel-in-use stocks around the world. As previously described developed countries, such as EU member states have not seen steel demand or steel-in-use stocks rise over the past decades. Research has therefore focused on estimating the levels of steel-in-use stocks for developing countries to estimate when and at what level steel-in-use stocks will peak globally (Igarashi et al. 2008; Yue et al. 2016). These values are both relevant as it would indicate when we would, theoretically not need any more iron ore and how large recycling capacity would need to be capable of managing all steel scrap flows.

As introduced in Chapter 2.2.3 the potential of steel scrap does however not only depend on the mere existence of steel-in-use stocks but rather on the potential to recycle scrap. One of the areas which has been identified by many is an improvement regarding the system for collecting and separating end-of-life steel as "current post-consumer scrap classes in particular cannot fulfil the required quality criteria with regard to their composition" (Dworak et al. 2023). The improvements identified on the one hand involve logistics in the form of improved pre-sorting by differentiating scrap streams according to their composition (Delasalle et al. 2022). This could for example include establishing steel certification of supply chain members on the demand side such as demolition contractors (Taghipour et al. 2022).

On the other hand, attention has been drawn to the recycling processes itself, referred to as secondary metallurgical processes, which could be used for the removal of undesirable accompanying elements (Delasalle et al. 2022). To this end research does however point out that the “understanding of the interaction of different accompanying elements” (Dworak et al. 2023) still needs to be improved (Dworak et al. 2023).

Beyond the outstanding research on metallurgical processes, research also points out that especially for developing countries, the improvements regarding steel scrap recycling infrastructure will heavily rely on “government policies and the implementation of these policies by recycling companies” (Taghipour et al. 2022). This is further underlined by findings from China where various policies have been adopted including “tax incentives, import facilitation, support for supply, industry reorganisation, and recycling parks” (Wübbeke and Heroth 2014) though “limited availability of scrap, high scrap prices, inadequate steelmaking capacities, industry fragmentation and unclear responsibilities for manufacturers […] (prove to remain) the main obstacles for steel recycling” (Wübbeke and Heroth 2014).

5.2 Demand Side Measures

While much of resource research has focussed on optimising steel supply, almost all reports include demand side improvements as equally important with regards to enabling decarbonisation. While these measures do not affect the CO_2 emission per t crude steel, they do affect overall emissions attributable to the industry as such measures are aimed at reducing demand, either through optimised production, optimised use or (partial) substitution (Held et al. 2020; Delasalle et al. 2022; Hasanbeigi 2022; Guevara Opinska et al. 2021; IEA 2023a; Gangotra et al. 2023b; Somers 2022; World Economic Forum 2023). While some of these strategies are applicable regardless of the downstream sector, targeted measures have been for the two of the largest industry sectors namely building and infrastructure as well as automotive, which are responsible for 52% and 12% respectively of global demand (worldsteel Association 2024).

5.2.1 Material Efficiency Strategies

Beyond limiting capacity, improving production, and traditional recycling optimisation, a significant number of reports suggest that implementing material efficiency strategies would be able to achieve an overall reduction of 41% of today's global steel demand (Delasalle et al. 2022) or 30% of UK's domestic demand (Allwood 2013) even while accounting for a continuous expansion of the global economy. While the specific terminology varies among reports in principle all research identifies three distinct areas for improvements namely material recirculation, utilisation productivity and manufacturing efficiency, which will each require corresponding and to that extent appropriate policy measures (Delasalle et al. 2022; Held et al. 2020).

While the outstanding obstacles for recycling from a supply side perspective have already been discussed, material recirculation also includes policy on product design that allows for end-of-life use, reuse and facilitates recycling. The EU's Ecodesign Regulation will be an important milestone towards facilitating this aim as it requires products to be designed to be "more durable, reliable, reusable, upgradable, reparable, recyclable and easier to maintain" (Council of the European Union 2023) if and once it will come into effect.

In contrast to recycling which is clearly within the boundary definition of the steel industry, increases in utilisation productivity refer to a demand reduction that for the most part will require wider-reaching policy measures. Such demand reduction would come from improvements regarding the overall mobility system and buildings sector, which could be optimised to require less steel overall, and will initially most likely be able to be covered by procurement policies, which have been called for by many (Held et al. 2020; Delasalle et al. 2022; Hasanbeigi 2022; Guevara Opinska et al. 2021; IEA 2023a; Gangotra et al. 2023b; Somers 2022; World Economic Forum 2023). Furthermore, a more durable product design to extend product lifetimes may also be attributed to this group, though this would already be covered by the abovementioned Ecodesign Regulation (Council of the European Union 2023).

Finally, manufacturing efficiency refers to the optimisation potential located at the steel end-usage sector. While optimisation for the two largest consumer sectors, namely construction and automotive industry, are covered in the succeeding individual chapters, demand reduction within this area could also come from minimising fabrication scrap through product design and processes improvements as well as using 3D printing and powder metallurgy to minimise crude steel demand (Delasalle et al. 2022).

The share of demand reduction each of these areas could have, as estimated by the Mission Possible Partnership (MMP) is shown in Figure 24, though other estimates exist that offer similar results (International Energy Agency 2020; Somers 2022; Koolen and Vidovic 2022).

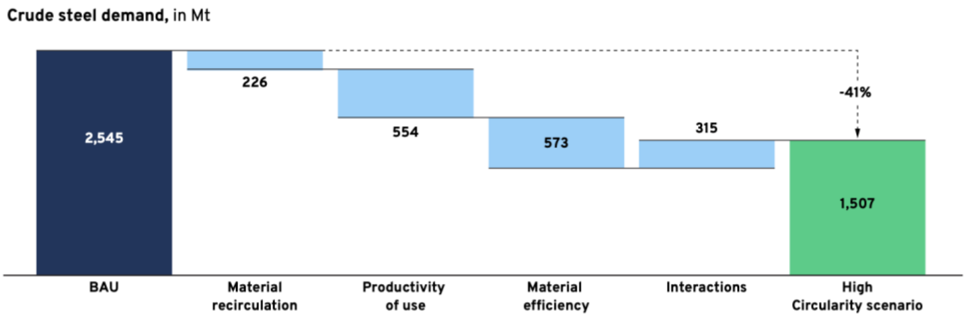


Figure 5.1: Circular economy impacts on global crude steel demand in 2050 in the High Circularity scenario.

Source: MPP analysis (Delasalle et al. 2022)

5.2.2 Construction

As previously discussed, usability of steel made from scrap does heavily depend on the quality of recycling. This has been further underlined by a study investigating collapsed building sites in Nigeria, which highlighting the danger of using low quality secondary scrap (Adeleke et al. 2018). On the flipside, urban mining, which refers to resource recovery from demolition sights "has been projected as a crucial measure for improving resource efficiency (though) its adoption as a practice in the construction industry remains at a very symbolic stage" (Arora et al. 2021). Nevertheless, researchers do attribute great potential to this measure especially as "demolition waste generation figures solely based on statistical data probably underestimate the total waste generation" (Kleemann et al. 2017) of the construction industry. This is especially relevant as analysis of the non-residential building sector in the Rhine-Main area found that steel is available in large quantities, being the third largest stock after concrete and masonry, brick & tiles (Schebek et al. 2017). New methodological approaches that better quantify building material and component stock and hence increase awareness of the potential of urban mining could unlock this opportunity (Kleemann et al. 2017; Arora et al. 2021). Though it has been pointed out that appropriate training and economic incentives will also be needed to increase urban mining (Arora et al. 2019).

Another approach towards demand optimisation in the construction industry is presented through emergy accounting, which presents itself as an alternative to a life cycle assessment by expanding system boundaries of the assessment and thereby offering a more meaningful evaluation approach (Santagata et al. 2020). According to emergy accounting steel has by far the highest emergy value of all building materials, which is twice as high as both brick and cement and almost three times higher than wood (Thomas and Praveen 2020). While these findings do not allow to derive immediate demand side actions, it has been suggested that this approach should be given more consideration with regards to policy making (Y. Liu et al. 2021; Thomas and Praveen 2020).

Finally, as the construction industry does not only include buildings but equally the construction of infrastructure such as electricity grids, the energy transition is believed to push steel demand in developed countries such as the EU where demand had been stagnating up once again. Researchers have therefore called for "a metal-efficient and green supply chain for upstream suppliers as well as downstream renewable power installers for just transition in the power sector across the globe" (Fu et al. 2023).

5.2.3 Automotive

While much attention has been directed to the switch from combustion engine to eclectic vehicles, a factor equally important towards sustainable automotive manufacturing is the vehicle weight. Strategies to reduce this weight to lower energy demand during the use are referred to as vehicle lightweighting (Lewis, Kelly, and Keoleian 2014). While this approach has seen wide adoption for certain automobile parts that are already being produced by advanced/high strength steel (A/HSS), further R&D efforts are still needed to produce all standard vehicle parts with lightweight materials. Nevertheless, an even farther-reaching obstacle towards limiting the emission intensity of both the automotive as well as the steel industry is the fact that "lightweight materials used in automotive manufacturing generates significant amount of GHG emissions […] from the production and end-of-life disposal of these materials (which) could offset the environmental benefits of their use" (Yao et al. 2024) hence further research will most likely be needed until we will see large scale policy measures.

While limitations of scrap usability as well as lightweight have already been described, where applicable it has nevertheless been found that promoting the demand for remanufacturing as well as remanufactured components through regulation optimisation in the sense of incentive alignment can be achieved as "American, Chinese, Canadian, and German governments' tax incentive programs applied to items produced from recyclables are a sound strategy in the way of spurring their circular economies, improving environmental sustainability, and reducing economic loss" (Genc 2024). What is more other research also suggest that an "OEM prefers to purchase remanufactured components when (1) its brand image advantage is significant; or (2) its brand image advantage is limited but the environment tax rate is high; or (3) its brand image advantage is limited, the environment tax rate is low, but the subsidy to supplier is high, even if Supplier R has self-brand and competes with the OEM"(Niu, Ruan, and Zeng 2022). From these findings one can deduct that while the automotive industry will not be excluded from EU's Ecodesign Regulation (Council of the European Union 2023), it will be critical to incentivise OEMs towards product optimisation as well as moving towards green and remanufactured steel.

6 Country Level Analysis on Potential of Transition Policies

The preceding chapters have primarily focused on the status quo, transition trends as well as the prevailing opportunities to transform the steel industry that have been identified up to the present day. The emission intensity of the steel industry has however already been a topic of discussion for at least a decade, or more specifically since the enforcement of the EU-ETS whose effects have equally already been covered (Rossetto 2023a) or at least since the conclusion of the Paris Agreement in 2015 (Marlene Arens, Åhman, and Vogl 2021). For this reason, the past 10 to 15 years already offer a valid time frame upon which researchers have already evaluated policy and corresponding industry developments. Having provided this context it has been argued that "overall, the global steel industry seems not be on track yet, though differences between steel producing countries are large. Common shortcomings across countries are a lack of access to renewable electricity and a lack of demanding medium-term CO_2 reduction targets" (Marlene Arens, Åhman, and Vogl 2021). This chapter will therefore provide a brief overview of research that has investigated sector specific policy approaches, split up according to the five global groups that have been afore identified.

Before focusing on regional polices it is worth highlighting prior research on the transition potential of countries with regards to the steel industry, that has suggested distinct indicators to evaluate county specific transition potentials. Firstly, the relevance of the steel industry with regards to overall CO_2 emissions and secondly the growth pattern of the industry have been identified as relevant indicators. A high contribution and an expanding industry are considered accelerators of transition efforts as these two factors are assumed to indicate the likelihood and ability that for one a government will develop effective plans to support its decarbonisation and secondly that a steel sector will change its production processes. Figure 25 clearly depicts the stark differences for these indicators across the globe, as they are mapped against each other (Marlene Arens, Åhman, and Vogl 2021).

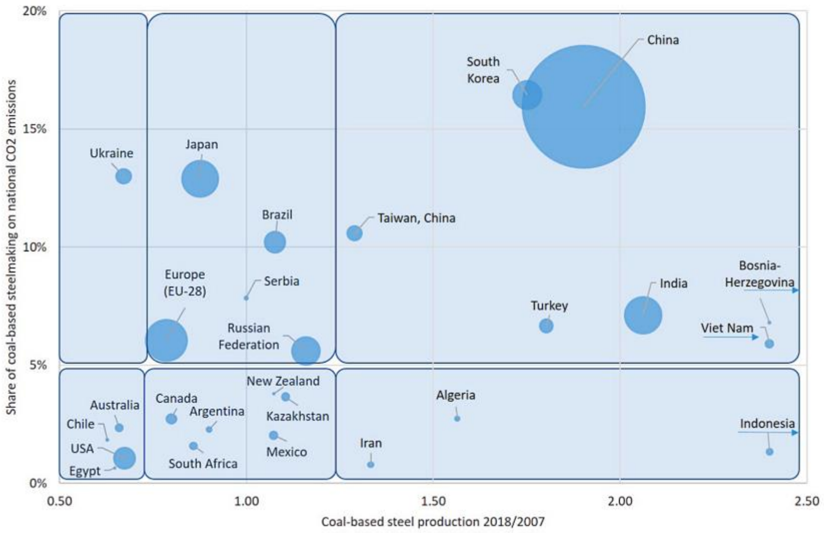


Figure 6.1: Change in production of coal-based steel by country from 2007 to 2018 against share of steel industry's total national CO_2 emissions, note: size of bubbles reflects total amount of CO_2

Source: (Marlene Arens, Åhman, and Vogl 2021) *with data from IEA*

As a third indicator, the stage of decarbonisation of the national electricity generation has been identified, where the ability to meet additional electricity demand from low-carbon sources is considered to indicate the ability to facilitate transition efforts as decarbonised steel will require high levels of renewable energy. While the national energy production mix for the year can be seen in Figure 26, it is worth mentioning that the two single largest and comparatively emission-intensive steel producing countries, namely China and India, which currently both heavily depend on fossil energy, have both announced 2030 renewable energy targets of 35% and 40% respectively. (Marlene Arens, Åhman, and Vogl 2021)

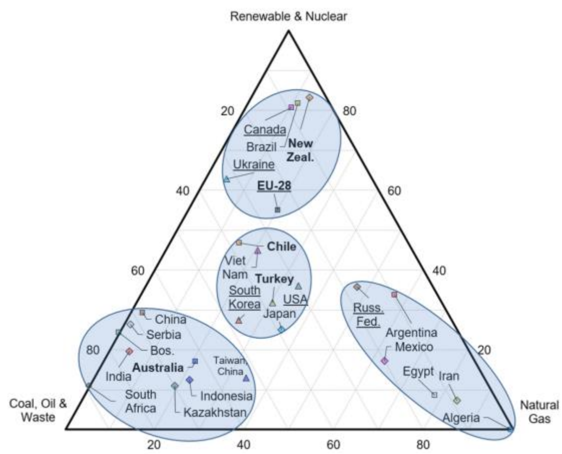


Figure 6.2: Electricity production from coal, oil & waste, from natural gas and from renewables & nuclear by 2018.

Note: Countries in bold: electricity production from non-hydro, non-biofuels renewable (NHB-RES) sources (mainly wind and solar PV) contributes more than 10% to the total electricity production; countries underlined: electricity production from nuclear of more than 15%

Source: (Marlene Arens, Åhman, and Vogl 2021) *with data from IEA*

6.1 European Economic Area

As argued before, it has been said that the steel industry has been a notoriously slow innovator over the past decades. Research that investigated the diffusion of energy efficient technologies in the German steel industry over a 30-year period, as well as research focused on the energy efficiency of the Swiss metals sector each offer support for this argument (Bhadbhade, Zuberi, and Patel 2019; M. Arens and Worrell 2014). On the on hand the Germany focused research found that while steel production technologies which provide essential productivity benefits next to energy savings were adopted relatively rapidly, diffusion of solely energy efficient technologies was minor and for the most part levelled off in the 1990s (M. Arens and Worrell 2014). On the other hand, research from Switzerland finds that even while the national metals sector does not include any primary steel production and its secondary steel industry is considered to be ahead of the European-wide developments, there still seems to be an energy efficiency potential of up to 19%. What is more sensitivity testing further suggests that sector-wide economic potentials "are relatively insensitive to exogenous variables such as energy prices, discount rate and CO_2 levy" (Bhadbhade, Zuberi, and Patel 2019).

While these findings must be considered in their pre-Covid setting, more recent research highlights one significant barrier towards the transition of the European steel industry, which is its energy infrastructure. On the one hand it has been found that for North-European countries, which offer unique renewable energy resources and already have a high-renewable energy mix "the additional electricity demand from an electrified steel industry is met mainly by increased investments in wind and solar power […] while it is found to be cost-efficient to invest in overcapacity for steel production units (electrolyzers, DR shaft furnaces and electric arc furnaces) and to invest in storage systems for hydrogen and hot briquetted iron, so that steel production can follow the variations inherent to wind and solar power"(Toktarova et al. 2022). On the other hand, it has been found that in order for technology transfer from the most advanced steel production facilities in Sweden, where "nearly zero carbon electricity generation and low-cost electricity prices" (Ohman, Karakaya, and Urban 2022) are already a reality, to happen "it is key that energy and industry transitions are aligned, that a policy framework that supports these transitions is in place, and that key actors representing all aspects of these transitions cooperate, from industry and research, to academia, policymakers, and civil society"(Ohman, Karakaya, and Urban 2022).

6.2 Anglo Transatlantic Allies

With regards to the UK a comparative analysis that tried to explain the varying decarbonisation reorientation speeds of domestic steelmaking, oil refining and petrochemical industries identified specific factors as pertinent to explain why UK oil refineries had seen the fasts and steelmakers the slowest transition. The steel industry's slow transition was firstly attributed to policy support being least beneficial for steel, and the prevailing corporate strategy remaining resistant to change. Secondly, high international competition and low financial performance, have once again been identified as explanations, as they once again have been linked to international competitiveness and economic feasibility of decarbonisation endeavours. Finally, the study highlighted that while "hydrogen and carbon-capture-and-storage are technically feasible […] (they) face wider feasibility problems (with scrap steel supply, electricity grids, and electricity prices)" (Geels and Gregory 2024) which ultimately also limited their implementation (Geels and Gregory 2024). Finally, as downstream industries, including construction, that are demanding steel are of high importance in the UK, the importance of demand side policies has been highlighted as it had been estimated that steel demand would need to be "reduced to 30 per cent of present levels by 2050" (Allwood 2013) to reach decarbonisation goals (Allwood 2013).

6.3 China

China is the biggest steel producer globally and, measured in CO_2 emission per tonne steel, also one of the most emission intensive. Furthermore, it lags behind in both, the uptake of abatement technologies as well as recycling opportunities while corresponding end of life steel stocks remain only limited, especially compared to the EEA (International Energy Agency 2020). Analysing energy efficiency and emission reduction potentials of the Chinese Industry moreover underline the inertia that shaped the industry to this date.

Multiple studies suggest that half of abatement technologies readily available to Chinese steel makers in 2016 remained unutilised though they were found to be cost-efficient (Wu et al. 2016; Ma et al. 2016). Furthermore, as described in Chapter 5.1.2 the steel industry in advanced economies profits significantly from selling off-products, in particular from financial gains created from the recovery and utilisation of residual energy and heat systems. While such systems have an implementation rate of 90% in advanced economies, this rate stood at only 30% - 50% for Chinese production plants in 2015 (Chen et al. 2015). Research from the same period hence suggested that in the short-run policy focus will be directed on energy efficiency updates of BF-BOF facility (Wenying, Xiang, and Ding 2014). While this aligns with actual policy and industry developments over the past decade (C. Song et al. 2024) more recent research still finds significant greening potential though the uptake of proper optimisation strategies that would be able to cost-efficiently increase energy efficiency while simultaneously decreasing both input resource and total energy demand hence in turn also decreasing CO_2 emissions (Na et al. 2022). Finally, China has seen the most rapid expansion of its steel production capacity especially between 2005 and 2010 when almost exclusively BF-BOF capacity was built at comparatively low environmental standards. This corresponds to the average age of a Chinese facility to be 13 years old, hence environmental improvements on these existing facilities remains of essence (International Energy Agency 2020).

The inertia of the Chinese steel industry is further underlined as other green transition targets have been almost entirely neglected. This is exemplified by a 2013 study that suggested that EAF capacity in China could be close to 50% by 2025 (Wenying, Xiang, and Ding 2014). A decade later we see that this target will not only not be reached by 2025, but that policy targets are still far from enabling such transitions. This stands as Chinese policy targets for 2025 have been downgraded from 20% to aim for 15% of domestic steel production to come from EAF capacity, a goal that has been considered unambitious as it can be achieved with the capacity that is currently already available (Swalec, Zhi, and Zhang 2024).

As highlighted in Chapter 4.3, China has the lowest exposure to capital markets by far, which is a staggering 57 times lower than the EEA average and even 64 times lower than the respective value for Austria. What is more, research based on a "comprehensive panel dataset comprising 11,136 iron and steel firms in China from 1998 to 2009" (Sheng, Xu, and Rozelle 2024) found that market reforms to enhance competition and enable resource reallocation where only effective at the national level. On a provinces level, significant regional monopoly power seems to significantly limit the "effects of resource reallocation within provinces […], suggesting that market fragmentation or frictions hinder the expansion of more productive firms within the same province" (Sheng, Xu, and Rozelle 2024). What is more with regards to large scale Chinese subsidies schemes, it has been found that "officials seek rents and other reasons, so that government subsidies may appear to go against the laws of the market, pursue short-term interests and interfere directly with enterprises" (Qi, Yang, and Deng 2023). In effect this does not only further hinder efficient resource allocation within China but also further distorts global competition (Qi, Yang, and Deng 2023).

Nevertheless, over the recent years, there seems to be a green shift in China which could affect the speed of progress in the Chinese steel industry and will most likely have implications on the global steel industry, as well as for the competitiveness of Chinese production both domestically and beyond (Nechifor et al. 2019). One example for this shift is a new focus on secondary steel, for which it has been estimated that it could be able to take up almost 60% of the projected demand of Chinees construction in 2030, though effects on output for downstream industries of Western European economies would be negative (Nechifor et al. 2019). On the other hand, it has been estimated under policy incentives BF-BOF capacity could be reduced to 25% and "CO_2 emissions per unit of crude steel to 0.88t CO_2/t steel" by 2060 (Y. Li et al. 2024).

To conclude, while there does seem to be a shift towards environmental awareness, the findings on capital market exposure further highlight that the Chinese steel industry, traditionally was much less concerned about and to some extend even seems to have been unaffected by typical capital market drivers such as resource allocation efficiency, which makes its transition less predictable and hence poses further pressure on the European steelmaking industry (Nechifor et al. 2019).

6.4 Rest of the World

Turkiye is not part of the EEA though 43,5% of its steel exports go towards the EEA. Towards reaching net-zero Turkiye is on the one hand currently in the process of aligning its ETS system to the EU-ETS in coordination with the EC. This will ensure that relevant exports that would be covered by the CBAM will already align with relevant carbon regulation hence no import fees on the exported goods would arise. On the other hand, studies evaluated Turkiye's potential regarding green steel production and found that "the northern part of the Aegean Sea in Turkiye is the most suitable alternative for green steel production, with offshore wind energy being used for hydrogen production" (Canat and Özkan 2024)

With consideration to global trends one firstly needs to note that most countries are projecting their domestic steel production to increase and hence some developing countries, such as Thailand that to this day primarily relies on EAF where considering BF-BOF implementation as recently as 2016 (Juntueng, Towprayoon, and Chiarakorn 2014) though a decade long decrease in steel output and an uptake in steel scrap imports have prevented such developments (Iron and Steel Institute of Thailand 2024). Other countries such as Pakistan face similar barriers as China regarding the implementation of energy efficiency initiatives due to "limited awareness and inadequate managerial commitment […] (while) ineffective policies and a lack of government implementation plans contribute to diminishing demand for energy-efficient technologies" (Yousuf, Irshad, and Umair 2024) Though we do see technological catch-up happening in some developing countries such as Iran (Soltanzadeh, Rahmani, and Majidpour 2023). Finally, for more developed economies such as Japan, it was found that increasing the share of obsolete scrap in the BF-BOF process would become increasingly important to both ensure global competitiveness as well as reduce emissions (Kuramochi 2016).

Australia has a unique position within the steel supply chain as it is the world's largest iron ore exporter. It is therefore estimated that an uptake of secondary steel production would highly negatively impact Australia's iron mining industry, while similar effects have also been suggested for other major mining countries (IETA 2024). It has been suggested that Australian iron ores could nevertheless greatly benefit from a green transition as availability of local renewable energy is ample. The success of shifting towards green mining will however most likely depend on "R&D funding, project financing and (low-)emissions certification" (Venkataraman et al. 2022). To this end, recent academic research investigated the potential of novel "low-emission hydrogen production via the thermo-catalytic decomposition of methane" (Lumbers, Barley, and Platte 2022). Finally, as Europe currently massively imports iron ore from Australia, considering Austria's import dependency of 86 per cent (BMK 2020), it has been suggested that for countries where hydrogen and renewable energy are not readily available, such as Austria, a switch towards importing DRI as in intermediate product would have economic benefits for both parties and be much less costly than importing both hydrogen and iron ore (Verpoort et al. 2024).

7 Policies for a Green Steel Industry in Europe

When the EU-ETS was introduced and started to effectively regulate CO_2 emissions of the EU's steel industry in 2006, these policies were leading the way towards climate neutrality and resulted in emissions going down domestically and sustainability trends notably started to emerge (Enrique Villalva 2023). Nevertheless, on a global scale CO_2 emissions are still rising and will most likely continue to do so due to an ongoing rise in steel demand especially in developing economies (Enrique Villalva 2023). More specifically "CO_2 emission associated with global steel production has increased by 2.5-fold from 2000 to 2015, and the global steel production has only increased by 1.9-fold, indicating a worsening environmental performance with emission intensity increasing from 2.1 t CO_2 /t in 2000 to 2.8 t CO_2 /t in 2015" (P. Wang et al. 2022). These trends therefore serve as a justification for the EU to continue and adjust its regulation of both steel supply as well as demand.

What is more "improving technologies, strengthening material recycling, and promoting (a) circular economy" (Tiejun 2015) are all suggestions that have been made for a decade while many of the technologies that could enable a decarbonisation of the steel industry remain at TRLs that do not allow for a meaningful comparison of their large-scale suitability. Finally, most research now suggest that a combination of all available measures will be needed at different time horizons (Luh et al. 2018). While we have seen a shift in sentiment within the steel industry willing to take up a key role towards enabling a larger decarbonisation transition, it remains unclear who should pay the price as the "costs of industry transition are moderate, but still ones that may represent a barrier for implementation because the generation deciding on low-carbon technologies and bearing (macro)economic costs might not be the generation benefitting from it" (Mayer, Bachner, and Steininger 2019)

The following section touches upon EU Policy considerations found to be appropriate to promote an EU wide industry transition. Because industrial policy is generally governed by EU Law and as Austria's steel industry is an important part of its total economy, it can be deduced that Austria's political decision makers should actively promote all following actions.

7.1 Summary of EU's Economic and Political Circumstances

As a summary and while there are significant differences among EU member states, the EU as a whole and in comparative terms has little experience with EFA technologies, a high exposure to capital markets, and is a shrinking industry while world demand continues to increase. What is more, EU member states have inhomogeneous existing energy infrastructures as well as a heterogeneous potential with regards to using renewables to decarbonise their respective energy mix. Moreover, it has been suggested that meeting emission targets could require anywhere from 12 TWh up to 274 TWh of additional renewable electrical power, depending on the technology being used ranging from reduced conventional blast furnace production in combination with an increase of EAF steel production as the least energy intensive option whereas H-DRI produced by steam reforming requires most energy (Otto et al. 2017). From this is follows that a one-size-fits-all-approach cannot exist. Nevertheless, as industrial policy is an EU matter the following section describes policy measures in response to global trends that are suitable to promote a transition irrespective of certain domestic idiosyncrasies.

7.2 Policy on Technology and Infrastructure

Having provided this concise overview, the following section focuses on supply side measures that are addressing the steel sector directly. These can be summarised in technology open R&D&I support as well as infrastructure investments for both energy and hydrogen grids as well as recycling capacities.

7.2.1 Promote R&D&I of Both CCS/U and CDA as well as Knowledge Sharing

Firstly, one needs to note that the EU has been a major diver of the development of green steel R&D in the past (Somers 2022). What is more, research investigating different location factors recognised that the uptake of H-DRI technologies will vary across EU countries though they highlight that knowledge sharing and cooperation across the EU would be greatly beneficial where cumulative emissions up until 2050 have been estimated to be "13% higher than if spillovers are assumed and approximately 15% and 20% higher in China and India respectively" (Pye et al. 2022). As the EU is deeply invested in generating spillovers especially from climate-related knowledge, best practices should be used to further promote knowledge sharing (Hewitt et al. 2021). Furthermore, it has been argued for some time that "the core policy to promote these (energy-efficiency and emission reduction) technologies is to fund the research institutions which study and improve them, which enhances their performance and competitiveness" (Ma et al. 2016). As consensus on which technologies will win has yet to form (Gerres et al. 2018) it can be suggested that for now policy measures should endorse a combination of all possible technologies (Luh et al. 2018). With regards to knowledge transfers it has also been highlighted that cooperation between "key actors representing all aspects of these transitions (…), from industry and research, to academia, policymakers, and civil society" (Ohman, Karakaya, and Urban 2022) will be of essence and further that cooperation within the so called knowledge triangle between business, higher education and research will play an especially important role in the transition to a circular economy of the raw material sector (Smol and Kulczycka 2019).

The EU has already introduced a multitude of European wide funding projects that could be used by the steel industry including *Horizon Europe* as well as the *European Innovation Fund.* These instruments have however been criticised of being technologically biased and more easily attainable for larger corporations from larger EU member states. One other particularly promising measure that focusses on facilitating the industrialisation part of R&D&I are carbon contracts for difference. To this end research found that to induce large scale implementation of technologies *Carbon Contracts for Difference* seem to be a suitable policy tool with regards to de-risk innovative investments of the steel industry (Richstein and Neuhoff 2022). While we have already seen such policies being implemented at the member state level such subsidies schemes could also find implementation in an EU-wide scheme. Nevertheless, providing a comprehensive list of all policy instruments that have already been established to promote R&D&I by the EU and an evaluation thereof would be outside the scope of this thesis, hence further evaluation of other R&D&I measures is suggested.

7.2.2 Construct and Couple Hydrogen and Renewable Energy Infrastructure

As the H-DRI-EFA process uses electricity in all steps of its production, namely hydrogen production, ironmaking, and steelmaking, research conclusively points towards the importance and premises of decarbonising the electricity sector in orden to enable a meaningful decarbonisation of the steelmaking sector (Sasiain et al. 2020; Boretti 2021). Furthermore, as iron and steel production has such a high energy demand, many have also pointed out the potential for sector coupling of the steel and energy industry (Vogl, Åhman, and Nilsson 2018; Elsheikh and Eveloy 2022; Trinca et al. 2023). This would mean that power and heat needed for iron- and steelmaking would be provided by coupling their plants to renewable power generation and using respective excess energy. To this end estimations from Germany have found that while H-DRI would enable reductions of 95% of both CO_2 emissions against 1990 levels and primary energy demand against 2008 can be achieved, an 237 to 274 TWh of renewable electrical power would be required (Otto et al. 2017). Research additionally found that an overcapacity in direct reducing furnaces could become a useful vector to deal with inherent renewable energy fluctuations (Toktarova et al. 2022) while iron could also serve as a carrier of renewable energy (Debiagi et al. 2022).

While it has been argued that aligning energy and industry transitions will be one significant key to success (Ohman, Karakaya, and Urban 2022) the EU has solely put great emphasis on the expansion of renewable energy generation up until now. Meaningful sector coupling can however equally only be done at a European level especially due to the alternating nature of renewable sources and the great discrepancies in national availability. While both the EC and the EP had requested an evaluation on sector coupling focusing on how to enhance foster grid stability as well as decarbonisation potential only limited policy action has followed to date. For this reason, the EU would be well advised to implement the still outstanding policy suggestions and focus on facilitating EU-wide sector coupling (Van Nuffel et al. 2018; Riechmann et al. 2019).

With regards to hydrogen, the new delegated act *Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin* supplementing *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652*, in short the revised Renewable Energy Directive, for the first time offers policy certainty regarding the definition of green hydrogen with regards to its production which is believed to incentivise a ramp up of necessary infrastructure (Brandt et al. 2024).

7.2.3 Build Recycling Markets for Steel Scarp

Derived from case study on Thailand interdependencies between government policies and the steel recycling manufacturers' behaviour towards sustainable management can be identified. What is more this study is also highlighting the importance of "broad enablers such as financial assistance, logistics, and fundraising guidance" (Taghipour et al. 2022) towards achieving a circular steel economy (Taghipour et al. 2022). Furthermore, many researchers have highlighted the continuously increasing obsolete steel scrap stocks as well as increasing iron in-use stocks (Igarashi et al. 2008; Yue et al. 2016) though a lack of infrastructure and market maturity are considered to limit steel recycling (Wübbeke and Heroth 2014).

From a technical perspective the eminent need to implement better recycling in order to increase quality of secondary steel (Panasiuk et al. 2022) has equally been pointed out before while it is simultaneously being argued that improvements in steel scrap collection may leverage one of the most significant environmental benefits (Dworak et al. 2023). Finally, subsidies and environment tax both seem to be efficient in promoting remanufacturing (Niu, Ruan, and Zeng 2022), though optimum collection channels and appropriate consumer behaviour could further improve circularity and mitigate distortions (Genc 2024). While EU's recent Ecodesign directive did already promote a move towards this direction, further focus should be directed to unifying collection channels across Europe with consideration to the requirements of downstream industries (Dworak et al. 2023). For this reason, policy should not only focus on recyclability of products but equally on improving user-friendliness of the existing steel scrap recycling market from a steel produced perspective so that steel scrap use becomes more attainable and scrap exports are thereby reduced. Additionally, the EU could also directly legislate the construction of recycling infrastructure such as scrap yards and logistics, similar to the efforts we have seen for green hydrogen and carbon evasion, using auctioning tools, or follow a similar approach to the one chosen for plastic recycling were industries that sell goods in plastic bottles are equally obliged to make financial contributions towards building a recycling infrastructure, in order to speed up the establishment of a steel scrap market that offers reliable prices and ensures continuous availability (EC 2024b).

Finally, to tackle the issue of steel recycling the EC should also pay attention to the concept of Extended Producer Responsibility, short ERP, which has proven to be a suitable measure to increase recycling feasibility and thereby also recycling rates within the EU. At the moment "more than 80% of the EU countries utilize an EPR system for packaging waste" though these systems do not yet include steel and are rather inhomogeneous.

7.3 Policy on Market Requirements

While the three afore mentioned policy areas cover issues directly linked to the steel industry, it has been suggested before that these actions alone would not be sufficient to decarbonise the industry as a whole. For this reason, five further policy areas have been identified for which EU policy action would be desired.

7.3.1 Encourage Green Public Procurement

As shown in all above chapters, green primary steel cannot yet compete with conventional steel from a cost perspective, as production methods are still being evaluated and green hydrogen production only just commenced. Furthermore, driving early demand for low-emission cement, concrete and steel has been found to be an important factor in order to boost transition efforts, and green purchasing, or procurement, has been found to be one of the most effective policy measures (Gangotra et al. 2023a). “Within the public sector, this means prioritising the purchase of low-carbon products in government-funded construction projects” (UNIDO 2023). Nevertheless, the most recent analysis from 2017 that investigated public procurement across the EU single market found that 55% of procurement decisions still use lowest price as the only award criterion hence not sufficiently making use of strategic procurement possibilities (EC 2017).

In this decade we have already seen international initiatives and agreements on green procurements being concluded among them UNIDO's Industrial Deep Decarbonization Initiative (IDDI), World Economic Forum's First Movers' Coalition (FMC) and the Climate Group's SteelZero and ConcreteZero Initiatives with some EU member states joining. Nevertheless, we have yet to see European regulation on green procurement or the EU as a solid entity joining one of these initiatives. For this reason it needs to be suggested that the EU should take more affirmative actions on green procurement than it has taken so far, especially with consideration to the numerous large scale infrastructure projects currently underway (Gangotra et al. 2023a). In doing so the EC could closely follow existing elaborate suggestions provided by UNIDO's Clean Energy Ministerial in their 2021 report on “Fostering industry transition through green public procurement: A “How to” guide for the cement & steel sectors” (Hasanbeigi et al. 2021).

7.3.2 Advance Financial Incentive Setting

Similarly to the EU-ETS the EU-Taxonomy regulation is considered a global landmark ruling with regards to linking financial incentive setting and environmental concerns. Additionally, the private sector has been identified as an important part of procurement efforts, because large corporations could leverage their purchasing power to decarbonise their supply chains (UNIDO 2023).

Nevertheless, incumbent technologies will for some time still have to compete against much more favourable credit risk ratings for BF-BOF facilities, as these facilities have a track record of running at near optimal efficiency for decades which is decreasing their respective credit risk rating when considering further expansionary projects (Medarac, Moya, and Somers 2020). From this it follows that a funding gap between expected financial payoffs of investing in state-of-the-art conventional technologies compared to incumbent decarbonised technologies will continue to exist for some time, as the costly regulation hypothesis holds to for expectation which often hinders policy makers to take more affirmative actions. Empirical evidence however shows that those assumptions based on financial payoffs estimated at the time of an investment do not hold true in practice. In fact, empirical evidence found that actual profitability is consistent with the Porter hypothesis, which "asserts that properly designed environmental regulation motivates firms to innovate, which ultimately improves profitability" (Rassier and Earnhart 2015).

To counteract this imbalance the EU has already introduced a multitude of European wide funding schemes that are considered suitable to de-risk such investment decisions. Nevertheless, true financial market actions such as the *Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting*, known as the CSRD, and the *Proposal (EU) 2022/71 for a Directive of the European Parliament and of the Council on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937*, short CRDDD, are fairly new policy approaches, and so far, have not yet been able to truly shift financial incentive setting. For this reason, it can be suggested that the EU should further focus on aligning policy with financial objectives.

As we have seen that the EEA has an above average exposure to capital markets, in addition to publishing regulation on financial investing the EU could also use its reach to actively encourage investors to accustom themselves with the long-term financial payoff of R&D expenditure. For one it has been found that company visits and private meetings between executives and investors can curb myopic R&D behaviour (Ge, Cahan, and Chen 2024). Secondly, country level environmentally sustainable practices positively influence R&D intensity, especially in countries with high institutional quality (Banerjee and Gupta 2019), while corporate social responsibility equally effects innovative capacity. As ESG policy has already been identified as a significant pillar of European economic development strategies, EU member states would not only profit above average from a stronger linkage of ESG implementation and industrial development, but research suggests that the industry itself would also profit. For this reason, extending the EU-Taxonomy to include mandatory R&D spending rates, would be one policy suggestion. As conventional steelmaking may become unprofitable soon (Fischedick et al. 2014) which would then affect the majority of European steel plants, pricing in decarbonisation as soon as possible and thereby increasing transformation efforts should therefore be of interest for the financial industry as well as investors and industry alike.

7.3.3 Align Global Approximations and Improve Projections

As pointed out before, per capita steel stock in developed countries can vary between 8 and 16 tonnes. These estimations do however not yet fully account for recycling potential as well as material efficiency gains. These discrepancies in steady state steel demand are further highlighted by estimations stating that "With the stock-based approach, global steel demand decreases by 0.8%/a to reach 1600 Mt/yr, while with the flow-based approach it increases by 0.3%/a to reach 2600 Mt/yr in 2100"(Kermeli et al. 2021). What is more, researchers equally criticised that it is not only the steel demand itself but also the projected electricity demand in absolute terms of the steel sector, that is typically overstated (Mayer, Bachner, and Steininger 2019). It has also been argued that this should also include a uniform boundary definition for the steel industry (Hasanbeigi 2022). These discrepancies do not only hinder ongoing decarbonisation ambitions they also help to discredit the feasibility of an industry wide green transformation. For this reason, newer models that account for time-varying losses have been established (Gauffin et al. 2017). With consideration to all these factors it has therefore logically follows that improved projections in combination with unified emission measurements and data collection could promote the feasibility and ease planning for a Net Zero Steel Industry (IEA 2023b)

7.3.4 Increase Public Awareness

As mentioned before, it has been found that public participation is of utmost importance to hold both policy makers as well as industry executives accountable and in turn push them towards implementing strong environmental regulation (D. Liu et al. 2024). This once again has been shown to effectively have a greater overall outcome for businesses and the general public alike as they respectively garner higher profits and stronger regulation (Rassier and Earnhart 2015). Moreover, the analysis of the automotive industry has shown that an OEMs choice to purchase remanufactured components can depend on the effect this choice would have on its brand image (Niu, Ruan, and Zeng 2022). Similar results towards to importance of public awareness can be found in comparative industry analyses on barriers to decarbonisation that however also show that public awareness regarding the environmental burden of the steel industry is low (Yousuf, Irshad, and Umair 2024; Geels and Gregory 2024).

For this reason, increasing public awareness regarding the environmental burden of the steel industry itself as well as the importance of moving towards a circular economy will be crucial. Furthermore, especially with regards to the use of secondary steel in critical applications such as buildings and vehicles, it has been found that ensuring customers of equal if not better quality is crucial in order to achieve acceptance. While nudging has been found to be a useful as well as cost-effective tactic to promote safety behaviour amongst workers in the steel industry (Costa et al. 2024), such strategies may also serve useful tools to promote general awareness. Finally, as diverse stakeholders have different opinions towards green hydrogen (Ohlendorf, Löhr, and Markard 2023), their awareness of the topic will be of utmost importance in order to even be able to consider their positions. For all these reasons, starting an awareness campaign focusing on both the importance of the steel industry itself as well as the importance of its transition seems to be a sound policy suggestion.

7.3.5 Create a Global Level Playing Field through International Agreements

While both the importance of the CBAM to boost European competitiveness as well as its controversial nature within the WTO framework have already been highlighted, it can be said that the EU to some extent has already achieved its political goal to induce emission regulation outside its realm of regulatory influence. As a consequence of these policies many countries, most notably China, have started to analyse, evaluate and to some extent even implement domestic carbon regulation (W. Li, Liu, and Lu 2023). Nevertheless, as retaliatory actions are yet to take place the EU would most likely be well advised to further focus on concluding international agreements to boost industrial decarbonisation efforts.

Mining has generally been excluded from this analysis as the EEA as well as most of the rest of the world currently heavily rely on iron ore imports for its national iron and steel industry form a selected number of countries. As pointed out in the country level analysis the highest iron ore exporter is Australia a country with whom the EU has close economic ties. Some of the countries that follow thereafter are part of the BRICS group, most notably Brazil as the second largest iron ore exporter, with whom economic cooperation has been more complex. As the EU has a high incentive to on the one hand promote ESG-policies abroad and on the other improve economic ties with important iron ore exporters, focusing on this relationship should be of high importance. With regards to the effect of domestic ESG-policies on FDI, research finds that a strong focus on domestic ESG-policies within a host country can reduce economic policy uncertainty apparent in the home and in turn boost corporate FDI from EU MNEs (Zhang et al. 2024).

As Brazil has already announced retaliation to the CBAM (IETA 2024), these policy findings should be of particular interest to EU policy makers. From this we can derive the suggestion that the EU would be well advised to focus on encouraging Brazil to promote ESG-policies and promise an increase in FDI activities in. Furthermore, as European steel companies would be incentivised to invest in Brazil, this could also lead to more environmentally friendly iron ore processing facilities being implemented abroad, which again would also promote international knowledge sharing as well as international cooperation (Zhang et al. 2024). The effect of such cooperative manufacturing approaches as already been tested through a Japan-Australia case study which found that "co-locating manufacturing processes with renewable energy resources would offer highest energy efficiency and cost reduction" (Devlin and Yang 2022) while similar results have already been presented for EU-Australia co-location steel manufacturing (Verpoort et al. 2024).

Another important step and significant priority towards global cooperation on industrial decarbonisation would be to focus on concluding the still outstanding *Global Arrangement on Sustainable Steel and Aluminium* which had initially been announced in 2021 (Marcu et al. 2023). Amid strong industry critique talks have stopped at the end of 2023, when negotiators reportedly were far away from reaching an agreement (EUROFER 2023b). Finally, research also points out that a "global partnership to coordinate investment in steel capacity, implement circular economy principles in steel making and reduce CO_2 emissions across the supply chain could be critical in avoiding rebound effects and the creation of new pollution hotspots" (Nechifor et al. 2019) From all these findings it follows that in order to enable global decarbonisation, the EU should not only implement punitive action but rather shift its focus towards international cooperation.

8 Tailored Policy Measures for Austria

Having provided these eight policy actions, that can generally be considered suitable to facilitate the decarbonisation of the steel industry, this final research chapter recalls some of the most important findings and combines it with distinctive national factors to derive policy suggestions for Austria.

8.1 Austria's Steel Industry

Austria has one of the highest shares of direct employment and one of the most substantially shrinking steel sector across the EU (EUROFER 2023a). What is more a simple analysis of the *Resource Use in Austria 2020* report shows that Austria has an above average demand for iron (BMK 2020). Nevertheless, it has been found that "macroeconomic costs of the transition (in Austria) are only moderate and that stakeholders might overestimate risks, when neglecting economy-wide feedbacks" (Bachner et al. 2020). The domestic importance of the steel sector is further highlighted by the fact that both OEMs as well as the building and construction sector, the two most important steel consuming sectors in Europe, each have a long history and are equally of economic importance. For this reason several transformation paths have already been developed, though their successful implementation will depend on an appropriate policy framework (Schützenhofer et al. 2023)

8.2 Distinctive National Characteristics and Location Factors in Austria

On a macroeconomic level Austria's household saving rate does not only exceeded the EU average in 2022 but has traditionally been high (Eurostat 2023). What is more while Austria ranks closely above the EU average on the Economic Freedom index, its score has been decreasing for three executive years, losing in comparative advantage. This turn can largely be attributed to scores consolidated as government size where Austria only scores 8.6 out of 100 for government spending while its scores on tax burden and fiscal health equally point towards being repressed (Kim and Roberts 2024). While these numbers have a multitude of contexts along which one should consider them, and policy intervention should not be ruled out simply because of high existing government spending these basic rankings should still find consideration when examining new policy measures.

With regards to its energy grid Austria has a comparatively well-developed waste to electricity as well as hydro power network, and an above average share of renewable energy in its electricity mix of 36.4% for the year 2021 when the EU27 average stood at 21.8%. The potential to further exploit natural phenomena to generate energy in Austria, however, is comparatively limited as biogenic sources and hydro power are close to being fully exhausted while remaining wind and solar power options are not expected to facilitate additional energy generation comparable to other EU member states (BMK 2022; BMNT 2019).

With regards to innovation readiness there are several factors that should be considered. For one while eight EU countries, including Austria, are listed among the top 20 with regards to the number of research studies in the field of industrial energy management, Austria shows the lowest score of all included EEA countries being overtaken by Switzerland, Sweden, Spain, France, Italy, and Germany as well as the United Kingdom (Golmohamadi 2022). What is more, as shown in Chapter 4 while Austria used to have one of the most advanced steel industries in terms of CO_2 abatement as seen in Figure 18 other EU countries have caught up. Furthermore, as seen in Figure 19, though governmental research expenditure has increased over the past 10 years, it is still only around average in comparison to other advanced European economies.

Finally, as research suggest that countries are prepared to green their coal-based steel industry with electricity if the general public is aware of the CO_2 burden inherent to an industry (Marlene Arens, Åhman, and Vogl 2021) a non-representative survey with 78% of participants having an academic degree has been carried out to estimate awareness across Austrian citizens, which is included in Annex 4.

For one this study shows that 47% of participants state that they do not think about the environment often while only 36% of participants state that they not often think about the Austrian economy. One of the most significant findings that follows is that participants rank the importance of the steel sector for the Austrian economy higher than the harmfulness of steel production, with 70% of participants attributing a more than moderate importance to the steel industry. With respect to the harmfulness of steel production, 48% of participants stated that they either have not yet considered the topic or rank steel production as only moderately harmful. This percentage however decreases to 35% if we only consider those participants with an academic degree. Furthermore, while the oldest age group from 55 and beyond considers steel the most important and the least harmful, it is the middle age group that considers steel least important and most harmful while the youngest age group lies somewhere in the middle.

To conclude, from these findings we can for one say that even among an academic group awareness of the issue is not yet universal, while it can be assumed that the majority of less educated people even seems to be unaware. This Secondly, there does not seem to be a trend that younger people are more aware of environmental issues with regards to the steel industry than their predecessors. Thirdly, the results also do not suggest that there is a strong correlation between people that state that they are thinking about the environment and their estimation of how harmful the steel production is. All these factors will therefore make it increasingly difficult to explain and justify policy intervention to the public without first creating an understanding for the topic and issues at hand.

8.3 Suggestions for Austria

Following up on the conducted survey one of the most important factors towards realising a transition will be to raise the awareness of the public and shift the imbalance between assumed importance and harmfulness of the steel industry. As it has been shown that Austria is already being criticised for its government size to repress economic freedom any further actions should be supported by strong public support and to ensure support creating awareness first will be imperative. Once public awareness and support is ensured additive policies to the ones highlighted for Europe should include CO_2 taxes that should then be used to increase government R&D expenditure as well es fund national recycling infrastructure.

With regards to taxes, as seen in Figures 17 and 18, Italy's CO_2 taxes in combination with an increasing pressure from BAT-requirements through the EU-ETS enabled a clear reduction of carbon intensity per value added, while Austria's carbon intensity per value added meanwhile stagnated. For this reason, CO_2 taxes may be able to set of a similar shift in Austria, but only if the preliminary CO_2 taxes that have been introduced in Austria 2 years ago increase to a level that effectively changes business decisions. Having provided that, Austria's saving rate has consistently been 2-3% higher than Italy's, hence it is not surprising that Italy was first to introduce meaningful CO_2 taxes, as "in a high-saving country, the lengthening of the government's effective horizon can incentivise it to tax less" (Acharya, Rajan, and Shim 2024). Policy makers should be made aware of these biases in their decisions and as a result therefore start to effectively tax CO_2 emissions and thereby act on the general academic consensus (Pang 2019; Z. Li et al. 2022; Siddiqui 2015).

As domestic location factors will indefinitely disadvantage green steel production in Austria (Bararzadeh Ledari et al. 2023), policy makers would most likely be well advised to support a continues update of BF-BOF plants as they are highly efficient and can produce at near zero emissions though use of CCU/S, scrap and biomass (Andrade, Desport, and Selosse 2024), while simultaneously promoting the uptake of secondary steelmaking once existing furnaces reach their end-of-life. Furthermore, all findings suggest that instead of funding unfeasible hydrogen projects policy should rather focus on supporting the development of CCS/U technologies and metallurgical processes for steel recycling, as they will most likely become much more important for Austria than elsewhere. To this end the K1-MET centre must be pointed out as an outstanding RTO focusing on metallurgy in Austria though efforts could still be improved. Furthermore, as Austria has neither natural gas or hydrogen needed for DR, research efforts should particularly focus on advancing metallurgical processes with regards to scrap and alloy treatment and consider design options with regards to different steel grades. Finally, as importing DRI will most likely be more profitable for Austria in the long run, an efficient recycling infrastructure will not only be of importance as a comparative advantage but equally promote resilience. Additionally, to suggesting that Austria should focus on advancing investments in recycling infrastructure and corresponding logistics, the aim should rather be to once again be at the European forefront of steelmaking, though now through the domiciliation of most novel metallurgical recycling processes and of corresponding recycling equipment manufacturers.

Finally, all these suggestions will admittedly increase prices and in turn limit the competitiveness of the Austrian steel sector, at least in the short run. For this reason and especially until public procurement is not dealt with at EU level, Austria would be well advised to join existing multilateral agreements that cover green procurements. This would come at a time when "governments of Canada, Germany, the United Kingdom and the United States, member countries of the Industrial Deep Decarbonization Initiative (IDDI), (on December 5th 2023 have) pledged to adopt timebound commitments to procure low-emission steel, cement and concrete, and/or to set emissions reduction thresholds for whole project life cycle assessments to achieve net zero emissions in public buildings and/or built infrastructure" (Gangotra et al. 2023a). Following suit by mandating public procurement of green steel for public buildings and/or built infrastructure will most likely be utterly beneficial as these sectors account for 50% of all steel demand. In turn procuring green Austrian steel would not only help the domestic steel sector to finance its transition but would most likely also find much more acceptance from the public that once again is fairly unaware of the topic at hand, than straight up subsidising transitionary efforts.

9 Summary, Conclusion, Limitations and Outlook

This thesis set out to conduct a holistic, historical, and inter-disciplinary analysis of the global steel industry, with a focus on finding dependencies and explanations for the developments we have seen across the EU and particularly in Austria, with an emphasis on this millennium. Furthermore, the research was conducted considering the overall aim to find scientific evidence that once combined would allow to derive policy recommendations to future-proof and decarbonise the steel sector.

Having provided this background, ample research has been found that both explains historic developments of the steel industry and allows to derive policy recommendations. More specifically it has been suggested that EU-policy should focus on (1) promoting R&D&I of both CCS/U and CDA technologies as well as knowledge sharing, (2) constructing and coupling hydrogen and renewable energy infrastructure, (3) building recycling markets, (4) ensuring green public procurement, (5) advancing financial incentive setting, (6) aligning global approximations and improving projections, (7) increasing public awareness and finally (8) creating a global level playing field through international agreements. What is more, additional policy recommendations for Austria include (A) an even stronger focus on public awareness as well as (B) the introduction of earmarked CO_2 taxes to finance (C) an increase in government R&D expenditure focused on advancing CCS/U technologies and recycling metallurgy as well as (D) national recycling infrastructure.

The above stated recommendations are derived from disaggregated academic research, according to which they each are cost-effective measures on an individual basis. One limitation of this work therefore is a lack of a holistic cost-benefit analysis. Further research should therefore consider cost-benefit structures of the proposed policy measures as a totality and should therefore also account for synergies as well as further geopolitical tension capable of effecting policy decisions, which have equally been excluded from this analysis.

What is more, as we have only very recently seen a clear shift from industry towards committing to decarbonisation strategies, an ex-post evaluation of promised industry efforts as well as a re-evaluation of the potential of technologies currently under industrialised development will mostly likely be necessary on an annual basis.

To conclude this research provides evidence that an inter-disciplinary academic approach can be a useful tool to analyse industries in transition and disaggregate global, regional, and domestic phenomena and their interdependent effects on each other. This research could therefore be seen as a starting point towards encouraging proactive rather than ex-post regulating policy measures. Finally, the steel industry as well as, more broadly, our globalised world order more broadly is currently undergoing massive turmoil hence meaningful projections on how the industry should or will develop cannot be made at this point in time but should be subject of to further research based on the findings as set out here.

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List of figures

Annexes

Annex 1: EU-Taxonomy for Steel Manufacturing

"The activity manufactures one of the following:

(a) iron and steel where GHG emissions(115), reduced by the amount of emissions assigned to the production of waste gases in accordance with point 10.1.5(a) of Annex VII to Regulation (EU) 2019/331 do not exceed the following values applied to the different manufacturing process steps:
   (i) hot metal = 1,331(116) tCO_2e/t product;
   (ii) sintered ore = 0,163(117) tCO_2e/t product;
   (iii) coke (excluding lignite coke) = 0,144(118) tCO_2e/t product;
   (iv) iron casting = 0,299(119) tCO_2e/t product;
   (v) electric Arc Furnace (EAF) high alloy steel = 0,266(120) tCO_2e/t product;
   (vi) electric Arc Furnace (EAF) carbon steel = 0,209(121) tCO_2e/t product.

(b) steel in electric arc furnaces (EAFs) producing EAF carbon steel or EAF high alloy steel, as defined in Commission Delegated Regulation (EU) 2019/331 and where the steel scrap input relative to product output is not lower than:
   (i) 70 % for the production of high alloy steel;
   (ii) 90 % for the production of carbon steel.

Where the CO_2 that would otherwise be emitted from the manufacturing process is captured for the purpose of underground storage, the CO_2 is transported and stored underground, in accordance with the technical screening criteria set out in Sections 5.11 and 5.12 of this Annex."

(EC 2021c)

Annex 2: Country Groups

Anglo-Transatlantic Allies (ATA)

Canada, United Kingdom, United States.

European Economic Area (EEA)

Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland.

Individual Countries

China including Taiwan, India.

Rest of the World (ROW)

Albania, Algeria, Angola, Argentina, Armenia, Australia, Azerbaijan, Bahrain, Bangladesh, Belarus, Bolivia, Brazil, Cameroon, Chile, Colombia, Costa Rica, Cuba, D.P.R. Korea, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Georgia, Ghana, Guatemala, Honduras, Indonesia, Iran, Iraq, Israel, Ivory Coast, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyzstan, Lebanon, Libya, Macedonia, Malaysia, Mexico, Moldova, Montenegro, Morocco, Myanmar, New Zealand, Nicaragua, Nigeria, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Qatar, Russia, Saudi Arabia, Senegal, Serbia, Singapore, South Africa, South Korea, Sri Lanka, Sudan, Syria, Tajikistan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkmenistan, Türkiye, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Venezuela, Viet Nam, Yemen and all other countries.

Annex 3: Data for Graphs

IEA Data on Carbon Intensity per value added for "Manufacture of basic metals"

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020
Austria	1.61	1.69	1.58	1.44	1.48	1.49	1.24	1.46	1.49
Belgium	1.88	2.08	1.94	1.92	2.19	2.34	2.4	2.24	1.94
Germany	2.15	2.13	2.02	2.16	2.11	2.07	2.02	1.83	1.75
Italy	2.45	1.84	1.54	1.37	1.25	1.21	1.43	1.42	1.4
Spain	2.96	2.06	1.45	1.43	1.24	1.98	1.89	1.6	n/a

Unit	kgCO2/USD PPP 2015
ISIC division description	Manufacture of basic metals (NACE Rev. 2)
Indicator	Per value added carbon intensity

Data on Exposure to Capital Markets

	Production in '000 t	Share of Production	Market Capitalisation in B$	Share of Market Capitalisation	Exposure to Capital Markets
ATA	128,826	5%	112.36	28%	5.34
Austria	7,133	0.4%	4.82	1.2%	3.18
China	1,038,229	55%	11.65	3%	0.05
EEA	99,120	7%	78.29	19%	2.86
India	485,155	7%	77.06	19%	2.58
ROW	140,706	26%	122.42	30%	1.19

Eurostat and EUROFER Data

Country	Capita	GDP	GDP/Capita	Employment	Employment /'000 Capita
			2022		
Austria	8,978,929	447,218	49,807	15,300	170
Belgium	11,617,623	554,214	47,705	11,477	99
Bulgaria	6,838,937	85,801	12,546	4,000	58
Croatia	3,862,305	67,990	17,603	180	5
Czechia	10,516,707	276,266	26,269	17,000	162
Denmark	5,873,420	380,618	64,803	426	7
Estonia	1,331,796	36,011	27,040	9	1
Finland	5,548,241	267,687	48,247	6,976	126
France	67,957,053	2,639,092	38,835	25,317	37
Germany	83,237,124	3,876,810	46,575	80,200	96
Greece	10,459,782	179,558	17,166	1,595	15
Hungary	9,689,010	168,550	17,396	5,300	55
Italy	59,030,133	1,962,846	33,252	30,714	52
Luxembourg	645,397	77,529	120,126	3,830	593
Netherlands	17,590,672	958,549	54,492	9,883	56
Poland	37,654,247	654,594	17,384	23,950	64
Portugal	10,352,042	242,341	23,410	1,000	10
Romania	19,042,455	284,174	14,923	21,474	113
Slovakia	5,434,712	109,645	20,175	11,045	203
Slovenia	2,107,180	57,038	27,068	4,100	195
Spain	47,432,893	1,346,377	28,385	17,150	36
Sweden	10,452,326	561,785	53,747	14,673	140
			2018		
Austria	8,822,267	385,274	43,671	15,688	178
Belgium	11,398,589	460,051	40,360	11,290	99
Bulgaria	7,050,034	56,200	7,972	4,150	59
Croatia	4,105,493	52,877	12,880	190	5
Czechia	10,610,055	210,971	19,884	17,800	168
Denmark	5,781,190	302,329	52,295	418	7
Estonia	1,319,133	25,932	19,659	9	1
Finland	5,513,130	233,462	42,347	8,124	147
France	67,026,224	2,363,306	35,259	21,900	33
Germany	82,792,351	3,365,450	40,649	84,230	102
Greece	10,741,165	179,558	16,717	1,455	14
Hungary	9,778,371	136,055	13,914	5,707	58
Italy	60,483,973	1,771,391	29,287	33,356	55
Luxembourg	602,005	60,121	99,868	4,360	724
Netherlands	17,181,084	773,987	45,049	9,552	56
Poland	37,976,687	499,004	13,140	24,100	63
Portugal	10,291,027	205,184	19,938	1,000	10
Romania	19,533,481	206,072	10,550	22,490	115
Slovakia	5,443,120	89,875	16,512	10,730	197
Slovenia	2,066,880	45,876	22,196	4,236	205
Spain	46,658,447	1,203,859	25,802	17,352	37
Sweden	10,120,242	470,673	46,508	15,700	155

Calculations including Correlation Between Relative Importance of Steel Industy and Change in Direct Employment

Country	Relative Change in Employment	Relative Change in GDP/Capita	Employment per '000 capita * GDP/capita for 2022 values	Log on average value
Austria	-4%	14%	8,487,138	1.024
Belgium	0%	18%	4,712,714	0.986
Bulgaria	-1%	57%	733,793	0.867
Croatia	1%	37%	82,039	0.726
Czechia	-4%	32%	4,246,355	0.979
Denmark	0%	24%	470,020	0.838
Estonia	-1%	38%	18,273	0.630
Finland	-15%	14%	6,066,289	1.002
France	14%	10%	1,446,764	0.910
Germany	-5%	15%	4,487,606	0.983
Greece	13%	3%	261,770	0.801
Hungary	-6%	25%	951,578	0.883
Italy	-6%	14%	1,730,115	0.922
Luxembourg	-18%	20%	3,061,528	0.958
Netherlands	1%	21%	1,105,732	0.893
Poland	0%	32%	226,138	0.791
Portugal	-1%	17%	1,682,871	0.920
Romania	-2%	41%	4,100,174	0.977
Slovakia	3%	22%	5,266,749	0.993
Slovenia	-5%	22%	1,026,294	0.888
Spain	-3%	10%	7,545,069	1.016
Sweden	-10%	16%	71,286,792	1.160
Average			5,863,446	
Correlation			-0.566	

Annex 4: Survey Data

Survey Questions

	German	English
Q1	Wie oft denkst du über den Klimawandel und die Umwelt nach?	How often do you think about climate change and the environment?
Q2	Wie oft denkst du über die österreichische Wirtschaft nach?	How often do you think about the Austrian economy?
Q3	Wie wichtig glaubst du ist die Stahlindustrie für die österreichische Wirtschaft?	How important do you think the steel industry is for the Austrian economy?
Q4	Wie umweltschädlich schätzt du die Stahlproduktion ein?	How harmful do you think steel production is to the environment?

Survey results

	Q1	Q2	Q3	Q4
Aggregated Results (225 replies)				
Up to moderate (0* - 6)	106	82	69	107
More than moderate (7 - 10)	119	143	156	118
MSc. Mag. PhD or similar (120 replies)				
Up to moderate (0* - 6)	50	38	39	54
More than moderate (7 - 10)	70	82	81	66
BSc. or apprenticeship (56 replies)				
Up to moderate (0* - 6)	29	24	16	27
More than moderate (7 - 10)	27	32	40	29
Compulsory School and Matura (49 replies)				
Up to moderate (0* - 6)	27	18	14	26
More than moderate (7 - 10)	22	31	35	23

*It was pointet out that 0 referes to “I have not yet considered the issue in question.”

List of all responses

ID	Time submission m.d.y hh:mm:ss	Email	Q1	Q2	Q3	Q4	Age	Academic Degree
1	5.14.24 11:59:48	anonymous	10	4	9	5	25-40	MSc. Mag. PhD or similar
2	5.14.24 12:11:53	anonymous	4	7	6	8	25-40	MSc. Mag. PhD or similar
3	5.14.24 12:23:03	anonymous	3	10	8	6	25-40	MSc. Mag. PhD or similar
4	5.14.24 12:26:51	anonymous	5	7	5	7	55-70	MSc. Mag. PhD or similar
5	5.14.24 12:27:28	anonymous	5	6	4	4	55-70	MSc. Mag. PhD or similar
6	5.14.24 13:01:14	anonymous	6	10	9	5	55-70	MSc. Mag. PhD or similar
7	5.14.24 13:10:24	anonymous	7	5	10	2	25-40	BSc. or apprenticeship
8	5.14.24 13:10:57	anonymous	8	8	5	10	25-40	BSc. or apprenticeship
9	5.14.24 13:11:48	anonymous	10	10	6	7	25-40	BSc. or apprenticeship
10	5.14.24 13:21:04	anonymous	8	10	5	8	25-40	Matura
11	5.14.24 13:22:10	anonymous	8	6	8	8	25-40	BSc. or apprenticeship
12	5.14.24 13:26:00	anonymous	10	10	0	0	40-55	Compulsory school
13	5.14.24 13:29:37	anonymous	7	9	9	6	25-40	MSc. Mag. PhD or similar
14	5.14.24 13:41:47	anonymous	6	7	8	7	25-40	BSc. or apprenticeship
15	5.14.24 13:43:53	anonymous	5	0	0	6	< 25	BSc. or apprenticeship
16	5.14.24 14:51:26	anonymous	5	6	7	7	25-40	MSc. Mag. PhD or similar
17	5.14.24 14:53:23	anonymous	4	10	10	3	25-40	MSc. Mag. PhD or similar
18	5.14.24 15:05:17	anonymous	2	10	10	3	70+	Compulsory school
19	5.14.24 15:09:34	anonymous	8	10	10	1	25-40	MSc. Mag. PhD or similar
20	5.14.24 15:10:13	anonymous	6	6	7	8	25-40	BSc. or apprenticeship
21	5.14.24 15:10:34	anonymous	8	9	6	7	25-40	MSc. Mag. PhD or similar
22	5.14.24 15:11:54	anonymous	5	10	10	5	55-70	Compulsory school
23	5.14.24 15:12:09	anonymous	5	10	10	5	70+	Compulsory school
24	5.14.24 15:14:25	anonymous	9	3	7	8	25-40	MSc. Mag. PhD or similar
25	5.14.24 15:17:02	anonymous	7	7	6	7	25-40	MSc. Mag. PhD or similar
26	5.14.24 15:17:29	anonymous	7	6	8	3	25-40	MSc. Mag. PhD or similar
27	5.14.24 15:18:21	anonymous	7	10	8	9	25-40	BSc. or apprenticeship
28	5.14.24 15:21:46	anonymous	3	8	8	8	25-40	BSc. or apprenticeship
29	5.14.24 15:22:56	anonymous	9	9	6	8	< 25	MSc. Mag. PhD or similar
30	5.14.24 15:25:48	anonymous	10	9	8	8	25-40	MSc. Mag. PhD or similar
31	5.14.24 15:32:36	anonymous	9	10	6	6	40-55	MSc. Mag. PhD or similar
32	5.14.24 15:32:03	anonymous	6	3	5	6	25-40	BSc. or apprenticeship
33	5.14.24 15:37:46	anonymous	0	10	8	7	25-40	MSc. Mag. PhD or similar
34	5.14.24 15:43:02	anonymous	2	3	6	3	< 25	BSc. or apprenticeship
35	5.14.24 15:43:38	anonymous	0	3	4	0	25-40	MSc. Mag. PhD or similar
36	5.14.24 15:44:34	anonymous	5	7	3	8	25-40	MSc. Mag. PhD or similar
37	5.14.24 15:45:18	anonymous	4	2	9	6	25-40	MSc. Mag. PhD or similar
38	5.14.24 15:53:26	anonymous	9	0	0	8	25-40	MSc. Mag. PhD or similar
39	5.14.24 15:54:34	anonymous	7	6	6	5	55-70	MSc. Mag. PhD or similar
40	5.14.24 15:57:53	anonymous	10	7	0	0	25-40	MSc. Mag. PhD or similar
41	5.14.24 16:10:10	anonymous	2	4	6	5	25-40	MSc. Mag. PhD or similar
42	5.14.24 16:10:55	anonymous	4	9	5	0	25-40	MSc. Mag. PhD or similar

43	5.14.24 16:11:44	anonymous	5	6	5	8	25-40	MSc. Mag. PhD or similar
44	5.14.24 16:13:00	anonymous	8	7	9	8	25-40	MSc. Mag. PhD or similar
45	5.14.24 16:13:52	anonymous	10	5	10	10	25-40	MSc. Mag. PhD or similar
46	5.14.24 16:13:46	anonymous	3	7	7	5	25-40	MSc. Mag. PhD or similar
47	5.14.24 16:13:53	anonymous	5	2	10	8	25-40	MSc. Mag. PhD or similar
48	5.14.24 16:18:16	anonymous	8	7	10	4	25-40	MSc. Mag. PhD or similar
49	5.14.24 16:22:12	anonymous	8	10	7	7	25-40	MSc. Mag. PhD or similar
50	5.14.24 16:22:22	anonymous	4	10	6	7	25-40	MSc. Mag. PhD or similar
51	5.14.24 16:22:27	anonymous	6	3	0	8	25-40	MSc. Mag. PhD or similar
52	5.14.24 16:31:25	anonymous	8	3	8	10	25-40	MSc. Mag. PhD or similar
53	5.14.24 16:36:55	anonymous	7	8	7	6	< 25	Matura
54	5.14.24 16:41:51	anonymous	10	6	7	10	25-40	BSc. or apprenticeship
55	5.14.24 16:55:13	anonymous	5	5	7	7	40-55	Matura
56	5.14.24 17:03:44	anonymous	8	8	7	7	25-40	MSc. Mag. PhD or similar
57	5.14.24 17:07:03	anonymous	7	8	10	6	25-40	MSc. Mag. PhD or similar
58	5.14.24 17:13:05	anonymous	6	4	6	8	< 25	MSc. Mag. PhD or similar
59	5.14.24 17:18:39	anonymous	10	8	5	6	25-40	MSc. Mag. PhD or similar
60	5.14.24 17:24:57	anonymous	10	8	5	10	25-40	BSc. or apprenticeship
61	5.14.24 17:40:42	anonymous	3	10	10	2	25-40	BSc. or apprenticeship
62	5.14.24 17:42:04	anonymous	9	2	8	8	25-40	MSc. Mag. PhD or similar
63	5.14.24 17:55:30	anonymous	7	7	10	7	25-40	MSc. Mag. PhD or similar
64	5.14.24 18:14:15	anonymous	3	9	3	0	25-40	BSc. or apprenticeship
65	5.14.24 18:23:26	anonymous	8	8	8	3	25-40	MSc. Mag. PhD or similar
66	5.14.24 18:28:16	anonymous	10	7	0	0	< 25	MSc. Mag. PhD or similar
67	5.14.24 18:34:44	anonymous	7	10	10	10	25-40	BSc. or apprenticeship
68	5.14.24 18:38:36	anonymous	6	8	8	10	25-40	MSc. Mag. PhD or similar
69	5.14.24 17:19:24	anonymous	9	0	0	0	70+	Compulsory school
70	5.14.24 19:17:57	anonymous	7	9	5	6	25-40	MSc. Mag. PhD or similar
71	5.14.24 19:19:18	anonymous	8	9	10	6	< 25	BSc. or apprenticeship
72	5.14.24 19:35:21	anonymous	9	8	5	5	55-70	MSc. Mag. PhD or similar
73	5.14.24 20:10:03	anonymous	5	10	7	9	25-40	Matura
74	5.14.24 20:14:18	anonymous	0	10	8	5	55-70	BSc. or apprenticeship
75	5.14.24 20:18:08	anonymous	8	5	7	8	25-40	MSc. Mag. PhD or similar
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77	5.14.24 21:58:42	anonymous	3	7	10	7	25-40	MSc. Mag. PhD or similar
78	5.14.24 22:00:45	anonymous	2	6	9	2	25-40	BSc. or apprenticeship
79	5.14.24 22:02:31	anonymous	8	10	7	5	25-40	MSc. Mag. PhD or similar
80	5.14.24 22:04:10	anonymous	5	6	8	5	55-70	BSc. or apprenticeship
81	5.14.24 22:16:43	anonymous	6	4	3	5	25-40	BSc. or apprenticeship
82	5.14.24 22:24:22	anonymous	5	10	10	8	55-70	Matura
83	5.14.24 22:31:32	anonymous	2	8	5	3	55-70	MSc. Mag. PhD or similar
84	5.14.24 22:33:24	anonymous	6	8	10	1	55-70	Matura
85	5.14.24 22:35:50	anonymous	1	1	3	0	55-70	MSc. Mag. PhD or similar
86	5.14.24 22:38:33	anonymous	0	5	4	0	40-55	MSc. Mag. PhD or similar
87	5.14.24 22:40:57	anonymous	6	9	7	3	55-70	MSc. Mag. PhD or similar
88	5.14.24 22:42:15	anonymous	8	9	8	5	55-70	MSc. Mag. PhD or similar

89	5.14.24 22:48:03	anonymous	9	7	9	10	25-40	MSc. Mag. PhD or similar
90	5.14.24 22:57:38	anonymous	8	4	9	4	55-70	MSc. Mag. PhD or similar
91	5.14.24 23:01:09	anonymous	5	10	3	0	55-70	Matura
92	5.14.24 23:03:36	anonymous	7	9	10	8	55-70	MSc. Mag. PhD or similar
93	5.14.24 23:37:25	anonymous	9	6	7	9	25-40	MSc. Mag. PhD or similar
94	5.14.24 22:39:04	anonymous	7	7	5	9	55-70	MSc. Mag. PhD or similar
95	5.15.24 0:07:42	anonymous	5	10	10	6	55-70	Matura
96	5.15.24 0:14:28	anonymous	9	7	8	9	25-40	BSc. or apprenticeship
97	5.15.24 4:43:55	anonymous	6	9	9	6	25-40	MSc. Mag. PhD or similar
98	5.15.24 6:35:46	anonymous	4	7	1	7	25-40	MSc. Mag. PhD or similar
99	5.15.24 7:15:32	anonymous	8	8	8	8	55-70	MSc. Mag. PhD or similar
100	5.15.24 7:53:04	anonymous	8	4	7	7	25-40	MSc. Mag. PhD or similar
101	5.15.24 8:14:29	anonymous	6	4	8	6	25-40	BSc. or apprenticeship
102	5.15.24 8:26:34	anonymous	3	8	9	6	25-40	BSc. or apprenticeship
103	5.15.24 8:46:10	anonymous	8	9	9	7	25-40	MSc. Mag. PhD or similar
104	5.15.24 8:50:07	anonymous	7	8	6	8	40-55	MSc. Mag. PhD or similar
105	5.15.24 9:02:02	anonymous	10	4	10	10	40-55	MSc. Mag. PhD or similar
106	5.15.24 9:34:18	anonymous	9	7	8	6	25-40	Compulsory school
107	5.15.24 9:38:05	anonymous	10	7	8	7	25-40	MSc. Mag. PhD or similar
108	5.15.24 9:39:42	anonymous	6	8	8	6	25-40	BSc. or apprenticeship
109	5.15.24 9:44:41	anonymous	10	10	8	8	25-40	Matura
110	5.15.24 9:49:28	anonymous	8	9	8	8	55-70	Matura
111	5.15.24 10:25:45	anonymous	10	4	6	10	25-40	BSc. or apprenticeship
112	5.15.24 10:28:21	anonymous	5	8	8	7	55-70	MSc. Mag. PhD or similar
113	5.15.24 10:33:06	anonymous	6	5	7	7	25-40	MSc. Mag. PhD or similar
114	5.15.24 10:32:37	anonymous	6	10	7	6	55-70	MSc. Mag. PhD or similar
115	5.15.24 10:59:40	anonymous	1	10	10	4	55-70	MSc. Mag. PhD or similar
116	5.15.24 11:05:25	anonymous	6	7	8	0	< 25	BSc. or apprenticeship
117	5.15.24 11:34:52	anonymous	8	10	8	5	55-70	MSc. Mag. PhD or similar
118	5.15.24 11:40:06	anonymous	7	1	5	8	25-40	MSc. Mag. PhD or similar
119	5.15.24 11:41:26	anonymous	5	5	8	0	55-70	BSc. or apprenticeship
120	5.15.24 11:41:47	anonymous	4	10	10	8	55-70	MSc. Mag. PhD or similar
121	5.15.24 11:44:10	anonymous	6	2	6	7	< 25	Matura
122	5.15.24 11:50:30	anonymous	4	4	7	7	40-55	MSc. Mag. PhD or similar
123	5.15.24 11:58:27	anonymous	10	10	10	2	40-55	Compulsory school
124	5.15.24 11:58:54	anonymous	10	8	7	8	25-40	Matura
125	5.15.24 11:59:05	anonymous	8	7	9	5	40-55	MSc. Mag. PhD or similar
126	5.15.24 12:01:12	anonymous	4	6	2	6	25-40	BSc. or apprenticeship
127	5.15.24 12:04:38	anonymous	9	6	7	8	25-40	BSc. or apprenticeship
128	5.15.24 12:09:07	anonymous	8	4	3	9	40-55	Matura
129	5.15.24 11:49:43	anonymous	8	8	7	9	25-40	BSc. or apprenticeship
130	5.15.24 12:37:04	anonymous	6	5	8	8	40-55	Matura
131	5.15.24 12:42:28	anonymous	8	10	9	7	55-70	MSc. Mag. PhD or similar
132	5.15.24 12:47:49	anonymous	4	7	8	3	55-70	Matura
133	5.15.24 12:49:52	anonymous	2	10	10	6	< 25	BSc. or apprenticeship
134	5.15.24 12:56:31	anonymous	8	9	8	7	55-70	BSc. or apprenticeship

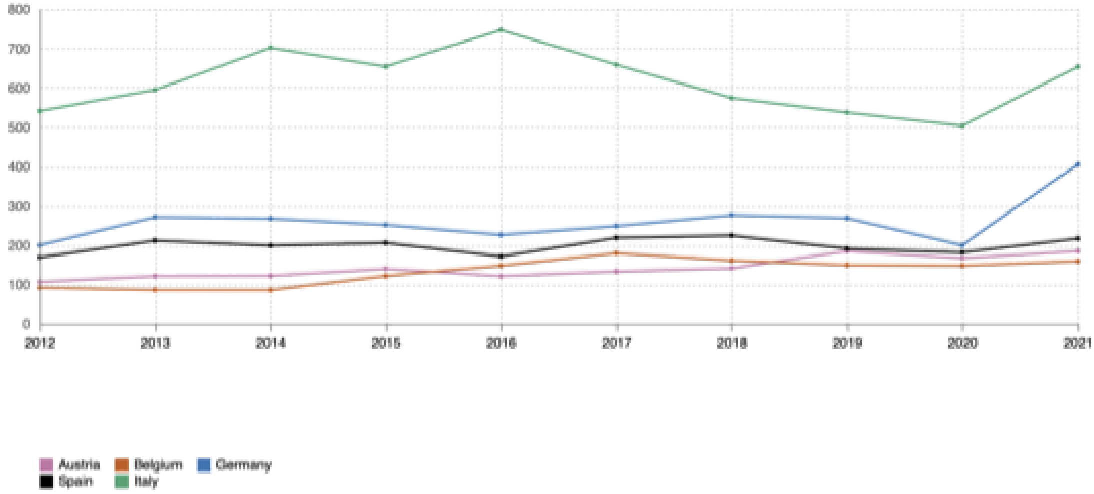
135	5.15.24 12:04:57	anonymous	7	8	0	7	40-55	MSc. Mag. PhD or similar
136	5.15.24 13:05:33	anonymous	9	1	7	10	40-55	BSc. or apprenticeship
137	5.15.24 13:08:54	anonymous	4	2	2	8	40-55	MSc. Mag. PhD or similar
138	5.15.24 13:28:12	anonymous	5	6	8	9	55-70	MSc. Mag. PhD or similar
139	5.15.24 13:29:43	anonymous	6	4	8	7	< 25	Matura
140	5.15.24 13:42:39	anonymous	5	5	7	6	55-70	MSc. Mag. PhD or similar
141	5.15.24 13:47:51	anonymous	10	8	8	8	55-70	MSc. Mag. PhD or similar
142	5.15.24 13:48:54	anonymous	9	5	7	8	40-55	MSc. Mag. PhD or similar
143	5.15.24 13:49:48	anonymous	3	9	8	7	25-40	MSc. Mag. PhD or similar
144	5.15.24 13:51:27	anonymous	9	9	9	8	25-40	BSc. or apprenticeship
145	5.15.24 13:56:22	anonymous	5	5	10	0	40-55	MSc. Mag. PhD or similar
146	5.15.24 13:58:29	anonymous	6	7	7	5	40-55	MSc. Mag. PhD or similar
147	5.15.24 14:00:17	anonymous	4	7	2	2	25-40	BSc. or apprenticeship
148	5.15.24 14:02:19	anonymous	7	5	7	7	25-40	MSc. Mag. PhD or similar
149	5.15.24 14:01:33	anonymous	8	10	7	7	25-40	MSc. Mag. PhD or similar
150	5.15.24 14:02:58	anonymous	6	5	7	8	25-40	MSc. Mag. PhD or similar
151	5.15.24 14:06:40	anonymous	8	8	7	8	40-55	MSc. Mag. PhD or similar
152	5.15.24 14:09:45	anonymous	6	7	5	5	40-55	MSc. Mag. PhD or similar
153	5.15.24 14:11:59	anonymous	8	7	6	8	25-40	MSc. Mag. PhD or similar
154	5.15.24 14:12:37	anonymous	7	8	9	4	55-70	BSc. or apprenticeship
155	5.15.24 14:13:22	anonymous	10	5	7	3	70+	MSc. Mag. PhD or similar
156	5.15.24 14:15:07	anonymous	5	5	8	4	55-70	Compulsory school
157	5.15.24 14:15:41	anonymous	2	2	1	1	55-70	BSc. or apprenticeship
158	5.15.24 14:18:27	anonymous	9	10	8	10	40-55	MSc. Mag. PhD or similar
159	5.15.24 14:21:05	anonymous	5	6	10	5	55-70	BSc. or apprenticeship
160	5.15.24 14:24:12	anonymous	8	10	8	8	55-70	BSc. or apprenticeship
161	5.15.24 14:28:52	anonymous	8	8	9	7	25-40	BSc. or apprenticeship
162	5.15.24 14:34:29	anonymous	3	9	4	6	25-40	BSc. or apprenticeship
163	5.15.24 14:34:12	anonymous	7	7	6	9	< 25	BSc. or apprenticeship
164	5.15.24 14:35:05	anonymous	8	5	7	10	< 25	Matura
165	5.15.24 14:35:09	anonymous	0	9	10	0	< 25	Matura
166	5.15.24 14:35:10	anonymous	3	5	8	6	25-40	Matura
167	5.15.24 14:31:52	anonymous	8	10	9	9	< 25	Matura
168	5.15.24 14:35:02	anonymous	10	10	5	8	40-55	Compulsory school
169	5.15.24 14:37:45	anonymous	10	7	3	10	25-40	MSc. Mag. PhD or similar
170	5.15.24 14:39:00	anonymous	1	3	0	0	< 25	Matura
171	5.15.24 14:39:23	anonymous	9	8	10	7	25-40	BSc. or apprenticeship
172	5.15.24 14:39:29	anonymous	8	8	6	7	< 25	Matura
173	5.15.24 14:39:34	anonymous	7	7	9	6	< 25	Matura
174	5.15.24 14:39:45	anonymous	6	6	8	5	25-40	BSc. or apprenticeship
175	5.15.24 14:32:15	anonymous	9	7	10	8	55-70	MSc. Mag. PhD or similar
176	5.15.24 14:46:39	anonymous	8	10	9	6	25-40	MSc. Mag. PhD or similar
177	5.15.24 14:49:40	anonymous	10	8	5	9	55-70	MSc. Mag. PhD or similar
178	5.15.24 14:48:47	anonymous	8	8	10	10	55-70	BSc. or apprenticeship
179	5.15.24 14:56:12	anonymous	6	8	9	10	25-40	BSc. or apprenticeship
180	5.15.24 14:58:29	anonymous	5	10	8	8	55-70	MSc. Mag. PhD or similar

181	5.15.24 15:00:39	anonymous	5	7	8	5	55-70	MSc. Mag. PhD or similar
182	5.15.24 15:01:22	anonymous	8	8	7	8	< 25	Matura
183	5.15.24 15:02:18	anonymous	6	6	6	7	25-40	MSc. Mag. PhD or similar
184	5.15.24 15:08:30	anonymous	5	9	7	5	55-70	Matura
185	5.15.24 15:10:53	anonymous	8	6	9	5	55-70	Compulsory school
186	5.15.24 15:12:23	anonymous	6	8	8	6	40-55	Matura
187	5.15.24 15:37:49	anonymous	5	5	8	6	55-70	MSc. Mag. PhD or similar
188	5.15.24 15:47:42	anonymous	10	9	7	8	40-55	MSc. Mag. PhD or similar
189	5.15.24 15:49:18	anonymous	8	7	9	7	25-40	MSc. Mag. PhD or similar
190	5.15.24 15:59:15	anonymous	7	7	5	9	25-40	Matura
191	5.15.24 16:03:38	anonymous	7	8	8	9	25-40	BSc. or apprenticeship
192	5.15.24 16:05:53	anonymous	10	5	10	8	55-70	BSc. or apprenticeship
193	5.15.24 16:10:54	anonymous	5	8	5	9	< 25	Matura
194	5.15.24 16:18:22	anonymous	10	6	6	4	25-40	Matura
195	5.15.24 16:27:21	anonymous	3	6	7	7	25-40	BSc. or apprenticeship
196	5.15.24 16:29:19	anonymous	9	10	8	8	55-70	MSc. Mag. PhD or similar
197	5.15.24 16:38:06	anonymous	9	5	10	9	55-70	Matura
198	5.15.24 16:40:16	anonymous	8	9	6	10	25-40	BSc. or apprenticeship
199	5.15.24 16:58:09	anonymous	5	5	5	8	55-70	Matura
200	5.15.24 17:34:31	anonymous	0	6	6	5	< 25	Matura
201	5.15.24 17:34:25	anonymous	9	5	7	8	25-40	BSc. or apprenticeship
202	5.15.24 17:35:05	anonymous	6	6	7	7	< 25	Matura
203	5.15.24 17:38:10	anonymous	8	10	7	5	40-55	MSc. Mag. PhD or similar
204	5.15.24 17:47:24	anonymous	2	5	10	5	55-70	BSc. or apprenticeship
205	5.15.24 18:02:41	anonymous	5	5	10	5	55-70	BSc. or apprenticeship
206	5.15.24 18:42:48	anonymous	8	5	9	6	55-70	MSc. Mag. PhD or similar
207	5.15.24 19:15:51	anonymous	10	10	9	3	70+	BSc. or apprenticeship
208	5.15.24 20:24:22	anonymous	5	7	6	8	55-70	BSc. or apprenticeship
209	5.15.24 20:40:44	anonymous	8	10	10	7	55-70	Matura
210	5.15.24 17:26:47	anonymous	6	9	10	3	55-70	Matura
211	5.16.24 7:39:18	anonymous	7	7	5	6	55-70	MSc. Mag. PhD or similar
212	5.16.24 8:31:28	anonymous	9	10	9	4	55-70	MSc. Mag. PhD or similar
213	5.16.24 9:52:16	anonymous	5	5	7	2	40-55	Compulsory school
214	5.16.24 10:30:51	anonymous	9	8	8	9	40-55	MSc. Mag. PhD or similar
215	5.16.24 10:53:09	anonymous	5	2	7	5	25-40	MSc. Mag. PhD or similar
216	5.16.24 11:09:49	anonymous	5	7	8	5	25-40	Matura
217	5.16.24 11:12:16	anonymous	6	4	8	6	25-40	Compulsory school
218	5.16.24 13:36:34	anonymous	10	6	5	5	70+	MSc. Mag. PhD or similar
219	5.16.24 14:33:09	anonymous	5	7	8	7	25-40	MSc. Mag. PhD or similar
220	5.16.24 15:10:42	anonymous	5	8	8	6	25-40	MSc. Mag. PhD or similar
221	5.16.24 21:47:04	anonymous	8	9	7	6	25-40	MSc. Mag. PhD or similar
222	5.17.24 11:35:18	anonymous	9	9	8	3	55-70	MSc. Mag. PhD or similar
223	5.18.24 14:11:31	anonymous	4	7	9	7	25-40	MSc. Mag. PhD or similar
224	5.18.24 14:59:51	anonymous	7	7	8	5	70+	MSc. Mag. PhD or similar
225	5.19.24 21:07:49	anonymous	10	10	9	8	55-70	Matura

Annex 5: Eurostat Data

Environmental taxes by economic activity (NACE Rev. 2)

Time frequency: **Annual** Taxes: **Energy taxes** Unit of measure: **Million euro** Statistical classification of economic activities in the European Community (NACE Rev. 2): **Manufacture of basic metals**



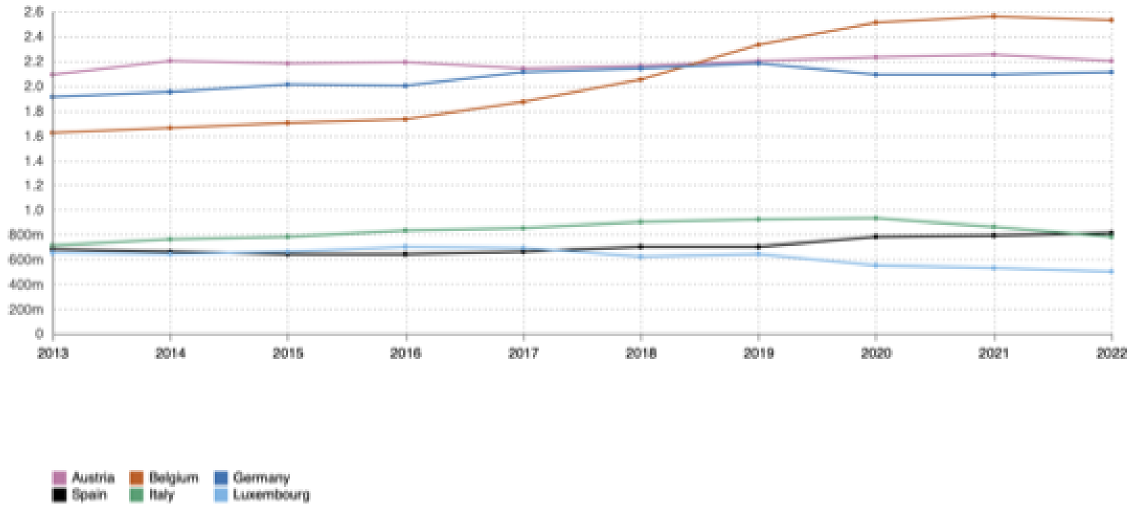
This graph has been created automatically by ESTAT/EC software according to external user specifications for which ESTAT/EC is not responsible.
General disclaimer of the EC website: https://ec.europa.eu/info/legal-notice_en.html

eurostat

Environmental taxes by economic activity (NACE Rev. 2) [env_ac_taxind2]
Source of data: Eurostat - Last updated date: Wednesday, January 31, 2024 11:00 AM
Disclaimer: This graph has been created automatically by ESTAT/EC software according to external user specifications for which ESTAT/EC is not responsible. Graphic included.
General disclaimer of the EC website: https://ec.europa.eu/info/legal-notice_en

Gross domestic expenditure on R&D by sector

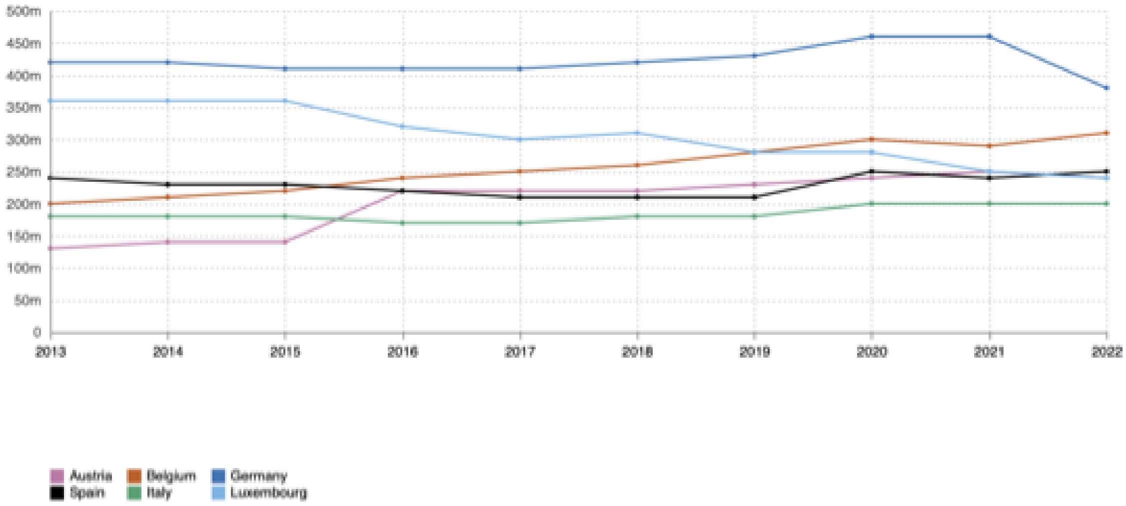
Time frequency: **Annual** Sector of performance: **Business enterprise sector** Unit of measure: **Percentage of gross domestic product (GDP)**



Gross domestic expenditure on R&D by sector [sdg_09_10]
Source of data: Eurostat - Last updated date: Sunday, March 17, 2024 11:00 PM

Gross domestic expenditure on R&D by sector

Time frequency: **Annual** Sector of performance: **Government sector** Unit of measure: **Percentage of gross domestic product (GDP)**



Gross domestic expenditure on R&D by sector [sdg_09_10]
Source of data: Eurostat - Last updated date: Sunday, March 17, 2024 11:00 PM
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