# The EU Waste Shipment Proposal and Its Implications for the Secondary Route Steel Production

A scenario analysis considering energy use, CO2 emissions, and environmental costs

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# The EU Waste Shipment Proposal and Its Implications for the Secondary Route Steel Production

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# Abstract:

The steel industry is one of the most polluting industries globally. There exists an EU waste shipment proposal that aims to restrict the EU export of waste in order to raise safe, environmental standards and circularity within the EU. Under this proposal, steel scrap is defined as waste and since the EU is the largest exporter of steel scrap globally, this has implications for the EU steel industry. This thesis intends to quantitatively analyse these implications in terms of energy demand, GHG emissions, and environmental costs. The quantitative method used is based on scenario analysis and applies the 'scrap bonus' approach. Results indicate there will be an increase in electricity energy demand leading to an increased demand for green electricity. $CO_2$ emissions might increase, however, there are also possible savings of increased scrap use, also in costs. On EU level, the proposal is identified as beneficial to the steel industry.

**Keywords: EU Waste Shipment proposal, secondary steel production, steel industry, scenario analysis, decarbonization, scrap bonus**

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## List of Abbreviations

BF/BOF = Blast Furnace/Basic Oxygen Furnace

EAF = Electric Arc Furnace

EC = European Commission

EU-27= European Union with its 27 member states

EU ETS = EU Emissions Trading Scheme

Eurofer = European Steel Association

GHG = Greenhouse Gas

# 1 Introduction

The iron and steel industry generates over 7% of all global greenhouse gas emissions and thus is the most polluting heavy industry sector globally creating 2.6Gt $CO_2$ annually (IEA, 2020b). Steel as a product is highly interwoven with society which not only depends on it for buildings, transportation, or domestic appliances, but also is integral for enabling the green energy transition in form of contributing to the construction of dams, wind turbines, solar technology, or electric vehicles (Eurofer, 2021b). Since there is currently no commercially available substitute, global demand for steel is predicted to increase even further and subsequently, so are greenhouse gas (GHG) emissions during steel production to be expected to increase in the coming decades if current polluting manufacturing practices are maintained (Eurofer, 2019).

To achieve the climate targets set out by the Paris Climate Agreement or the European Green Deal, the decarbonization of the steel and iron sector is inevitable (Vogl, Olsson, et al., 2021). While in the EU, 60% of steel is produced through the primary route of steel making via blast furnaces (BF) which causes the majority of GHG emissions (ca. 80%), 40% of steel is melted and recycled in electric arc furnaces (EAF) from steel scrap. Consequently, the main emissions savings can only be achieved through the replacement of BFs with low-emission technologies such as direct reduction with the use of hydrogen or feedstock such as biomass instead of the use of coal (Arens et al., 2017; Vogl, Olsson, et al., 2021). However, the role of scrap steel and its recycling through the secondary route is relevant and a central aspect in achieving a low-carbon transition of the steel sector and increasing circularity within the EU (EC, 2021a; Eurofer, 2022). Furthermore, the share of steel produced through the secondary route is predicted to increase and might even hold a larger share than the primary route by 2050 due to an increase in available scrap and the EU circular economy policy (Vogl & Åhman, 2019; Wörtler et al., 2013). Recently, in line with the European Green Deal, the Industrial Strategy and the Circular Economy Action Plan, the EU commission worked out a revised version of the Waste Shipment Regulation in November 2021 with the aim of raising environmental standards, safe practices and increasing circularity within the EU (EC, 2019a, 2019b, 2020, 2021a, 2021). It essentially entails restrictions on waste shipments to non-EU member states. It also encompasses ferrous scrap and since the EU is the largest exporter of steel scrap globally with 22.627 million tonnes in 2020 (BIR, 2021), this proposal, consequently, likely will have an effect on the EU scrap steel sector concerning its energy consumption, Greenhouse Gas (GHG) emissions and economic dimensions.

### *Research Aim and Scope*

Due to the novelty of the proposed EU waste shipment proposal, its effect and potential implications for the EU steel industry are academically underexplored specifically from an environmental perspective. Current studies indicate the decarbonisation of the steel industry is crucial and decisive in achieving net-zero emissions by 2050 (Paris Agreement, UN,2015; IEA, 2020b; Wörtler et al., 2013). Even though of the steel industry's high relevance in remaining below 2°C of global warming, it seems to be often overlooked. Since the new EU waste shipment proposal amongst raising waste management standards focuses on environmental and sustainability goals, combined with the fact that the EU is the largest exporter of steel scrap globally, this was identified as a thesis topic worth pursuing.

The aim of this thesis is to comprehensively explore possible policy implications for the EU's secondary steel industry. The initial goal was to cover all three pillars (social, economic, and environmental) of sustainability (e.g Brundtland, 1987; Purvis et al., 2019). However, after extensive research, the focus was put on the environmental and economic dimensions due to a lack of data related to the social dimension. $CO_2$ emissions have been identified as an important indicator due to their relevance in form of the EU Emissions Trading Scheme (EU ETS) for the steel industry and its global significance as a driver of global warming. The closely related energy consumption was chosen as it is one of the primary sources of $CO_2$ emissions in EAF steel production (Wörtler et al., 2013). The environmental cost dimension was chosen in evaluating the topic from an economic perspective but environmentally related. Therefore, the scope of this research is limited to the dimensions of energy consumption, GHG emissions and environmental costs. Consequently, the following research question can be formulated:

**RQ: To what extent does the EU waste shipment proposal influence the secondary EU steel industry concerning energy consumption, GHG emissions, and environmental costs?**

Based on scenario analysis theory, after reviewing the waste shipment proposal, three different scenarios are created and quantitatively analysed according to each dimension.
To evaluate to what extent the proposed waste policy impacts the secondary steel industry concerning relevant environmental indicators such as energy use, $CO_2$ emissions, and environmental costs, the following sub-questions can be formulated:

I. To what extent does the new proposal impact **energy consumption** of the EU secondary steel industry for each scenario?

II. In how far does the waste proposal impact **$CO_2$ emissions levels** that occur during secondary steel production for each scenario?

III. To what extent exist potential **$CO_2$ emissions** and **environmental cost savings** for the EU steel industry for each scenario?

***Structure***

In order to explore these questions, first, the EU waste shipment proposal is reviewed, then the steel industry, specifically the secondary steel industry and its environmental impact are highlighted. Thirdly, the theoretical basis of this research is explained. Then, after outlining the method used, the results are presented, analysed and discussed, and finally, there will be a conclusion.

## 2 Setting the Scene

### 2.1 EU Waste Policies

Since 1984, waste management has been prioritised as part of the UN Environment Programme (UNEP, 2011). There exist various waste policies and international treaties to ensure the control of waste shipments and the health of environment and people. In 1989, the Basel Convention on the control of transboundary movements of hazardous waste and their disposal and later with its various amendments was put in place with the aim of preventing hazardous and toxic waste shipment from the EU and OECD member countries to third countries (UNEP, 2011). Some argue the Basel Convention has fallen short of achieving its aim due to loopholes, unclear definitions, and lack of commitment from the USA being the third-largest exporter of waste having signed the convention but never actually ratifying it (Ahmad Khan, 2020; Kummer, 1992; U.S. Department of State, n.d.).

At the EU level, the EU Waste Shipment Regulation (WSR) (EC) NO 1013/2006 applies the resolutions of the Basel Convention in EU law (EC, 2021; EUR-Lex, 2006).

In November 2021, the European Commission published a new proposal of the WSR with stricter guidelines on the management of waste attempting to increase circularity within the EU, safety and environmental standards which is supposed to be implemented until a 3-year transition period has passed (EC, 2021). The following extends upon the described proposal.

### *2.1.1 EU Waste Shipment Proposal 2021*

The EU waste shipment proposal's main objective is to improve intra-EU shipments, ensure "waste shipped outside the EU is managed in an environmentally sound manner" and prevent illegal waste shipment within and outside of the EU (EC, 2021b, p.1).

The EU impact assessment[1] identified a need for a revision of the existing regulation concerning three identified weaknesses: (1) Shipments within the EU are burdensome; (2) insufficiency in ensuring environmentally sound and safe management of exported waste to the same standard as in the EU and a dependency of the EU on secondary materials and vulnerability to global value chain disruptions; and (3) ineffective enforcement allows for illegal shipment of waste within and outside of the EU (EC, 2021, 2021b).

Subsequently, the European Commission's proposal attempts to address these aspects identified with changes to the existing regulation and the establishment of a new sustainable waste management framework, the introduction of a digital data exchange base and a more powerful enforcement (EC, 2021). The new proposal differentiates between OECD member states and non-OECD members. The export of waste to the former will be restricted and might only be allowed by the country in question making an official request under the condition that it offers the capacity for safe and environmentally sound management. Increased exports to OECD countries will be "monitored" and in the case of unsound waste treatment, exports will be stopped by the European Commission (EC, 2021). If EU companies want to export waste to other countries they have to ensure independent audits are taken place in these foreign waste facilities (EC, 2021).

To increase circularity and trade of recyclable waste within the EU and decrease bureaucracy, the European Commission proposes digitalisation of all procedures between EU member countries. Furthermore, recyclable waste is supposed to be shipped faster to so-called "pre-consented facilities" which have an EU certification (EC, 2021, p.50). Additionally, the classification of waste should be made consistent within the EU to ensure efficient waste shipments (EC, 2021).

While one could potentially see a disruption of free global trade, the European Steel Association (EUROFER) in general welcomes the proposal while, however, identifying areas for "significant improvement" (Eurofer, 2022, p.1).

One main point of EUROFER's concern is the differentiation and different treatment between non-OECD and OECD member countries and sees a threat of loopholes that might prevent the achieving of the objectives and the risk of discrimination of third countries. The proposal assumes that facilities in

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[1] An EU Impact Assessment is usually conducted before the finalisation of a new proposal for a new law and aims at identifying possible impacts and needs for action (EC, n.d.).

OECD member countries automatically provide a higher standard than third countries, but this claim is lacking evidence and evaluation and thus, remains unjustified (Eurofer, 2022). Furthermore, it might lead to waste simply being moved from third countries to OECD members without actual proof of safer practices. Moreover, EUROFER doubts the consistency and effectiveness of proposed measures and advocates for a risk-based approach applying to the country and facility level of all export countries (Eurofer, 2022). Additionally, they identified a lack of clarity and definition of environmental, social and safe standards of facilities and propose defining auditing standards in the legislative text in writing. For these audits to be effective, EUROFER (2022, p.3) suggests these audits to be conducted by an "EU-based independent and accredited third party" which must meet certain objectivity and professionalism requirements. Furthermore, they endorse further evaluation into the proposal's modernisation and digitalisation suggestion, in order not for it to become an additional bureaucratic burden instead of lessening administrative loads (Eurofer, 2022).

In general, EUROFER stresses the importance of steel scrap as an important part of decarbonisation and circularity of the EU steel industry and in line with the EU Impact Assessment makes clear that there exists enough capacity to use increased amounts of materials, and thus does not see a need for a 3-year transition period (Eurofer, 2022).

Eurofer's view was highlighted due to Eurofer's knowledge of the workings of the steel industry. Moreover, it was deemed important to include a perspective related to the practical side of steelmaking. Furthermore, due to the novelty of the proposed waste shipment proposal, there exists a lack of academic literature concerning the topic specifically considering the steel industry.

### *2.1.2 EU's Export and Import of Steel Scrap*

Since the aforementioned waste policy proposal intends to restrict waste and ferrous scrap exports, the following is outlining the current volumes of EU steel scrap exports. In 2020, the European Union prevailed as the largest exporter of steel scrap globally with 22.627 million tonnes, a 4% increase compared to the previous year (BIR, 2021). It is to be noted that these numbers include the UK which contributed the largest share of steel scrap exports among EU member countries. For 2021, there is not yet comprehensive and reliable data available. The EU-28 was also the second-largest user of steel scrap in its steelmaking after China with 77.539 million tonnes of steel scrap use (BIR, 2021). Due to the covid-19 pandemic and reduced production, the EU's use declined by more than 10 percent (BIR, 2021). Volumes of EU imports and export vary significantly with 2.866 million tonnes imported in 2020, making it the 7th largest steel scrap importer globally with Turkey being number one with over 22 million tonnes of steel scrap imported.

The fact that the EU is the largest exporter of steel scrap globally positions the EU as an important global trade partner. Consequently, changes in the export volume or export regulations are likely to have global consequences. Since steel scrap, a valuable secondary raw material, is also defined as waste by the European Commission, it falls under the new EU proposal of stricter exports of waste as previously elaborated on.

## 2.2 Secondary Steel Production

In the EU in 2020, 43% of steel was produced via the electric arc furnace (EAF) route, also known as secondary steel production (Eurofer, 2021b). While 57% was produced mainly through the blast furnaces (BOF) or basic oxygen furnaces (BOF) route, which is also described as primary steelmaking since the main raw material input consists of iron ore which needs to be reduced with coke (Arens et al., 2017). Whereas the EAF route mainly uses steel scrap, which is melted with the use of electrical energy and therefore produces significantly fewer emissions than BF/BOF steelmaking (EC, 2021a; Vogl, Olsson, et al., 2021; Wörtler et al., 2013). Nonetheless, the secondary route constitutes a crucial part of the decarbonisation of the EU steel industry in terms of increasing circularity and recycling rates and thus minimising the need for primary steelmaking. Furthermore, the share of production via EAF is predicted to increase to 60% of total steel production until 2050 (Vogl & Åhman, 2019). Subsequently, EAFs would be the main steel production route stressing the relevance of exploring this topic from a sustainability perspective.

In theory, steel scrap can be recycled indefinitely without down recycling, and therefore, can contribute to the EU's circularity objective of the waste shipment proposal and the EU Green Deal (EC, 2019a, 2021). In practice, the concern of copper contamination in the recycling of scrap steel is not yet solved which can lead to lower quality than primary route produced steel (Wörtler et al., 2013). Thus, EAFs can gain a larger share in steel production but cannot fully replace primary route production which stresses the importance of finding less polluting technological solutions for the BF/BOF route (Oda et al., 2013; Vogl, Olsson, et al., 2021). The emissions are targeted under the EU emissions trading scheme (EU ETS). It is currently one of the most effective instruments in decreasing emissions on an industrial level (EC, 2021a). To prevent carbon leakage and ensure competitiveness, the EU steel industry gets free allowances. However, these are supposed to slowly be reduced until 2050 to further stimulate the heavy industries' decarbonisation (European Council, 2022).

### *2.2.1 Secondary Steel Industry and the Environment*

During the EAF melting process it can be distinguished between local environmental impacts such as the formation of dusts, water contamination and waste material production in the form of so-called slag and more global impacts such as the emission of $CO_2$ during the production process and due to electrical energy consumption (Matino et al., 2017; Pothen et al., 2020). Furthermore, further efficiency developments are expected to be gained for the most part in indirect emissions thus, in the development of 'green' electrical energy (Wörtler et al., 2013). One tonne of steel scrap does not produce one tonne of steel, this is due to contaminations and other chemicals that are a by-product of steel scrap that forms as a so-called slag on top of the ladle and is essentially waste. However, it can also be used as asphalt for streets or in construction (Informal communication with Steel Plant Manager Andreas Metzen, 2021).

After extensive research, the focus of this thesis has been put on the broader dimensions which have been identified as energy consumption, $CO_2$ emissions and environmental costs.
These dimensions were chosen due to their relevance for sustainability, the availability of consistent data and adapting to the thesis's intended scope. In the following sections, these dimensions regarding the secondary steel production are further explained.

#### *Energy Consumption*

The energy input of an EAF is mainly electrical energy (IEA, 2020b). Thus, in theory, if this energy would be completely produced by renewables, the production of steel through EAF furnaces would be on target toward low-carbon emissions since the majority of $CO_2$ emissions are created in the electricity generation process (Arens et al., 2017).
However, in practice, the energy is bought from the grid wherever it is the cheapest at the point of its need by steel companies. Due to the global competitiveness of the steel market and the current high energy prices, it is infeasible to consider putting a focus on buying green electricity from an economic and business perspective (Informal communication with Steel Plant Manager Andreas Metzen, 2021). This reflects the general high energy price sensitivity of steel producers due to the large amounts of energy required and the volatility of energy markets (Eurofer, 2021a).
Recent studies indicate an average electrical energy consumption of modern EAFs of 400 to 500kWh per tonne of steel (Logar & Škrjanc, 2021). Energy efficiency and the amount of energy consumed are

dependent on a variety of factors such as the quality of input steel scrap, and the intended quality of the produced steel (Matino et al., 2017).

***Greenhouse Gas Emissions (GHG)***

The main GHG emissions in EAF steelmaking are $CO_2$ emissions (Wörtler et al., 2013). Furthermore, $CO_2$ emission levels are the most widely reported and monitored due to international and national regulations, treaties and policies that incorporate $CO_2$ reduction targets (Echterhof, 2021). Furthermore, the EU Emissions Trading Scheme which constitutes the current most effective instrument in reducing emissions on an industrial level, is also based on carbon prices (EC, 2021a). This underlines the relevance of quantifying and analysing $CO_2$ emissions for this thesis' objectives.

It can be differentiated by direct or indirect emissions (IEA, 2020b). Indirect emissions include the $CO_2$ emissions that were generated in electricity production, whereas direct emissions describe the $CO_2$ emissions that occur directly during the production process for instance by the use of lime, natural gas or and the consumption of the graphite electrodes which are made of coke and coal tar (Alian Moghadam et al., 2021).

The EU is among the most $CO_2$ efficient steel industries globally (EC, 2021a). Still, the EAF route produces average emissions of about 0.5t to 0.63t $CO_2$ per tonne of steel in indirect and direct emissions (EC, 2021a; Pothen et al., 2020). About half of these emissions can be attributed to electricity generation (Wörtler et al., 2013)

Moreover, according to the findings of Pothen et al. (2013) the use of one tonne of scrap steel can potentially save 1.67t of $CO_2$ if assumed that one tonne of processed scrap steel replaces one tonne of steel produced by blast furnaces with ore and coke. This concept is further explained in the theory section.

# 3 Theory

Just as environmental issues are often interwoven with a wide variety of systems, so is sustainability science highly interdisciplinary and draws on a variety of knowledge from different fields (Clark & Harley, 2020). As in the words of Swart et al. (2004, p. 141): "*Sustainability science must consider the interplay and dynamic evolution of social, economic and natural systems – it requires an integrated and long-term perspective.*" So, is also the very nature of this research that incorporates political, technical and environmental knowledge but also considers socioeconomic aspects, in order to comprehensively understand the possible implications of a new policy proposal. It also must deal with the uncertainty that comes when analysing future implications. For these purposes, this thesis makes use of and draws on scenario analysis theory.

Additionally, in order to answer research question III, the so-called concept of the 'scrap bonus' (Pothen et al., 2020) and its related potential $CO_2$ emissions and environmental cost savings are further elaborated in the last theory section.

## 3.1 Scenario Analysis

### *3.1.1 Scenario Analysis & Sustainability Science*

As Swart et al. (2004, p. 139) remark "*the systemic character of sustainability problems demands a holistic perspective that unifies across sectors, problems, methods, disciplines, spatial scales and time*" and attribute the use of scenarios as an important part of sustainability science, especially for decision-making processes and in preparing for an uncertain future. Due to this uncertainty and the wide variety of complex sustainability issues, a rather open, flexible and creative approach is required which a scenario analysis provides (Mahmoud et al., 2009; Swart et al., 2004). However, this openness and flexibility also lead to rather vague and ambiguous available definitions of scenario analysis (Swart et al., 2004). Nonetheless, one definition shared by the leading scenario development researchers and also inherent to the scenario modelling by the IPCC is the following (Mahmoud et al., 2009, p.799):

> "*A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold.*"

It is important to stress that scenario analysis is not a forecast or prediction, but an "evolving concept" (Swart et al. 2004, p. 139) that supports the preparedness of companies, organisations or governments and helps maintain some degree of stability, even when faced with for instance economic fluctuations or the occurrence of unlikely political events (Leney et al., 2004; Schwartz, 2007). Through different scenario development, perspectives are broadened and key elements are highlighted while inspiring decision-makers or other stakeholders in imagining different possible and desirable futures, which ultimately and ideally leads to focused and informed action towards the most desirable one (Mahmoud et al., 2009; Means et al., 2005).

One of the first uses of scenario modelling in conjunction with environmental concern occurred with the publication of "Limits to Growth" by the Club of Rome in 1972 (Meadows et al., 1992; Swart et al., 2004). Other studies focused on modelling of scenarios for water scarcity, land use, or change in biodiversity (e.g. Alcamo et al., 1997; Muller & Middleton, 1994; Sala et al., 2000; Veldkamp & Fresco, 1996). Then, the IPCC started to use emissions scenario development in its reports (e.g. (IPCC, 1994). Due to scenario development's flexible, holistic and adaptive nature in order to deal with the complexity of sustainability-related problems, scenario analysis can be quantitative as well as qualitative (Mahmoud et al., 2009; Swart et al., 2004). The following sections elaborate further on the types of scenarios, attributes, use of data, and scenario development.

### *Types of Scenarios and their Scope*

Swart et al. (2004) distinguish between quantitative and qualitative scenario analysis. Whereas, quantitative refers to modelling which uses "mathematical algorithms and relationships to represent key features human and environmental systems" (p. 140), qualitative might entail non-quantifiable factors or narratives such as behaviours, cultural values, or other changes (Swart et al., 2004). While Swart et al. (2004) continue in differentiating further between '*descriptive*' and '*normative*' scenarios, in Mahmoud et al. (2009) this is similar to the description of '*exploratory'* and '*anticipatory*' scenarios, respectively. Scenarios of exploratory nature are developed on the basis of knowledge of past patterns and trends (IPCC, 2001; Mahmoud et al., 2009). These can then be further divided into the categories *prospective* and *projective w*ith the former referring to anticipated change in the future which deviates from past trends, and the latter using the same past patterns to project the future (Mahmoud et al., 2009).

When scenarios are constructed with the objective of highlighting possible policy implications and the desired vision in mind, they are commonly referred to as *anticipatory* and *policy-responsive* scenarios (Godet & Roubelat, 1996; IPCC, 2001). Mahmoud et al. (2004) describe anticipatory scenarios as being based on visions of the future which are either desired or undesired and stress the high inherent degree of subjectivity. Policy-responsive scenarios are often developed with the policy's objectives in mind based on the identification of the perceived most urgent issues (Mahmoud et al., 2009). Consequently, this approach is often used at an organisational or political level in order to better understand, identify and manage risks and ensure the success of proposed policies (Schwartz, 1996). Furthermore, scenarios usually focus on a particular issue and are thus driven from a certain perspective. While the strength of scenarios lies in their interdisciplinarity, there are different scopes in which scenarios can be defined, for instance technological, environmental, socioeconomic or climate (Mahmoud et al., 2009).

It is important to stress, that it is possible and might also be enriching and necessary for scenario analysis to combine different types and scopes due to the interrelatedness of environmental issues, subsequently they do not have to be limited to only one category (Swart et al., 2004).

### ***Scenarios Attributes***

With the support of scenarios, potential changes in the short-, medium- or long-term future can be anticipated and appropriate decisions of dealing, preparing or adapting or mitigating possible effects can ideally take place in a timeous manner before the anticipated events may occur (Mahmoud et al., 2009). Moreover, one central attribute of scenario analysis is its capacity to conciliate scientists' and decision-makers' perspectives (Mahmoud et al., 2009; Swart et al., 2004) while highlighting vulnerabilities of systems (Schwartz, 2007). Furthermore, scenario analysis often tends to confront conventional beliefs and ideas and thus, provokes and stimulates the often overdue deviation from 'old beaten tracks' (Mahmoud et al., 2009). In contrast to forecasting techniques which aim to depict the most likely events in the future, scenarios have their strength in anticipating unlikely futures or as Mahmoud et al. (2009, p. 800) puts it: "they are rather meant to portray a set of alternative futures that could occur no matter how improbable the occurrence is". According to Mahmoud et al. (2009) conventional forecasting restricts itself in 'ignoring' possible events with very low to low likelihood such as so-called 'wild card' events meaning unlikely events with, however, high impacts in the case of occurrence. Consequently, this leaves conventional probabilistic scenarios ill-prepared in such instances (Mahmoud et al., 2009; Swart et al., 2004). Whereas the inclusion of less likely or out of norm information or events can strengthen preparedness if such happen to occur and leave decision-makers better equipped to deal with sudden changes (Mahmoud et al., 2009).

### ***Data Input & Scenario Development***

No matter the degree of likelihood, for scenarios to be considered credible, there has to be a plausible and consistent common ground in the development of scenarios based on logical reasoning and descriptions (Mahmoud et al., 2009; Swart et al., 2004). This means for instance using the same consistent data input for all scenarios on the same time scale. Furthermore, for comparability reasons a set of common variables in the development of scenarios must be maintained while only key variables change in order to fulfill the set-out objectives (Swart et al., 2004).

For the development of scenarios, Mahmoud et al. (2004) propose a 5-step '*formal scenario development framework*' specifically for use in sustainability science or environmental studies. These steps incorporate (1) scenario definition, (2) scenario construction, (3) scenario analysis, (4) scenario assessment and (5) risk management. All steps usually require the interaction of both researchers and stakeholders, whereas steps (2) and (3) are usually the sole task of the researcher and the risk management is the main responsibility of stakeholders (Mahmoud et al., 2009).

In the *scenario definition* phase, the relevant attributes are defined, as well as the time and spatial frame. Furthermore, the key drivers of the system and their nature are being identified (e.g. predetermined, restricted, or desired outcomes). Which variables of a system are relevant to include depends on the type of scenario and are highly individual to the specific topic itself (Mahmoud et al., 2009). In the *scenario construction* phase, it is all about finding the relevant quantitative or qualitative data, the establishment of the causal relations within the defined boundaries of the scenario, and the identification of uncertainties. This phase can be further divided into 3 sub-steps, the so-called *system conceptualisation*, *model selection* and *data collection and processing.* Through analytical tools or statistical tools the identified characteristics, relationships of different variables, and data inputs are organised in the *scenario analysis* phase (Mahmoud et al., 2009). Then, in the *scenario assessment* phase, risks, trade-offs or potential implications for the defined issue are evaluated by using e.g., cost-benefit analysis, contingency planning, or diagrams. Lastly, the results can then be used to inform decision-making in the so-called risk management phase of governments, businesses or organisations (Mahmoud et al., 2009).

### 3.2 Concept of 'Scrap bonus'

The concept of the scrap bonus is based on findings that the use of steel scrap during production conserves natural resources and avoids $CO_2$ emissions (Pothen et al., 2020). Besides being based on the 'avoided burden method' (Guinée, 2006), it is based on economic theory and determined by the quantification of *environmental costs* that are avoided when using a tonne of scrap steel in steel production. It assumes that by reducing externalities such as environmental impacts economic welfare losses are avoided, and therefore a price and related cost savings (in euro) can be assigned for these reduced burdens (Pothen et al., 2020; Wörtler et al., 2013). In line with the 'avoided burden method' it is assumed that one tonne of scrap steel avoids the corresponding amount of energy, iron ore and coke that would be required to produce one tonne of steel through the primary route (Pothen et al., 2020).

In order to determine the scrap bonus, environmental impacts that occur during steel production need to be translated into monetary values. This is done with the use of life cycle assessment which takes into account the different processes during steel production and its level of released GHG emissions

(Guinée, 2006) and other direct and indirect emissions and environmental externalities. Then, these are impacts are translated into monetary values.

The scrap bonus is calculated by differentiating and considering the so-called *social costs of carbon* and *social costs of local environmental burden*. As defined by Pearce (2003, p.363) social cost of carbon refers to "the monetary damage done by emitting one more tonne of carbon at some point of time". One important aspect in determining the social cost of carbon is dependent on the value of the 'pure rate of time preference' which discounts future welfare losses to a value in the present (Nordhaus, 2017; Pothen et al., 2020). It essentially attributes a value to the wellbeing of future generations against present generations wellbeing (J. Harris et al., 2001). Since exact consequences of climate change driven by $CO_2$ emissions are difficult to predict, the monetary value of social cost of carbon is based on assumptions (Pearce, 2003). Tol (2018) notes social costs tend to be higher than actual carbon prices that are traded in the EU ETS for instance. Therefore, Pothen et al. (2020) define a low, medium and upper scenario for the social cost of carbon with values of 30 euro, 70 euro and 110 euro. Since social cost of carbon only entails $CO_2$ emissions, Pothen et al. (2020) translate other environmental impacts such as local pollution in form of water contamination, and the release of dusts into monetary value. These are the *social costs of local environmental burden*, which they estimate as 29 euros per tonne of steel produced.

Subsequently, the scrap bonus can be calculated by multiplying the amount of avoided $CO_2$ emissions which they estimate at 1.67t per tonne of steel scrap used, by the social cost of carbon per tonne of $CO_2$ plus the social cost of local environmental burdens per tonne of scrap steel.

*Scrap bonus = avoided* $CO_2$ *emissions of 1.67t/tonne of scrap steel * social cost of carbon/t of* $CO_2$ *+ social cost of local environmental burden/t of scrap steel*

Henceforth, a scrap bonus of 79 euros for the lower scenario, 146 euros for the medium scenario and 213 euros for the upper scenario can be established (see Fig. 1) (Pothen et al., 2020). Furthermore, it is important to note that social factors such as work conditions in mines are not considered due to a lack of data (Pothen et al., 2020).

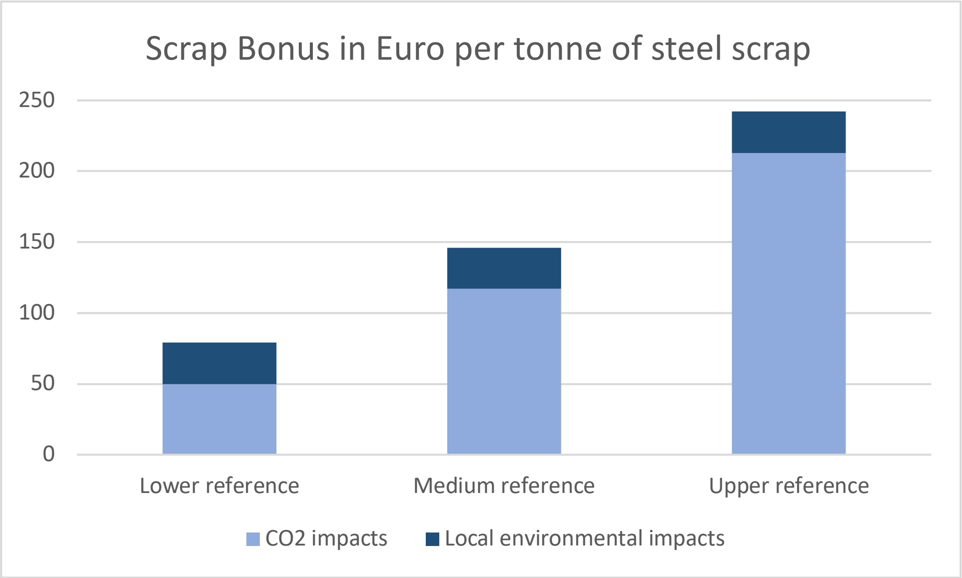

**Figure 1**. Scrap bonus in € per tonne of steel for the lower, medium and upper reference scenario

*Figure description.* This figure is from Pothen et al. (2013) and depicts scrap bonus according to the three reference scenarios. The cost allocation for each is shown regarding the costs for local environmental impacts and the costs for $CO_2$ that is emitted relating to steelmaking.
Source: Pothen et al. (2013), p.32

# 4 Methodology

## 4.1 Research Approach & Research Design

For this thesis, firstly, the EU waste shipment proposal is summarised. Secondly, based on the review of the EU waste proposal, relevant scenarios are created and quantitatively analysed according to the energy consumption, $CO_2$ emissions and environmental costs dimensions. Lastly, the implications for the steel sector based on the analysis are elaborated on. For the scenario development Mahmoud et al. (2004)'s *scenario development framework* was used.

### *4.1.1 Scenario Type, Scope and Definition*

Since this thesis attempts to identify possible implications of a proposed policy, the scenario type can be defined as *policy-responsive*. It is, however, of *exploratory* nature, (and not anticipatory as often referred to when constructing policy-related scenarios) since this research explores how far the proposed policy will impact the EU's steel industry based on both past trends and patterns and *prospective* future developments and trends (Mahmoud et al., 2009). Thus, not intending to build possible scenarios that are able to reach certain policy objectives that are anticipatory and highly

subjective, but to remain as scientific and objective as possible, carefully choosing data inputs and using scientifically-backed future trends. The geographic scale is focusing on every current EU-27 member state. The scope encompasses environmental, energy, emissions, and economic scenarios.
The time frame for this research focuses on 2020-2050. Since the coming decades are crucial years for the decarbonization of the steel industry and the year 2050 has been identified as a benchmark for reaching zero emissions by treaties such as the EU Green Deal or Paris Agreement (EC, 2019a; UN, 2015).

The baseline is the amount of scrap steel exports from the EU to other countries in the year 2020.
Due to the UK's leaving of the EU and subsequently, not having to comply with EU policies any longer, the UK's steel scrap exports are subtracted from the EU's total number of steel scrap exports in 2020 for validity reasons. The data was obtained through the latest World Steel Recycling in Figures Report (BIR, 2021).
Thus, the baseline (B) amount of total EU-27 exports in 2020 is:

*B (Total volume of EU-27 exports) = Total volume of EU-28 exports – Total volume of UK exports*

B *(Total volume of EU-27 exports)* = 22 627 000t – 5 661 000mt = $\underline{\underline{\text{16 966 000 t}}}$

**B (16 966 000 t)**

Since the new proposal's main objective and direct consequence is the reduction of EU waste (steel scrap) exports, three different future scenarios are constructed based on the aforementioned baseline (see also Table 1):

**Scenario 1: Business-as-usual – no changes: maintenance of status quo [Baseline]**
**Scenario 2: 20% of [baseline] exports remain in the EU**
**Scenario 3: 50% of [baseline] exports remain in the EU**

The percentages 20% and 50% (and 0% for the baseline scenario) of exports retained were chosen based on wanting to have a business as usual, moderate and a high scenario with the aim of covering a wide spectrum.
After the data required for the construction of the different scenarios and for each scope was collected, the different scenarios within their dimensions were established.

### *4.1.2 Data Collection*

Quantitative key numbers such as volume of exports and imports, produced steel and processed steel scrap were obtained through accredited official documents such as the current *World Steel Recycling in Figures* (BIR, 2021) and the *European Steel in Figures* (Eurofer, 2021b) report. Data on $CO_2$ emissions during EAF steel production was taken from the Frauenhofer Institute report (Pothen et al., 2020). The data for energy consumption was taken as an average from a study by Logar & Škrjanc (2021) and from the Boston Consulting report on low-carbon steelmaking (Wörtler et al., 2013).

The construction of the assumptions and scenarios was based on the various qualitative information that was obtained during the research process and the sources for this data are mentioned in this thesis at the point when they are referred to.

### *4.1.3 Selection of Models & Construction of Scenarios*

The main areas of interest were identified in terms of their significance concerning sustainability and in line with the thesis's objectives. These dimensions are energy, GHG emissions and economic factors. For each dimension models are created. In order to construct these models, key numbers such as the amount of EU steel produced via the EAF route needed to be established. Even though the UK does export a considerable amount of steel scrap, its steel production, in general, contributed 5.1% to the EU crude steel output in 2020 (Eurofer, 2021b), of which only 21.1% was EAF scrap based (Oxford Energy Society, 2021). Furthermore, 2.6 Mt of total UK steel scrap were used in UK based steelmaking in 2020 (Hall et al., 2021). For consistency reasons, this was considered and adjusted for throughout all calculations.

Next to the aforementioned definition of the baseline value, the volumes of processed steel scrap in the EU in the year 2020 are defined. The required data was obtained through EUROFER's (2021) current 'Steel in Figures' report. Then, it was adjusted for the UK share in processed scrap steel in the UK in 2020.

*Total volume of processed steel scrap in the EU-27 in 2020 in t =*
*Total volume of steel scrap processed in the EU-28 in t – Total volume of steel scrap processed by the UK in 2020*

As mentioned in the theory section, due to the uncertainty inherent in the creation of scenarios and the limitations in terms of data input, scenarios are often simplified and based on assumptions

(Mahmoud et al., 2009). Some assumptions that have been identified for the construction of the scenarios presented are the following:

- Scrap availability is predicted to increase in the coming decades (Wörtler et al., 2013).
- Due to a lack of data and feasibility, it was assumed that the total volume of retained EU steel scrap exports is processed in EAFs.
- Only steel scrap is used in EAFs (Even though the main EAF input material is steel scrap, some steel mills add ore or other raw materials in reality, thus causing higher emissions (IEA, 2020b; Wörtler et al., 2013)).
- Energy efficiency improvements are not accounted for.
- For simplicity reasons, it is assumed that the only input product is carbon steel scrap.

### *Energy Demand Modelling*

I. *To what extent does the new proposal impact* ***energy consumption*** *of the EU secondary steel industry for each scenario?*

In order to establish the amount of energy that is required for the retained exports which then are being processed in the EU instead, the amount of 'additional' steel scrap that remains in the EU for each scenario needs to be calculated in the following:

Scenario 1 [Baseline scenario]: total volume of EU-27 exports in t - no changes
Scenario 2: total volume of EU-27 exports in t * 20% = volume of exports remaining in the EU in t
Scenario 3: total volume of EU-27 exports in t * 50% = volume of exports remaining in the EU in t

Then, the average number of electrical energy per tonne of steel produced in EAFs needs to be defined. Various studies point toward the use of 400 to 500kWh of electrical energy per tonne of steel (Logar & Škrjanc, 2021; Wörtler et al., 2013). For these reasons, the value of 450kWh was chosen. However, since one tonne of steel scrap (input) does not equal one tonne of steel produced (output) and a percentage of processed steel scrap is also used in the BF/BOF route, the volumes of EU steel scrap were adjusted. This was done by determining the percentage of the difference between scrap steel input (BIR, 2021) and EAF steel produced output (Eurofer, 2021b). Due to lack of data, the fact that a small percentage of steel scrap processed is also used in BF/BOF was neglected and not considered.

This then provides the theoretical average 'loss' of steel scrap between input and actual volumes of steel output through EAF. This percentage can be determined as 20%.

Thus, the following function was used to determine the change in electrical energy used for each scenario. Since scenario 1 is the baseline scenario, consequently, there is no change in volume due to retained exports. Therefore, only scenarios 2 and 3 are affected:

$450kWh * (\text{volume of share of exports in t} - \text{volume of share of exports in t} * 0.2)_{\text{scenario } 2,3} = \text{Electrical energy required to melt surplus in steel scrap in } kWh_{\text{scenario } 2,3}$

This then gives the amount of surplus energy compared to the baseline scenario that is required to process the additional quantities of steel scrap. Since in the EU the main and sole energy source of EAF in which steel scrap is melted is electrical (Wörtler et al., 2013), in this particular instance the calculations of energy demand refer to the electrical energy that is required.

The total energy demand for the total volume of steel scrap processed according to each scenario in the EU can be calculated as follows:

$450kWh * (\text{volume of total processed steel scrap in t} - \text{volume of total processed steel scrap in t} * 0.2)_{\text{scenario } 1,2,3} = kWh \text{ required to melt volume x of steel}_{\text{scenario } 1,\, 2,3}$

### *Emissions Modelling*

II. *In how far does the waste proposal impact **$CO_2$ emissions levels** that occur during secondary steel production for each scenario?*

The $CO_2$ emissions level of EAF steel during production is derived from looking at production volumes and multiplying these by indirect and direct $CO_2$ emissions for the EAF route, which mainly uses electrical energy as an energy carrier (Arens et al., 2017; Wörtler et al., 2013). The focus is put on $CO_2$ emissions since these are the majority of emissions emitted during production and also are widely measured on an industry plant level. Furthermore, $CO_2$ emissions are at the centre of the EU ETS which influences the steel industry and is one of the main drivers of incentivising the steel industry of using fewer polluting practices (EC, 2021a) and reaching net-zero by 2050 (EC, 2020; Pothen et al., 2020; UN, 2015; Wörtler et al., 2013). While the BOF steelmaking route $CO_2$ emissions yield on average of 2.11 t $CO_2$ per tonne of steel, the EAF route produces significantly fewer emissions. According to Pothen et al. (2020) and in line with EC (EC, 2021a) estimates average $CO_2$ emissions for the secondary route are on average about 0.63 t per tonne of steel in the EU.

Therefore, the following function can determine the $CO_2$ emissions for each scenario:

*Total $CO_2$ emissions of volume of share in t $_{scenario\ 2,3}$ = 0.63t $CO_2$/t of steel * (volume of share of exports in t - volume of share of exports in t * 0.2)* $_{scenario\ 2,3}$

*Total $CO_2$ emissions of total volume of steel* $_{Scenario\ 1,\ 2,3}$ *= 0.63 t* $CO_2$ */t of steel * (volume of total processed steel scrap in t - volume of total processed steel scrap in t * 0.2)* $_{Scenario\ 1,\ 2,3}$

### *CO₂ Emissions and Related Environmental Cost Savings*

III. To what extent exist potential **$CO_2$ emissions** and **environmental cost savings** for the EU steel industry for each scenario?

The potential $CO_2$ emissions savings are determined based on Pothen et al. (2020) findings that by using one tonne of scrap steel, 1.67 tonnes of $CO_2$ emissions are avoided. Therefore, the following functions can be used to establish the amount of $CO_2$ savings for the volume of the share of retained EU exports for each scenario and the total amount of potential $CO_2$ savings per tonne of scrap steel used for each scenario:

*Total $CO_2$ emissions savings of volume of share in* $_{scenario\ 2,3}$ *in t = 1.67t $CO_2$ avoided * volume of share in t* $_{scenario\ 2,3}$
*Total $CO_2$ emissions savings of total volume of processed scrap steel* $_{scenario1,\ 2,3}$ *in t = 1.67t $CO_2$ avoided * total volume of processed scrap steel in t* $_{scenario\ 1,2,3}$

In order to identify the environmental cost savings, the thesis makes use of the 'scrap bonus' as elaborated in the theory section. Since the scrap bonus depends on assumptions, there exist a high degree of uncertainty, in particular the calculation of the social cost of carbon. I decided to choose the Pothen et al.'s (2020) "medium reference scenario" as an average value of social cost of carbon for this thesis. This entails a social cost of carbon of 70 euros. Thus, the scrap bonus of one tonne of scrap steel was calculated by the following (based on Pothen et al., 2020):

*Scrap bonus$_{medium}$/ t of steel scrap in € = avoided $CO_2$ emissions of 1.67t/tonne of steel scrap * social cost of carbon/t of $CO_2$ + social cost of local environmental burden/t of steel scrap*
Scrap bonus$_{medium}$ /t of scrap steel in € = 1.67t $CO_2$/t of processed steel scrap * 70 € + 29 € = 145,9 € ≈ $\underline{146\ €}$

Then, the total potential environmental cost savings for the share of retained exports can be determined as follows:

*Total Scrap Bonus of volume of share in t in €* $_{\text{Scenario 2,3}}$ *= Scrap bonus*$_{\text{medium}}$ */t of processed steel scrap * volume of share in t*$_{\text{Scenario 2,3}}$

Lastly, the total scrap bonus for the total volume of processed steel scrap for each scenario is defined as:

*Total Scrap Bonus of total volume of processed steel scrap in €* $_{\text{Scenario 1,2,3}}$ *= Scrap bonus*$_{\text{medium}}$ */t of processed steel scrap * total volume of processed scrap steel scrap in t* $_{\text{scenario 1,2,3}}$

### 4.2 Methodological Challenges & Limitations

Since scenario analysis and modelling as well as the scrap bonus calculations are based on predictions, the results might not entirely reflect reality. There exists an inherent degree of uncertainty and unpredictability involved due to events or factors that have not been accounted for (Mahmoud et al., 2009; Pothen et al., 2020). Moreover, there is always a degree of oversimplification because it would be infeasible to account for all related aspects due for instance a lack of available data. However, this simplification also allows for transparent and consistent analysis and thus, can inform decision making. Moreover, ideally, the construction of the different scenarios could have been informed by further qualitative information (Mahmoud et al., 2009) obtained through interviews with key actors such as policymakers, steel companies, or steel organisations.

## 5 Results and Discussion

The amount of EAF steel produced in the EU-27 in 2020 was calculated as elaborated in the methods section:

*Total volume of processed steel scrap in the EU-27 in 2020 in t=*
*Total volume of processed steel scrap in the EU-28 in 2020 in t – Total volume of steel scrap processed by the UK in 2020 in t*
Total volume of processed steel scrap in the EU-27 in 2020 in t=
77 539 000 t – 2 600 000 t = **74 939 000 t = 74.939 Mt**

Compared to the baseline, scenario 1 will see a 4.53% and scenario 3 a 11.32% increase in the amount of steel scrap that remains in the EU-27. In 2020, the level of steel scrap processed in the EU amounted to 74.939 million tonnes of steel. 20% of exports remaining in the EU increases the amount of EU-27 processed steel scrap to 78.332 million tonnes. For scenario 3 with 50% of steel scrap remaining in the EU equals to 83.422 million tonnes (figure 2.) Furthermore, the surplus volume of steel scrap that would remain in the EU in addition to the baseline scenario in 2020 is pictured.

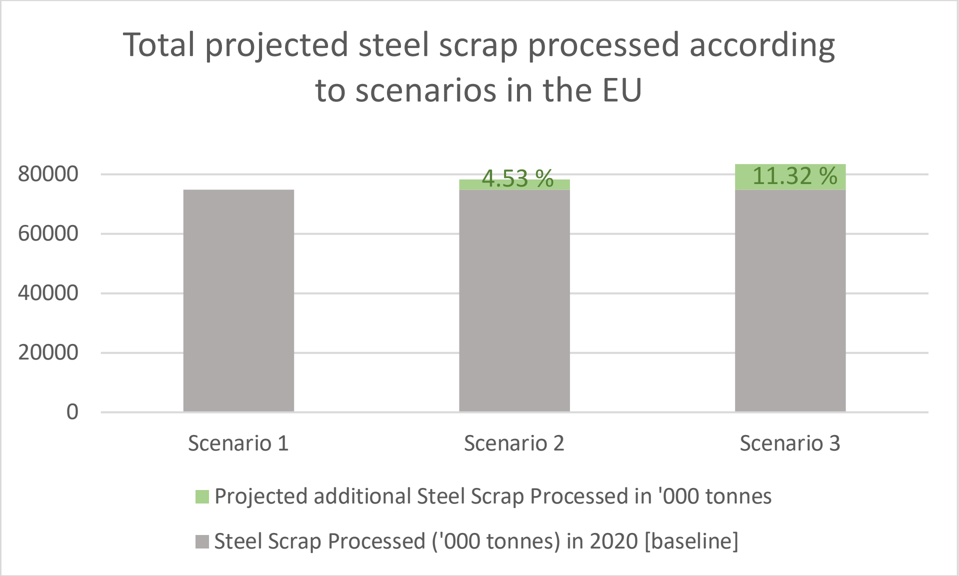

**Figure 2.** Total projected volume steel scrap processed in the EU according to the three scenarios. *Figure description.* This figure shows the total volume of steel scrap processed within the EU according to the three scenarios. Moreover, the projected increase in steel scrap due to the retained exports is pictured.
Source: Own calculations

**Table 1.** Overview scenarios and relevant data.

| | **Share of [baseline] exports that remain in the EU** | **Volume of share of steel scrap exports in t** | **Total volume of processed steel scrap within the EU in t** |
|---|---|---|---|
| Scenario 1 – maintenance of *status quo [baseline]* | 0% | 0 | 74 939 000 |
| Scenario 2 - *moderate* | 20% | 3 393 000 | 78 332 000 |
| Scenario 3 - *high* | 50% | 8 483 000 | 83 422 000 |

## 5.1 Energy Demand Modelling

I. *To what extent does the new proposal impact* ***energy consumption*** *of the EU secondary steel industry for each scenario?*

For the calculation of the electrical energy that is required to process the additional volume of steel scrap, the volume of steel scrap exports that remain in the EU instead (export retention) for each scenario were calculated as follows:

Scenario 2: total volume of EU-27 exports t * 20% = Volume of share of exports in t
16 966 000 t * 0.20 = **<u>3 393 000 t</u>**

Scenario 3: total volume of EU-27 exports t * 50% = Volume of share of exports in t
16 966 000 t * 0.50 = **<u>8 483 000 t</u>**

Then, the additional increase in electrical energy required for each scenario was identified as follows based on average energy consumption of 450kWh per tonne of steel produced based on findings of Logar & Škrjanc (2021). As described in the method section the average 'loss' of steel scrap meaning the difference in volume t between steel scrap input and output was accounted for in order to determine the volume of steel produced. This percentage can be determined as 20%.

*450kWh * (volume of share of exports in t - volume of share of exports in t * 0.2) = Electrical energy required to melt surplus in steel scrap*

Scenario 1 (baseline): no change in electrical energy

Scenario 2: 450kWh x (3 393 000t – 3 393 000t * 0.2) = **1 221 480 mWh = <u>1.22 TWh</u>**

Scenario 3: 450kWh x (8 483 000t – 8 483 000t * 0.2) = **3 053 880 mWh = <u>3.05 TWh</u>**

The below figure (see figure 3) depicts the amount of surplus electrical energy that is required in order to process the additional volume of steel scrap that is not exported but remains in the EU.
For scenario 2, 1.22 TWh would be required to deal with the additional quantity of steel scrap. For scenario 3, this amounts to 3.05 TWh. It is important to note, that this is based on the average energy consumption of 450kWh per tonne of steel, however, the actual energy consumption is dependent on a wide variety of factors such as steel scrap quality or energy-efficiency of EAFs which can vary between 300-700 kWh per tonne of scrap (Wörtler et al., 2013).

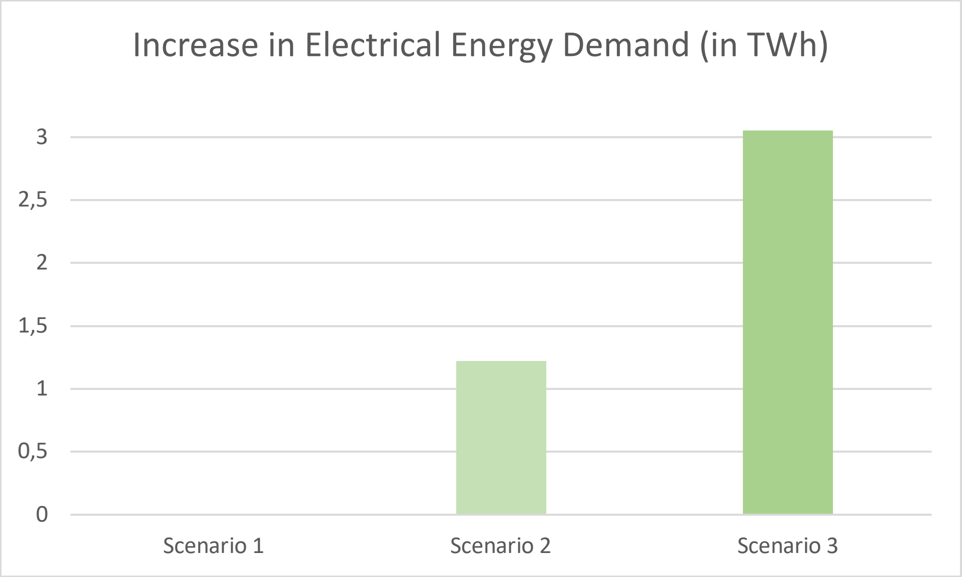

**Figure 3**. Increase in total electrical energy demand in TWh

*Figure description.* This figure shows the electrical energy increase in TWh that is required to deal with the additional quantity of steel scrap for each scenario. For scenario 1, this is zero due to it being the baseline scenario and thus there are no changes in electrical energy demand due to no additional volume of scrap. Scenario 2 would require 1.22TWh of electrical energy. For scenario 3 the energy demand amounts to 3.05 TWh.
Source: Own calculations

Following this logic and with the consistent use of the data input, the overall electrical energy demand for the entire secondary steel sector can be calculated as follows:

*450kWh * (volume of total processed steel scrap in t - volume of total processed steel scrap in t * 0,2* $_{scenario\ 1,2,3}$ *= kWh required to melt volume x of steel)* $_{scenario\ 1,\ 2,3}$

Scenario 1 (baseline):450kWh * 59 951 200 t = **26 978 000 mWh = 26.978 TWh**

Scenario 2: 450kWh * 62 665 600 t = **28 199 250 mWh** = **28.199 TWh**

Scenario 3: 450 kWh * 66 737 600 t = **30 031 650 mWh = 30.032 TWh**

A 4.53% (scenario 2) increase of additional steel scrap that is being processed within the EU compared to the scrap processed in 2020 (see figure 4.), would lead to an overall electricity consumption of 28.12 TWh for the secondary steel industry. Likewise, a 11.32% (scenario 3) would require a total consumption of 30.03 TWh. For comparability reasons, the electrical energy consumption of scenario 3 is more than 3.5 times the electricity consumption of the entire country of Luxemburg and nearly the entire electricity consumption of Denmark (IEA, 2020a), and that is solely for the secondary steel production via EAF's, not considering primary production.

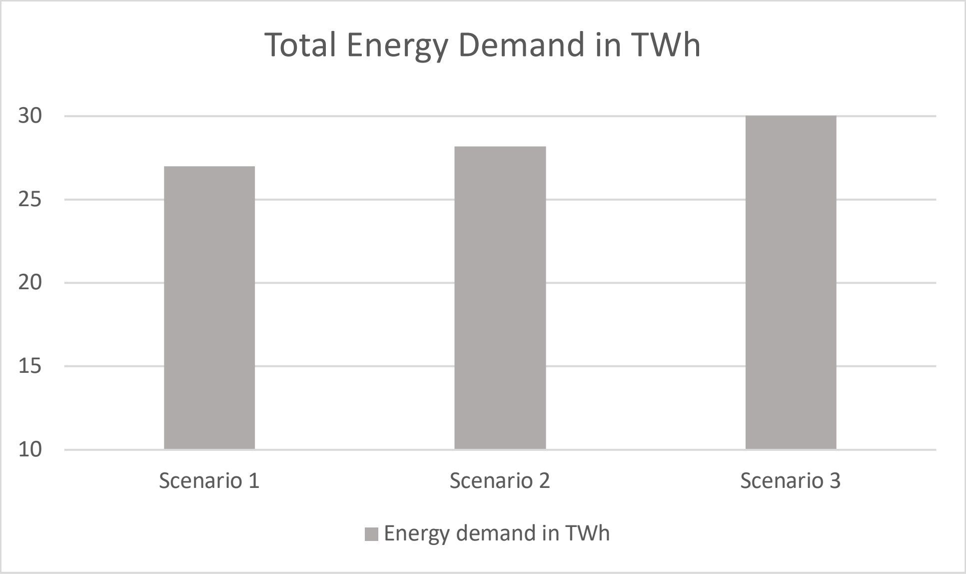

**Figure 4**. Total energy demand of the total volume of steel scrap in TWh

*Figure description.* Total energy demand of the total volume of EU steel scrap in TWh for each scenario can be seen. For scenario 1, total energy demand is 26.98TWh. For scenario 2 and 3 it amounts to 28.2 TWh and 30.03 TWh, respectively.
Source: Own calculations

These numbers reflect the general high energy intensiveness of heavy industries and the steel industry. Assuming that at least in the short-term the volumes produced via both routes remain stable or might even increase. This, however, is likely given the inevitability of steel for our society as elaborated on in the beginning, general predictions that global steel demand will further increase (IEA, 2020b; Worldsteel Association, 2021), the quality issue concerning copper-contamination of scrap steel (Wörtler et al., 2013) and the trend of increased EAF steel production (Vogl & Åhman, 2019). Therefore, **the EU waste shipment proposal will lead to a significant increase in electrical energy demand on an industrial level** within the EU. Considering current global world events, which put a strain on the energy market and given the energy price sensitivity of steel producers, **these results indicate the importance and need for further development of green electricity generation on an EU and national level**. In 2019, the share of renewable energy was at 15.5% within the EU (EC, n.d.). However, in order for the energy required for the secondary steel production to become ‘green’, this share needs to increase significantly, especially in the light of increased demand for energy of EAF-produced steel in the coming decades (Eurofer, 2019) and proposed policy revision.

It is to be remarked that the objectives of the EU waste proposal can only be successful if EU steel producers manage to stay competitive and in business. Moreover, the survival of the EU steel industry is also desirable from an environmental perspective due to the comparably lower level of pollution than the global average (Eurofer, 2019). While steel producers need to act and implement changes in terms of energy efficiency and introduction of new technologies, from an economic perspective the degree of uncertainty of volatile energy prices and global instability, likely do not give steel companies a lot of margins in implementing changes toward low-carbon due to investments in the steel industry being highly resource-intense and long-term (OECD, 2006). Thus, given this global instability, volatility of energy markets and high competitiveness of the global steel market, and urgent need for decarbonisation, **there exist the need for policy makers to consider ways in which the EU steel industry can be supported in order to achieve a low-carbon transformation until 2050**. The EU Green Deal and "Fit for 55" package already propose new measurements for instance the phasing out of free allowances until 2050 and the carbon border adjustment mechanism (CBAM) preventing carbon leakage and thus protecting the EU steel industry (EC, 2019a; European Council, 2022). If these proposed measurements will be successful remains to be seen and its assessment lies outside of the scope of this thesis but could be of great interest for further research.

These findings reflect the general trend toward a significant increase in industrial energy consumption until 2050 driven by the increase in EAF production and policies such as the EU waste shipment proposal, and the EU Green Deal. According to Eurofer (2019) energy of an additional 400TWh of $CO_2$-free electricity is going to be required in 2050 and stresses that this is seven-fold the current level of electricity use. Therefore, the importance of the development of green electrical energy infrastructure for the industrial sector within the EU cannot be overstated if the EU wants to achieve its goal of achieving net-zero emissions by 2050. Studies indicate without the decarbonisation of the steel sector, this cannot be achieved, underlining the importance of this endeavour for the EU (e.g. Eurofer, 2019; Vögele et al., 2020).

The following elaborates further on the findings for the $CO_2$ emissions that are closely related with energy consumption and its implications for the steel industry.

## 5.2 $CO_2$ Emissions Modelling

II. *In how far does the waste proposal impact **$CO_2$ emissions levels** that occur during secondary steel production for each scenario?*

For each scenario the $CO_2$ emissions for the volume of share were determined as follows:

$$\text{Total } CO_2 \text{ emissions of volume of share in } t_{\text{scenario } 2,3} = 0.63t\ CO_2/t \text{ of steel} * (\text{volume of share of exports in } t - \text{volume of share of exports in } t * 0.2)_{\text{scenario } 2,3}$$

Total $CO_2$ emissions of volume of share in $_{\text{scenario 2}}$ in t= 0.63t $CO_2$/t of steel * 2 717 400t = 1 711 962 t = **1.71 Mt $CO_2$**

Total $CO_2$ emissions of volume of share in $_{\text{scenario 3}}$ in t= 0.63t $CO_2$/t of steel * 6 786 400t = 4 275 432 t = **4.28 Mt $CO_2$**

Then, the total $CO_2$ emissions for the total volume of steel for each scenario are identified:

*Total $CO_2$ emissions of total volume of steel $_{\text{Scenario 1, 2,3}}$ = 0.63 t* $CO_2$ */t of steel * (volume of total processed steel scrap in t - volume of total processed steel scrap in t * 0.2)$_{\text{Scenario 1, 2,3}}$*

[baseline] *Total $CO_2$ emissions of total volume of steel $_{\text{Scenario 1}}$ = 0.63 t $CO_2$ /t of steel * volume of steel in t$_{\text{Scenario 1}}$*

0.63 t $CO_2$ /t of steel * 59 951 200 t

= **37 769 256t $CO_2$** = **37.77 Mt $CO_2$**

*Total $CO_2$ emissions of total volume of steel $_{\text{Scenario 2}}$ = 0.63 t $CO_2$ /t of steel * volume of steel in t$_{\text{Scenario 2}}$*

0.63 t $CO_2$ /t of steel * 62 665 600 t

= **39 479 328t $CO_2$ = 39.48 Mt $CO_2$**

*Total $CO_2$ emissions of total volume of steel $_{\text{Sceanrio 3}}$ = 0.63 t $CO_2$ /t of steel * volume of steel in t$_{\text{Scenario 3}}$*

0.63 t $CO_2$ /t of steel * 66 737 600

= **42 044 688t $CO_2$** = **42.04 Mt $CO_2$**

For the additional volume of scrap that remains in the EU, the total $CO_2$ emissions were found to be 1.71 Mt $CO_2$ (scenario 2) and for the higher export retention scenario 3, the total $CO_2$ emissions are 4.28 Mt $CO_2$ (see figure 5). To put this in relation, assuming that other steel production levels remain unchanged, scenario 3 would mean that retaining 50% of exports would lead to an increase of more than the total industrial $CO_2$ emissions that occurred in Portugal in 2019 (IEA, n.d.).

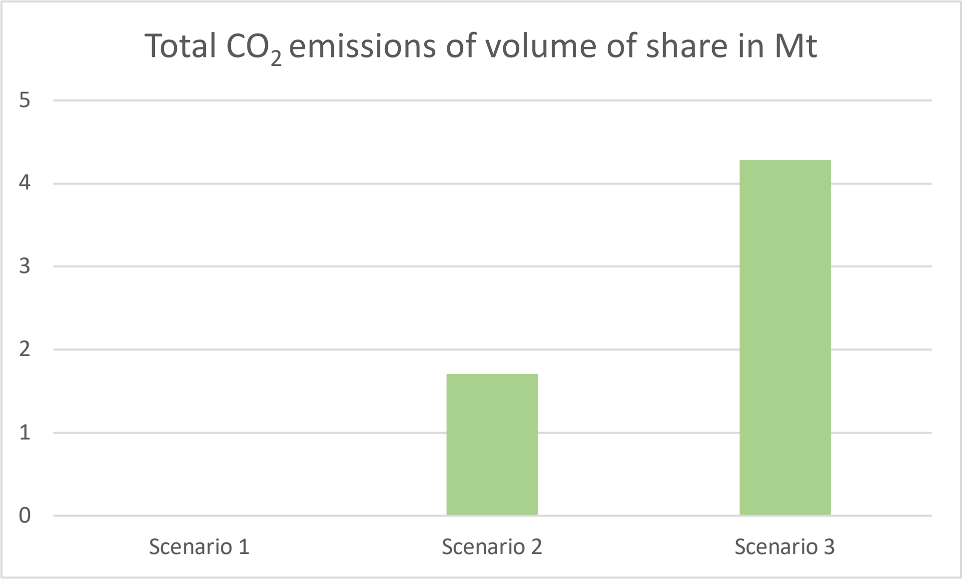

**Figure 5**. Total $CO_2$ emissions of the volume of share in Mt.

*Figure description.* Total $CO_2$ emissions of the volume of share of EU steel scrap exports in Mt are shown for each scenario. 1.71 Mt $CO_2$ emissions are caused by the volume of 2.72 Mt of additional steel for scenario 2. For scenario 3, 6.79 Mt of additional steel cause 4.28Mt $CO_2$ emissions.
Source: Own calculations

The results for the total $CO_2$ emissions that occur during production were found to be 36.46 Mt $CO_2$ for the baseline scenario 1. For scenarios 2 and 3, the emissions were 38.6 Mt $CO_2$ and 41.81 Mt $CO_2$ for the total volume of steel processed (see figure 6). Given that the entire EU steel industry annually produces approximately 221 Mt $CO_2$ in indirect and direct emissions (EC, 2021a), and considering that the secondary route accounts for approximately 20% of these emissions (Eurofer, 2019; IEA, 2020b; Vogl, Åhman, et al., 2021), the results can be identified as being credible. Slight deviations can be explained by variations in input data of $CO_2$ emissions and assumed average energy consumption per tonne of steel. However, based on the purpose of the theory of scenario analysis, these results aim to provide indications of potential challenges, risks and trends that the steel industry might face related to the proposed policy and its transition towards net-zero emissions.

Assumed that primary production levels remain unchanged, increased $CO_2$ emissions that would occur driven by the EU waste policy revision, are not only negative for the environment but also for the EU carbon budget, stressing the importance of further technological developments and effective policies in place that guide this crucial transition.

Since these numbers are based on the assumption that the level of primary route produced steel remains unchanged by an increase in EU processed steel scrap, it does not reflect the possible reduction of $CO_2$ emissions through its replacement of BF/BOF produced steel. Still, these results might be of relevance for decision-makers. However, research indicates that the use of one tonne of scrap can save the corresponding volume of $CO_2$ emissions and environmental impacts that would occur in the BF/BOF route (Pothen et al., 2020). Subsequently, the next section intends to highlight possible savings that might be achieved through an increased input of scrap steel and circularity within the EU.

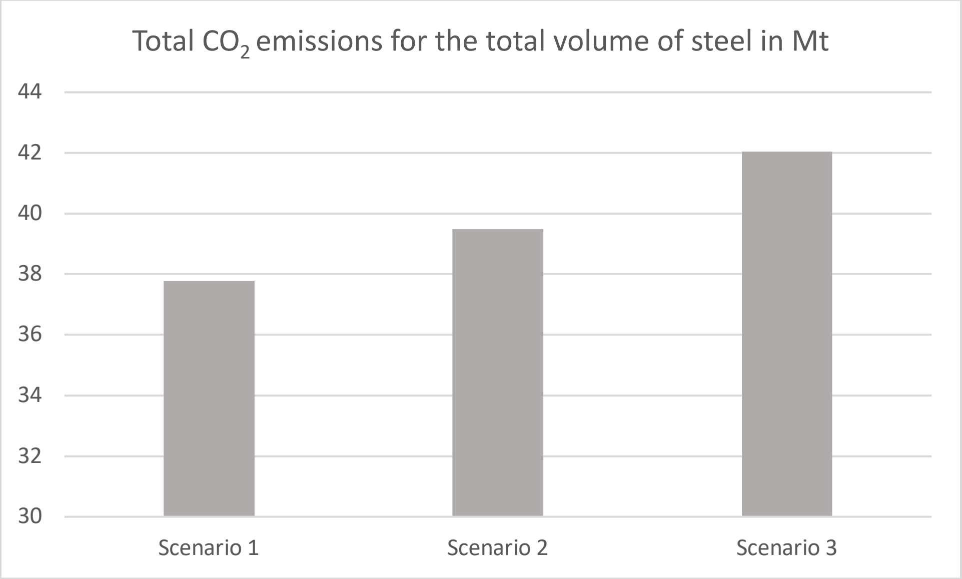

**Figure 6.** Total $CO_2$ emissions for the total volume of steel in Mt.

*Figure description.* Total $CO_2$ emissions of the total volume of steel in Mt are shown. The baseline scenario 1 generates 3.77 Mt $CO_2$ emissions, scenario 2 causes 39.48 Mt $CO_2$ emissions, and scenario 3 leads to 41.81 Mt $CO_2$ emissions.
Source: Own calculations

## 5.3 $CO_2$ Emissions and Related Environmental Cost Savings

III. To what extent exist potential **$CO_2$ emissions** and **cost savings** for the EU steel industry for each scenario?

***$CO_2$ Emissions Savings***

Following the reason in the methodology, the $CO_2$ emissions savings for the volume of the share of retained exports and the total volume of processed steel scrap are as follows:

Total $CO_2$ emissions savings of volume of share in $_{\text{scenario 2}}$ in t = 1.67t $CO_2$ * 3 393 000 t = **5 666 310 t $CO_2$** = **5.67 Mt $CO_2$**

Total $CO_2$ emissions savings of volume of share in $_{\text{scenario 3}}$ in t = 1.67t $CO_2$ * 8 483 000 t = **14 166 610 t $CO_2$ = 14.17 Mt $CO_2$**

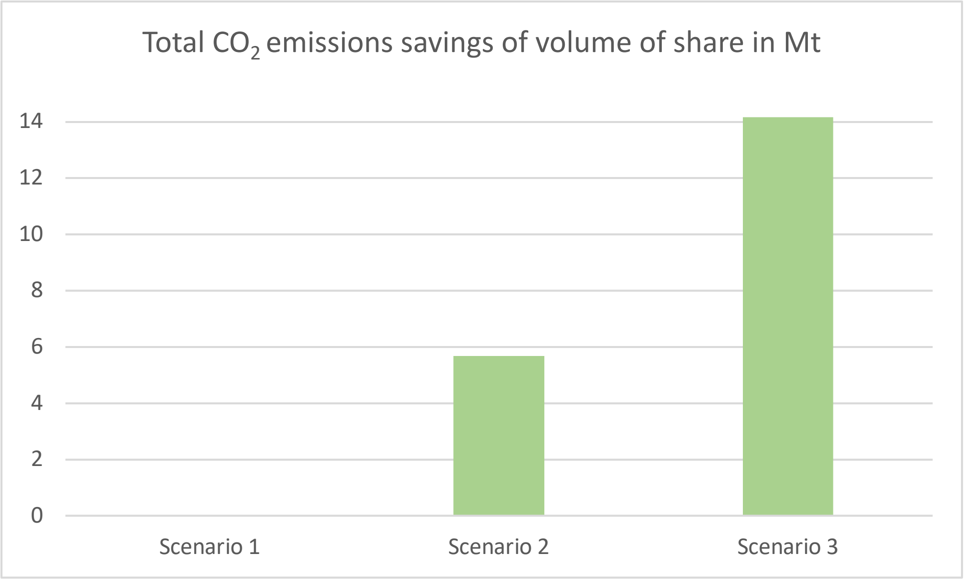

**Figure 7.** Total $CO_2$ emissions savings of the volume of share in Mt for each scenario.
*Figure description.* Total $CO_2$ emissions of the total volume of steel in Mt are shown. The baseline scenario 1 generates 3.77 Mt $CO_2$ emissions, scenario 2 causes 39.48 Mt $CO_2$ emissions, and scenario 3 leads to 41.81 Mt $CO_2$ emissions.
Source: Own calculations

Total $CO_2$ emissions savings of total volume of processed scrap steel $_{\text{scenario 1}}$ = 1.67t $CO_2$ * 74 939 000 t = **125 148 130 t $CO_2$ = <u>125.15 Mt $CO_2$</u>**

Total $CO_2$ emissions savings of total volume of processed scrap steel $_{\text{scenario 2}}$ = 1.67t $CO_2$ * 78 332 000 t = **130 814 440 t $CO_2$ = <u>130.81 Mt $CO_2$</u>**

Total $CO_2$ emissions savings of total volume of processed scrap steel $_{\text{scenario 3}}$ = 1.67t $CO_2$ * 83 422 000 t = **139 314 740 t $CO_2$ = <u>139.31 Mt $CO_2$</u>**

The total $CO_2$ emissions savings for the total volume of processed steel scrap for each scenario 1, 2 and 3 are accounting for 125.15 Mt $CO_2$, 130.81 Mt $CO_2$, 139.31 Mt $CO_2$, respectively (see fig. 8). Thus, retaining 50% of exports plus the baseline volume (scenario 3) might lead to $CO_2$ savings of total 139.31 Mt $CO_2$ which would be more than half of all emissions of the entire steel industry in 2020 (221 Mt $CO_2$).

However, in order to establish possible direct consequences from the EU waste proposal, the emissions savings from the additional share that is being processed within the EU itself is significant. For the 20% steel scrap export retention scenario, 3.4 million tonnes of scrap would save in total 5.67 Mt $CO_2$ emissions that would otherwise occur during more resource intense steel production via other routes. For the 50% scenario, potential $CO_2$ emissions savings even amount to 14.17 Mt $CO_2$ (see figure 7). Unsurprisingly, by applying the 'Scrap bonus' concept (Pothen et al., 2020), the more scrap steel is used, the greater the total emissions savings. Thus, these findings indicate the **great potential of**

**increasing scrap steel in steel production from an environmental perspective**. However, what are the potential limitations to the use of scrap in steel production, and thus, where lies the limit of reducing $CO_2$ emissions with the use of steel scrap? One main issue is the maintenance of steel quality which varies depending on the desired end-product (Eurofer, 2019). Furthermore, with every round of recycling there exists a greater share of copper (Wörtler et al., 2013). Quality issues can be reduced by adding direct reduced iron (DRI) or pig iron to scrap steel, but this, consequently, leads to greater $CO_2$ emissions than by just using scrap steel (Arens et al., 2017). Another issue might be scrap availability, while some predictions predict an increase in the supply of steel scrap of up to 136 Mt in 2050 (Wörtler et al., 2013), others indicate a shortage (e.g Oda et al., 2013). Furthermore, these findings do not consider stainless steel which requires alloying elements such as chromium, cobalt or nickel and thus have a higher environmental impact. Moreover, for simplicity reasons, it is not accounted for the small percentage of EU steel scrap used in the BF/BOF route which is more resource-intense and polluting. Consequently, the actual $CO_2$ emissions are likely to be higher.

Either way, **these findings show the EU waste shipment proposal will affect scrap availability positively within the EU. Thus, contributing to ensure possible $CO_2$ emissions savings through the increased use of scrap instead of ore and coke in the long-term** and in line with the EU Green Deal and its circularity objective.

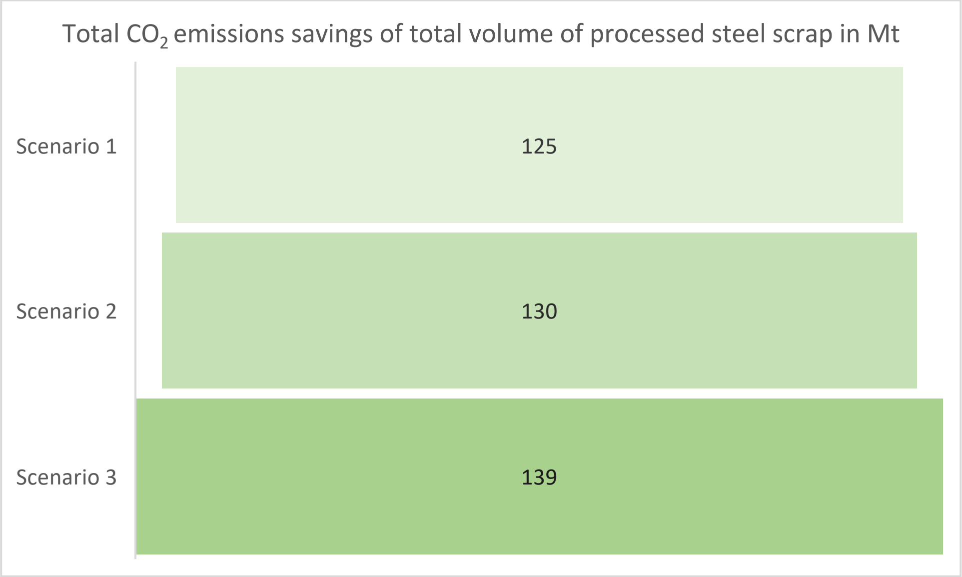

**Figure 8.** Total $CO_2$ emissions savings of the total volume of processed steel scrap in Mt.
*Figure description.* The total $CO_2$ emissions savings of total volume of steel scrap according to the different scenarios are shown. Potentially, 125.15 Mt $CO_2$ emissions are saved by using 75 Mt of steel scrap. For scenario 2 and 3 this amounts to 130.18 Mt $CO_2$ emissions and 139.31 Mt $CO_2$ emissions. The findings indicate the more scrap is used, the higher are the environmental benefits in form of $CO_2$ savings.
Source: Own calculations

***Environmental Cost Savings***

As explained in the methods section, the environmental or 'scrap bonus' for each scenario is the following:

Total Scrap Bonus of volume of share in € $_{\text{Scenario 2}}$ = 146€/t of processed scrap steel * 3 393 000 t = 495 378 000 € = **0.495 billion €**

Total Scrap Bonus of volume of share in € $_{\text{Scenario 3}}$ = 146€/t of processed scrap steel * 8 483 000 t = 1 238 518 000 € = **1.239 billion €**

These results show the scrap bonus for the additional volume of scrap steel amounts to 0.5 billion € in the 20% export retention scenario and for 1.24 billion € in scenario 3. Therefore, additional scrap that is being processed within the EU instead of being exported can potentially save 0.5 billion € (scenario 2) or in the more ambitious scenario 3, even 1.24 billion € in environmental cost savings (see figure 9).

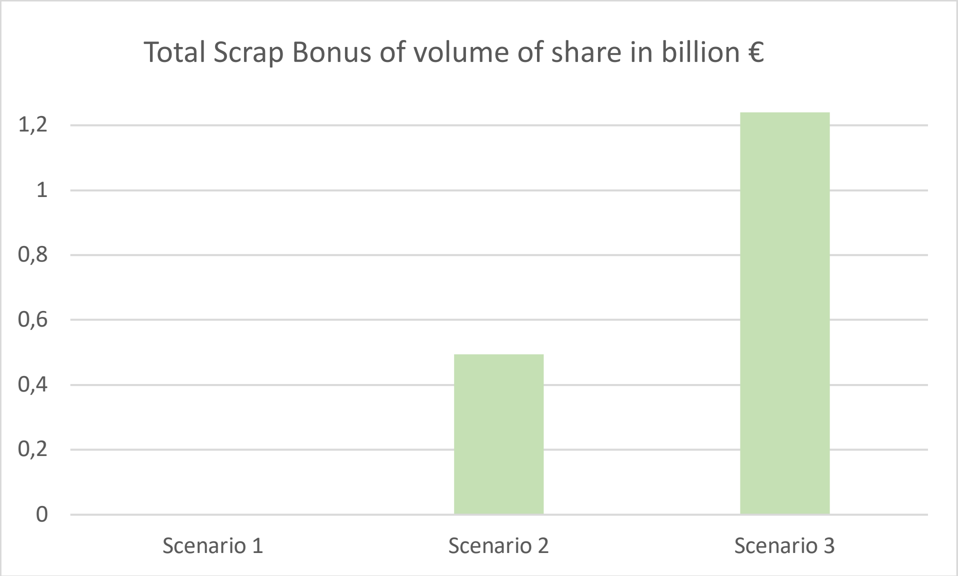

**Figure 9.** Total scrap bonus of the volume of share in billion euro.

*Figure description.* The total scrap bonus of volume of share in billion euros. The scenario 1 amounts to zero since there is no additional volume of scrap in the baseline scenario. The additional volume of retained exports in scenario 2 can potentially save 0.5 billion € of environmental costs, while for scenario 3 this amounts to 1.24 billion €.
Source: Own calculations

Lastly, the total scrap bonus for the total volume of processed steel for each scenario is defined as:

*Total Scrap Bonus of total volume of processed steel scrap in €$_{Scenario\ 1}$*= 146€ /t of processed steel srcap * 57 875 012 t = 8 449 750 000€ = **8.449 billion €**

Total Scrap Bonus of total volume of processed steel scrap in € $_{\text{Scenario 2}}$ = 146€ /t of processed steel scrap * 61 268 012 t = 8 945 128 000€ = **8.945 billion €**

Total Scrap Bonus of total volume of processed steel scrap in € $_{\text{Scenario 3}}$ = 146€ /t of processed steel scrap * 66 358 012 t = 9 688 268 000€ = **9.688 billion €**

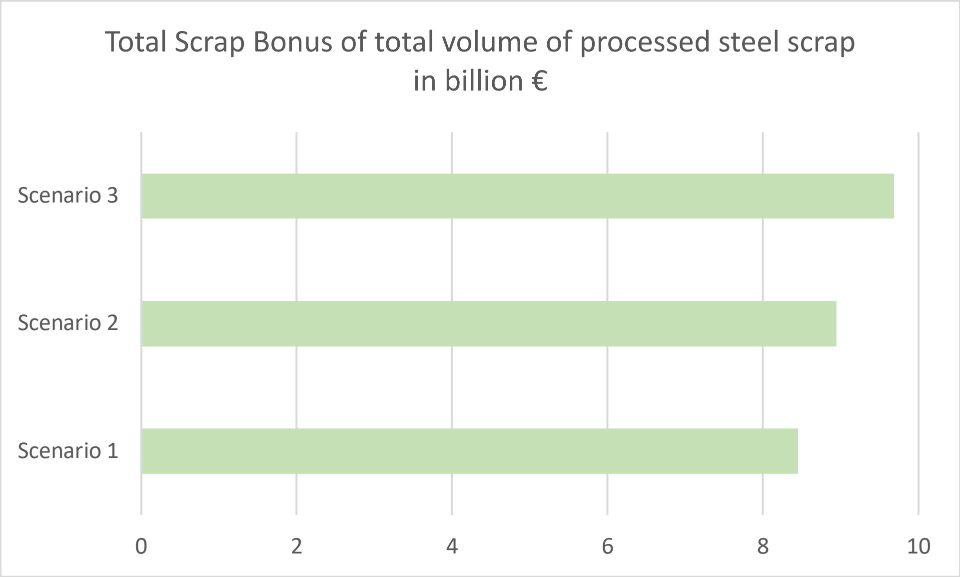

**Figure 10.** Total scrap bonus of the total volume of processed steel scrap in billion €.

*Figure description.* The total scrap bonus of the total volume of processed steel scrap in billion €. The larger the volume of steel scrap that is processed in the EU, the higher the environmental cost savings in form of the scrap bonus. For scenario 1 and 2 that is 8.5 billion € and 9 billion €. For scenario 3 this amounts to 9.7 billion €.
Source: Own calculations

The total scrap bonus for the baseline scenario in 2020, amounts to 8.45 billion, 8.4 billion euros for scenario 2 and 9.69 billion € for scenario 3. These results are in line with the results of Pothen et al. (2020), who calculated the cost savings for the year 2018. Even though, the results cannot be directly compared due to the difference in year, when calculating with data from 2018 from the same source as the data used in this thesis, the results are nearly identical. Thus, the credibility of obtained findings is strengthened.

Since the 'medium reference scenario' value for the scrap bonus was used as an average or moderate value and $CO_2$ production emissions of higher quality steels such as stainless steels were not accounted for, the actual $CO_2$ emissions are likely to be higher.

Another shortcoming of using social costs in order to determine environmental costs or externalities is the great ambiguity of assigning a monetary value to natural resources and environmental impacts and the ‘intergenerational asymmetry of decision power’, meaning that decisions are made rather short-sightedly and strongly influenced by the needs of current generations (J. Harris et al., 2001). Therefore, depending on the value chosen, results might vary widely. However, they do fulfil the aim of providing an estimate and can inform decision-making, and as Pearce (2003, p.363) remarks “acting on reasonable estimates is better than acting on no estimates”.

These numbers show the environmental costs that can be saved when using steel scrap considering the corresponding environmental costs that occur during primary production with coke and ore. Moreover, they indicate **the more steel scrap is used the higher the environmental cost savings**. According to economic theory, externalities such as the avoided environmental costs explained here, lead to market failure and can be classified as a welfare loss (Achim & Murphy, 2014; N. Harris, 2001). Thus, the main question is **how these externalities can be integrated and internalised in order to account for the benefits of using scrap steel**. Next to innovation projects such as the EU Clean Steel Partnership (Horizon 2020; ESTEP, 2022), policies such as the proposed waste shipment revision can act as one of these instruments in incentivising the use of scrap steel within the EU and thus, actualising some of the avoided environmental costs. Therefore, **from a European economic perspective, the EU waste shipment proposal can be identified as having a positive impact on the secondary steel industry**.

## 6 Further Discussion & Conclusion

As the findings show, from an EU-27 and environmental perspective, the EU waste shipment proposal can be encouraged based on that the benefits of possible emissions and cost savings outweigh the drawbacks such as increased energy consumption. However, in the light of a significant increase in electricity consumption driven by the proposed policy, the development of green electricity generation within the EU is integral to the secondary steel industry’s transition toward zero emissions. Moreover, EU policymakers on the EU and national level, need to consider pathways of how this transition can be supported. The EU waste shipment proposal and its objectives of raising circularity and production standards or waste management standards can only be successful if EU-27 secondary steel producers succeed in navigating the volatile energy market and current global instability. The survival and the global competitiveness of the EU steel industry are important due to the inevitability of the material steel for society and the importance of increased use of EAFs in the coming decades and their environmental benefits compared to BF/BOF steelmaking. Therefore, funding projects and policies need to take this into account. The increase in scrap availability within the EU driven by the EU waste shipment proposal can contribute to this endeavour and support the European steel industry.

Furthermore, the increasing circularity of steel scrap within the EU might also avoid excessively long transport ways, thus saving transport emissions. However, this lies outside of this thesis' scope and further research about other parts of the steel value chain in relation to the proposed policy is required.

Due to the novelty of the EU Waste Shipment revision, there exist various fields for further research. Another main important question is, however, if the EU Waste Shipment proposal is also beneficial to the overall global climate. Or might it lead to important global value chain disruptions? After all, the exported steel scrap seems to be needed in other parts of the world. What are the repercussions if this scrap is missing? Are these steel producers required to replace steel scrap with more polluting virgin materials such as iron ore and coke? Furthermore, as mentioned, the EU Waste Shipment proposal aims to raise waste management standards globally by only allowing accredited facilities to process EU steel scrap. However, is the EU-27 and waste shipment proposal powerful and consistent enough for the mentioned stricter regulations and waste treatment to raise standards outside of the EU, as well? These are some of the many crucial questions, that need to be further researched. This thesis explored the EU Waste Shipment proposal and its environmental implications on a European level. However, the global short and long-term implications might even be more important from a sustainability perspective showing the urgent need for further research.

Nonetheless, the hope is that this thesis has shed some light on the topic from an environmental and sustainability perspective, giving readers an understanding of the content of the policy highlighting the view of Eurofer, as being the voice for the EU steel industry and being close to practice, while creating different scenarios showing the possible implications for the EU's energy consumption, GHG emissions, and environmental costs.

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