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On behalf of Oryx (Stainless) Thailand Co., Ltd.

The Societal Welfare Gains of Stainless Steel Recycling in Thailand

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ON BEHALF OF ORYX (STAINLESS) THAILAND CO., LTD.

The Societal Welfare Gains of Stainless Steel Recycling in Thailand

THE SOCIETAL WELFARE GAINS OF STAINLESS STEEL RECYCLING IN THAILAND

A JOINT PROJECT BETWEEN THAI AND GERMAN SCIENTISTS FOR THE BENEFIT OF EXCELLENCE IN STAINLESS STEEL CIRCULAR ECONOMY RESEARCH

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List of Abbreviations

BCG	Bio-Circular-Green
BOI	Board of Investment of Thailand
CBAM	Carbon Border Adjustment Mechanism
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	United Nations Climate Change Conference of the Parties
CRI	Global Climate Risk Index
ETS	Emissions Trading System
EU	European Union
FU	Functional Unit
GDP	Gross Domestic Product
GHG	Greenhouse Gases
ISO	International Organization for Standardization
ITCZ	Inter-Tropical Convergence Zone
LCA	Life Cycle Assessment
MRV	Monitoring, Reporting and Verification
Mt	Metric tons
ND-GAIN	Notre Dame-Global Adaption Index
NGO	Non-Governmental Organization
PM	Particular Matter
SCC	Social Costs of Carbon
SDGs	United Nations Sustainable Development Goals
SEP	Sufficiency Economy Philosophy
TGO	Thailand Greenhouse Gas Management Organization
VOC	Volatile Organic Compounds
µg	Microgram
m^3	Cubic meter

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1 Abstract

Addressing the challenges of resource scarcity, local pollution and climate change requires a holistic approach. The circular economy constitutes an essential element of this approach. The steel industry, and the stainless steel industry in particular, holds significant potential in this regard, as demonstrated by the Fraunhofer UMSICHT study which analyzed the CO_2 impact of production sites within the Oryx Stainless Group using a Life Cycle Assessment (LCA) approach. The study found that producing one ton of stainless steel from scrap metal saves approximately 6.7 tons of CO_2 equivalents compared to the production based on primary commodities. To elucidate the social value of (stainless) steel recycling, the indicator Scrap Bonus quantifies the societal added value in units of money.

Building upon European research, a Thai-German team extended the analysis to Thailand, investigating local conditions and the impacts of climate change. The study "The Societal Welfare Gains of Stainless-Steel Recycling in Thailand" focuses on Oryx Stainless Thailand, being the lighthouse of a growing stainless steel recycling industry in Southeast Asia. Life Cycle Assessments and heightened climate impact assessments in Thailand reveal a significantly higher societal welfare gain, with an average reference value of 22,000 baht per ton of stainless steel scrap blend compared to the 2020 findings of 13,000 baht per ton blend. This corresponds to a price of 3,336 baht per ton of CO_2, highlighting the potential of recycling processes in mitigating climate change impacts. Policy implications, such as extending the Bio-Circular-Green Economic Model to scrap metals and strengthening carbon pricing mechanisms, emerge from these societal benefits.

Introduction

The challenges of the 21st century are manifold. But tackling climate change is plausibly the greatest of them. Major efforts across the globe are necessary to reduce CO_2 emissions and to change humanity's previous fossil-fuel-based way of life to a sustainable one. Other challenges, for instance resource scarcity and local pollution, are also important to tackle in order to create an environment worth living in for future generations. Moving towards a circular economy, in which resource inputs are reduced, products are reused or remanufactured, and materials are recycled, is a crucial part of these efforts.

Climate change will lead to very different consequences globally. For Southeast Asia in general and Thailand in particular, based on its topography and long coastline, droughts on the one hand and flooding on the other are to be expected. According to forecasts, the megacity of Bangkok will be affected by significantly more flooding in the future, some of which will be constant.[1]

The steel industry is responsible for around 7 % of global greenhouse gas emissions.[2]Furthermore, the steel sector is heavily dependent on the extraction of raw materials. At the same time, steel offers great opportunities to reduce humanity's impact on nature as it can be recycled indefinitely without a loss of quality. Stainless steel in particular has an important role to play in the fight against climate change. Its durability, recyclability and resistance to corrosion -which can lead to longer product lifetimes- make it a sustainable option in various sectors such as construction and renewable energy. The recycling of stainless steel is known to enable significant reductions in CO_2 emissions.

This study identifies the societal benefits of stainless steel recycling for Thailand. We illustrate these benefits using the example of the stainless steel recycling company Oryx Stainless (Thailand) Co., Ltd. (hereafter referred to as Oryx Stainless Thailand) and its operations in Bangpakong (Chachoengsao province) near Bangkok.

To this end, we build upon a study conducted by Fraunhofer UMSICHT (2023) which quantifies the emissions savings achieved by Oryx Stainless Thailand. We convert these savings, which are expressed in tons of CO_2, into something more tangible than tons of odorless and colorless gas: money. Hence, we compute the Scrap Bonus for stainless steel in Thailand.

The indicator Scrap Bonus is defined as "the social cost savings due to the environmental burdens avoided when using one ton of steel scrap" (Fraunhofer IMW 2022[3], Fraunhofer IMWS 2020[4]). It has been introduced to inform the public about the environmental benefits of (stainless) steel recycling in a comprehensible and intuitive manner as well as to promote the concept of a circular economy.

Thus far, the Scrap Bonus has not been applied in the Thai context. But, as illustrated before, Southeast Asia in general and Thailand in particular are disproportionately vulnerable to the dangers of climate change. Moreover, the circular economy promises economic gains in addition to the ecologic ones. Our study closes this gap in scientific understanding.

The study is structured as follows: Chapter 2 introduces the use, production and recycling of stainless steel. Chapter 3 provides a concise overview and assessment of climate change in Thailand. This is followed in Chapter 4 by the Life Cycle Assessment (LCA) of the Oryx Stainless Thailand near Bangkok. Building on the results of the previous chapters, the societal benefits associated with emission reductions from stainless steel recycling are determined in Chapter 5. To this end, various approaches quantifying the

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[1] Strauss et al. 2021.

[2] International Energy Agency 2020.

[3] Pothen and Brock 2022.

[4] Pothen et al. 2020.

costs of CO_2 emissions are presented and categorized. Ultimately, the monetary societal benefits, e.g., the Scrap Bonus, for Thailand are derived from these assumptions. Chapter 6 presents policy implications and recommendations based on these results. Chapter 7 concludes and provides an outlook.

2 Background on stainless steel

3.1 Stainless steel

Steel is defined as a "material with iron as the predominant element, having a carbon content generally less than 2.0 % and containing other elements"[5]. The term stainless steel denotes a class of steel which is particularly resistant to corrosion. It obtains this property from containing at least 10.5 % of chromium and a carbon content of less than 1.5 %.[6] Adding nickel improves corrosion resistance further. Approximately 50 to 60 % of global production is nickel-containing so-called austenitic stainless steel.[7]
Stainless steel is used in a variety of applications. These range from industrial machinery (e.g., in the food industry) over kitchenware to architecture. In all its applications, stainless steel is appreciated not only for its durability and utility but also for its aesthetic appeal.

3.1.1 Raw materials and processing

The manufacturing of stainless steel involves a series of processes sketched in Figure 1.[8]Stainless steel is predominantly produced in electric arc furnaces which use electricity, either from conventional or renewable sources, to melt the raw materials.
The raw materials used to manufacture stainless steel are either raw materials from recycling -stainless steel scrap- or primary raw materials such as ferronickel and ferrochrome. These ferroalloys are alloys of iron and nickel or chrome, respectively. If necessary, higher-grade materials (e.g., pure nickel) are added to achieve the desired composition. The molten steel is then further refined, for instance by using Argon Oxygen Decarburization converter, in order to reduce carbon content and achieve the final composition.[9]It is then cast into ingots or slabs, rolled or forged into its final form.
Note that electric arc furnaces emit limited amounts of CO_2 directly, primarily from adding natural gas in the melting process to improve energy efficiency. Their carbon footprint is largely determined by the electricity mix and the emissions associated with processing the raw materials. Figure 1 illustrates the process of steel production in the electric arc furnace route.

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[5] iTeh Standards 1982.

[6] iTeh Standards 2014.

[7] Austenite refers to the face-centered cubic crystal structure of stainless steel which becomes stable at room temperature if it contains more than 8 % of nickel. It can be distinguished from the body-centered cubic crystal structure of ferritic steel. The most obvious difference between them is that ferritic stainless steel is magnetic while austenitic stainless steel is not.

[8] Pothen and Brock 2022.

[9] Mauss and Pariser 2019.

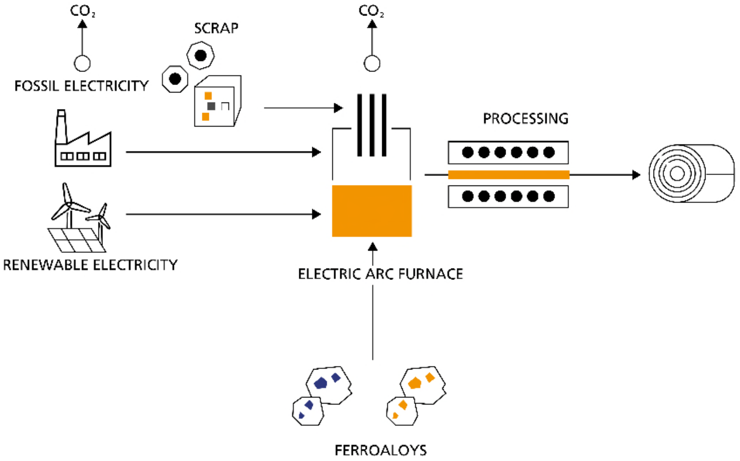

Figure 1: Diagram showing steel production in the electric arc furnace route.
Source: Pothen and Brock (2022).

3.1.2 Recycling

Stainless steel can be recycled without a loss of quality. Globally, 95 % of stainless steel is recycled by the end of its lifetime. 70 % is recycled as stainless steel again. Currently, scrap accounts for approximately 48 % of the raw materials in stainless steel production.[10]

Stainless steel scrap falls into one of three categories: home scrap, new scrap (also known as industrial scrap), and post-consumer scrap (also known as reclaimed scrap or old scrap). Home scrap constitutes scrap which occurs in the steel production itself. It is immediately and completely recycled within the mill. New scrap encompasses the trimmings and excess from manufacturing, fabrication, or construction. For example, the leftover pieces of sheet, trimmed rods, and other bits of waste from using stainless steel as a production material. Its composition is well known, and it contains little contaminants. Post-consumer scrap comes from products at the end of their lifetime such as consumer goods and home appliances, chemical tanks, structural elements, or equipment, or the structural remains of demolition.

Stainless steel scrap is collected, sorted and processed by specialized firms within the steel recycling sector. These firms provide a tailored mix of raw materials from recycling, the so-called blends, to their customers. The composition of the blends matches those of the type of stainless steel to be produced.

3.1.3 Markets

In 2019, global stainless steel production reached 52.2 million metric tons (Mt).[11]Production has expanded by close to 3 % per annum to about 58.4 million Mt in 2023. Looking ahead, the industry is expected to grow by 3 to 4 % annually until 2030.[12]

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[10] worldstainless 2024.

[11] International Stainless Steel Forum 2020.

[12] Moll 2023.

The global stainless steel market was valued at 118,940 million US dollars in 2019 and is expected to reach 163,530 million US dollars by the end of 2026, with a Compound Annual Growth Rate of 3 % from 2023 to 2027.[13]
The usage of stainless steel differentiates from the usage of carbon steel in that it is significantly more related to consumer-driven applications rather than infrastructure-growth driven applications. As such, the largest market segments for stainless steels are consumer goods, including white goods (e.g., washing machines) and home appliances, food processing, catering equipment and medical applications. In total, it is estimated that these account for 48 % of global demand. Chemical, petro-chemical and energy, automotive, heavy transport, as well as industrial and heavy industry, comprise another major share of applications. Architecture, building and construction make up some 16 % of stainless steel usage worldwide (compared to 52 % in the case of carbon steel).[14]

3.2 Stainless steel and scrap market structure in Thailand and Southeast Asia

The stainless steel industry in Thailand is closely related to the broader stainless steel industry in Southeast Asia. In 2023, stainless steel production in Asia (excluding China and South Korea) was 7.79 million metric tons.[15]Indonesia is the biggest producer in Southeast Asia with about 5 million metric tons in 2021.[16]The region has been attracting foreign investment, and some multinational companies have shifted their stainless steel production to Southeast Asian countries due to lower labor costs and favorable investment policies. For example, Yongjin Group who had a total output of 2.5 million tons of stainless steel, chose to establish factories in Vietnam and Thailand, contributing to the industry's global layout.[17]

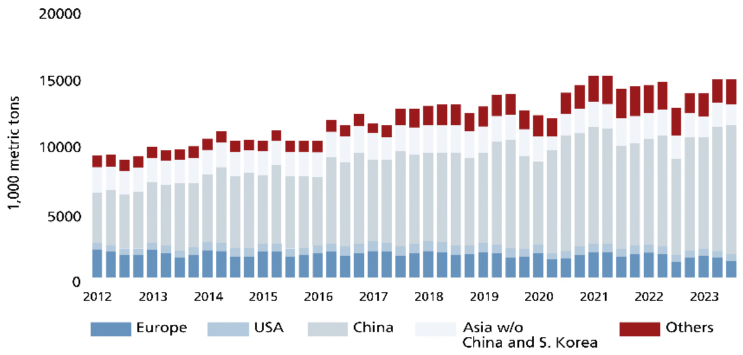

Figure 2: Stainless steel melt shop steel production per quarter [1,000 metric tons]. Source: worldstainless (2023).

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[13] Technavio.

[14] Moll 2023.

[15] James Duva Inc. 2014.

[16] Statista 2024.

[17] SMM Information & Technology Co., Ltd. 2021.

Background on stainless steel

Figure 2 shows the quarterly production of stainless steel in 1,000 metric tons. A constant slight upward trend can be observed and a clear dominance of the Chinese market in terms of production. The geographical proximity to China is also one of the market drivers for Southeast Asia.[18]

Thailand's apparent consumption of stainless steel was approximately 366,000 tons in 2022, making it the second biggest user of stainless steel in Southeast Asia. Domestically, Posco-Thainox produces cold-rolled stainless steel in Rayong and Amata, Thailand. Approximately 70 % of production is allocated to the domestic market.[19]Those activities can be seen as a starting point for a broader integration in the Southeast Asian and Asian Market. With the establishment of projects like Yongjin's 260,000 ton precision stainless steel strip project in Thailand,[20] there are expectations of an increase in Thailand's domestic stainless production and accordingly stainless steel imports and exports.

The Southeast Asian steel industry, including stainless steel, is expected to increase its production capacity significantly in the coming years, with countries like Malaysia and Indonesia adding millions of tons of new capacity. This growth is driven by investments from China and other countries, and it is anticipated to lead to a sharp increase in steel demand in the region.[21]The ASEAN[22] steel industry, which includes Thailand, has been a focus of investment, and the region is seen as a market with demand-supply gap opportunities.

However, the rapid pace of investment has also raised concerns about overcapacity in the future. Overall, the stainless steel industry in Thailand is part of the larger trend of increased steel production and demand in Southeast Asia, driven by both domestic and foreign investments. This growth is expected to have a significant impact on the global stainless steel supply landscape.

In terms of stainless steel scrap, Thailand imported 63,267 tons and exported about 178,756 tons in 2022.[23]Most Thai steel mills use scrap metal as their primary source of raw materials, reflecting the industry's reliance on stainless steel scrap.[24] Several companies, such as Oryx Stainless Thailand[25], Thanakhun Metal[26] and OHGITANI SIAM (Thailand)[27]in Thailand specialize in the metal recycling business, including stainless steel scrap.

Another interesting point for the development of stainless steel recycling is the future availability of stainless steel scrap in Thailand.[28] The life cycle of stainless steel applications must be considered in the context of the development of national economies. In the last decades of the rapidly developing Thai economy, a lot of stainless steel has been used, as illustrated by the demand of about 366,000 tons per year. This amount, if not exported, will eventually reach the end of its life cycle and can be recycled. The stainless steel industry in Southeast Asia, including Thailand, is experiencing growth and development, with an increasing focus on recycling and sustainable stainless steel production.

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[18] worldstainless 2023.

[19] POSCO - THAINOX 2024.

[20] SMM Information & Technology Co., Ltd. 2021.

[21] Quynh 2023.

[22] ASEAN (Association of South East Asian Nations).

[23] United Nations 2022.

[24] Taghipour and Akkalatham 2021.

[25] Recycling Today 2019.

[26] THANAKHUN METAL 2024.

[27] OHGITANI Corporation 2022.

[28] See e.g., Pothen and Hundt 2024 who study the availability of carbon steel scrap.

4 Emissions and climate change in Thailand

4.1 Local environmental factors and air quality

The Thailand State of Pollution report 2021 indicates improvements in air, solid waste and wastewater pollution due to collaborative efforts driven by national strategies and policies. Initiatives such as the Center for Air Pollution Mitigation and Action Plans on $PM_{2.5}$[29] and plastic waste management have contributed positively. The COVID-19 pandemic led to better air and water quality but increased the generation of infectious wastes like used masks and plastic garbage from food delivery systems.[30]

Air quality

In 2021, Thailand experienced a 4 % decrease in annual average $PM_{2.5}$ levels nationwide, reaching 22 µg/m^3, and a 7 % decrease in PM_{10} levels to 40 µg/m^3. The highest 8-hour average for ozone gas decreased by 5 % to 86 µg/m^3. Persistent pollution concerns included $PM_{2.5}$ in Bangkok and northern areas, PM_{10} in Na Phra Lan Subdistrict (Saraburi Province), and ozone gas in Bangkok and the central region.

In critical areas, the average $PM_{2.5}$ level decreased to 40 µg/m^3 in 2021, marking a 13 % drop from 2020's average of 46 µg/m^3. Locations such as Na Phra Lan Subdistrict in Saraburi, Bangkok, Map Ta Phut, and Southern Thailand were designated as critical zones. The number of days exceeding $PM_{2.5}$ standards decreased by 8 %, from 112 days in 2020 to 103 days in 2021, while hotspots reduced by 52 %. In Na Phra Lan Subdistrict, Saraburi Province, the number of days exceeding PM_{10} standards rose by 10 % to 101 days, while the annual average PM_{10} level decreased by 8 % to 98.6 µg/m^3 due to dust dispersion from industrial activities and traffic. Bangkok saw an improvement with 64 days of $PM_{2.5}$ exceeding standards, down from 70 days in 2020, which is attributed to stricter pollution control measures. Map Ta Phut experienced fluctuations in volatile organic compounds (VOCs) from chemical industrial factories. Southern Thailand faced haze issues from forest fires, with $PM_{2.5}$ levels staying within limits in 2021.

4.2 Climate change in Thailand

Thailand experiences a tropical climate shaped by seasonal monsoon winds. During the southwest monsoon from May to October, warm, moist air from the Indian Ocean leads to abundant rainfall, especially in mountainous areas. This phenomenon is intensified by the Inter-Tropical Convergence Zone (ITCZ) and tropical cyclones resulting in heavy precipitation. Thailand's susceptibility to climate change stems from a combination of political, geographic, and social factors, reflected in its ranking of 62nd out of 181 countries in the 2020 Notre Dame-Global Adaption (ND-GAIN) Index. This Index ranks 181 countries using a score which calculates a country’s vulnerability to climate change and other global challenges as well as their readiness to improve resilience. The lower a country's score, the more vulnerable it is, while a higher score indicates greater readiness for resilience-building.[31]

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[29] Particulate matter (PM). The fraction of particles with an aerodynamic diameter smaller than respectively 10 or 2.5. (PM).

[30] Pollution Control Department 2022.

[31] The World Bank Group and the Asian Development Bank 2021.

CRI 2000-2019 (1999-2018)	Country	CRI score	Fatalities	Fatalities per 100 000 inhabitants	Losses in million US$ PPP	Losses per unit GDP in %	Number of events (2000–2019)
1 (1)	Puerto Rico	7.17	149.85	4.12	4 149.98	3.66	24
2 (2)	Myanmar	10.00	7 056.45	14.35	1 512.11	0.80	57
3 (3)	Haiti	13.67	274.05	2.78	392.54	2.30	80
4 (4)	Philippines	18.17	859.35	0.93	3 179.12	0.54	317
5 (14)	Mozambique	25.83	125.40	0.52	303.03	1.33	57
6 (20)	The Bahamas	27.67	5.35	1.56	426.88	3.81	13
7 (7)	Bangladesh	28.33	572.50	0.38	1 860.04	0.41	185
8 (5)	Pakistan	29.00	502.45	0.30	3 771.91	0.52	173
9 (8)	Thailand	29.83	137.75	0.21	7 719.15	0.82	146
10 (9)	Nepal	31.33	217.15	0.82	233.06	0.39	191

The 10 countries most affected from 2000 to 2019 (annual averages)

Figure 3: Top 10 countries most affected (climate change) from 2000 to 2019 (annual averages). Source: Eckstein et al. (2021).

To compare this with past results, Figure 3 from the NGO Germanwatch shows the 10 countries most affected by climate change from 2000 to 2019.

Thailand occupies the 9th position in the Long-Term Climate Change Risk Index, spanning the years from 2000 to 2019. This ranking underscores again the nation's vulnerability to climate change, a vulnerability shared by other Southeast Asian countries such as Myanmar (2nd) and the Philippines (4th). Additionally, Bangladesh (7th), Pakistan (8th), and Nepal (10th) feature prominently in the top 10, signifying the region's heightened susceptibility to climate change impacts.[32]

Climate change trends in Thailand reveal significant shifts in temperature and precipitation patterns since the mid-20th century. In "Trends in Temperature and Its Extremes in Thailand" increases in daily maximum, mean and minimum temperatures at 65 meteorological stations between 1970–2006 (0.12–0.59 °C, 0.10–0.40 °C and 0.11–0.55 °C per decade, respectively) were observed.[33]Averaged over all stations, the number of warm days and nights significantly increased by 3.4 days/decade and 3.5 days/decade, respectively.[34]The continuation of this trend is shown clearly in the graph (Figure 4) depicting the temperature change in Thailand from 1890 to 2022.

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[32] Eckstein et al. 2021.

[33] Atsamon Limsakul et al. 2011.

[34] Atsamon Limsakul et al. 2011.

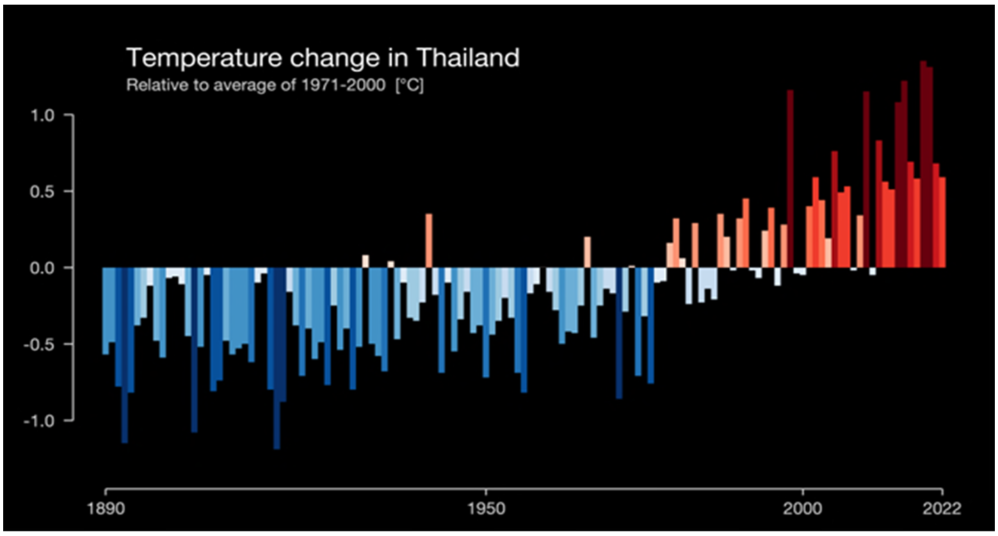

Figure 4: "Warming Stripes" (Temperature Change) for Thailand.
Source: Ed Hawkins (2022).

Regarding precipitation, studies indicate an increase in annual precipitation, predominantly during the wet season. The variability of precipitation in Thailand over the 20th century was largely influenced by El Niño Southern Oscillation, with years of strong El Niño correlating with moderate and severe drought conditions. A 2016 study noted a decrease in the frequency of precipitation events across the country, but an intensified nature of those that occur.[35]

Thailand faces high exposure to natural hazard risks such as heatwaves, droughts, floods, cyclones and storm surges. Floods pose the most significant threat to Thailand in terms of frequency and damage, earning the country a place among the top ten most flood-affected nations globally. The rising sea level combined with a coastline of about 2,960 km could be a strong threat in the future.[36]This is illustrated in Figure 5 below. The graphic shows how Bangkok would be affected by rising sea levels if the temperature rises to 1.5 °C in blue or 3 °C in red.[37]

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[35] The World Bank Group and the Asian Development Bank 2021.

[36] Aksornkoae and Bird 2010.

[37] Climate Central 2024.

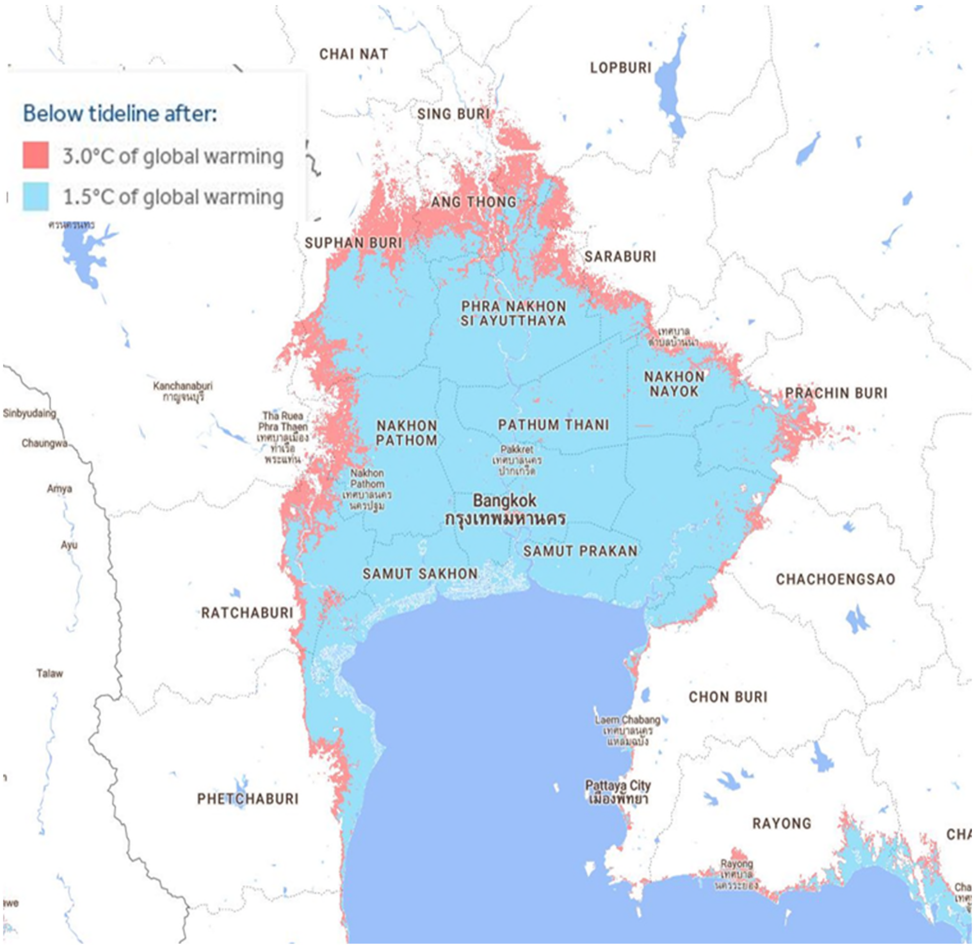

Figure 5: Flooding Area Bangkok-Region.
Source: Climate Central (2024).

In terms of heatwaves, the country experiences an average monthly maximum temperature of around 31.6 °C with April reaching an average maximum of 35.1 °C. The current median probability of a heat wave (defined as a period of three or more days where the daily temperature is above the long-term 95th percentile of daily mean temperature) is around 3 %. Additionally, Thailand faces an annual median probability of severe meteorological drought of around 4 %.[38]

Due to its location, topography and climatic conditions, the risks of a permanent rise in average temperatures and the associated climate changes are particularly high for Thailand. Thailand therefore benefits more than other countries from emission reductions.

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[38] The World Bank Group and the Asian Development Bank 2021.

5 From Life Cycle Assessment to the Societal Welfare Gains in Thailand

5.1 Methodology and procedure

This chapter presents the methodology behind the Scrap Bonus, the assumptions and instruments used to determine CO_2 prices and the challenges involved in calculating them. However, in order to be able to understand the assumptions on which the Scrap Bonus for Thailand is based, it is necessary to briefly illustrate the path at this point. First of all, there is the Life Cycle Assessment (LCA), which quantifies the environmental impact of Oryx Stainless Thailand. This includes different greenhouse gases and local environmental impacts.

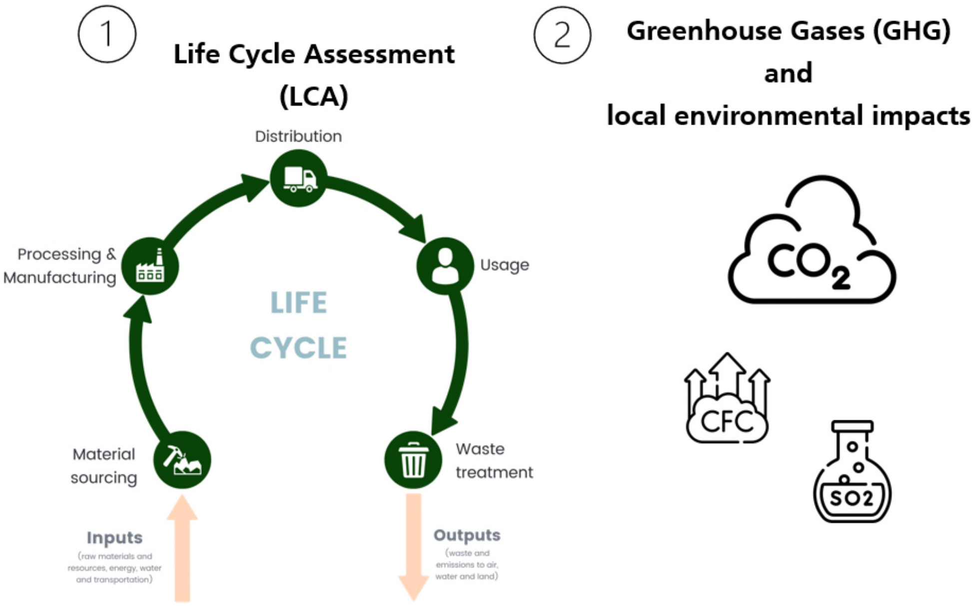

Figure 6: Illustration "From Life Cycle Assessment to the Societal Welfare Gains in Thailand" Step 1 and 2.
Source: Own creation and Root.

To see what it really means when CO_2 or other greenhouse gases are released, the classification of the effects of climate change in Thailand was carried out in Chapter 4.

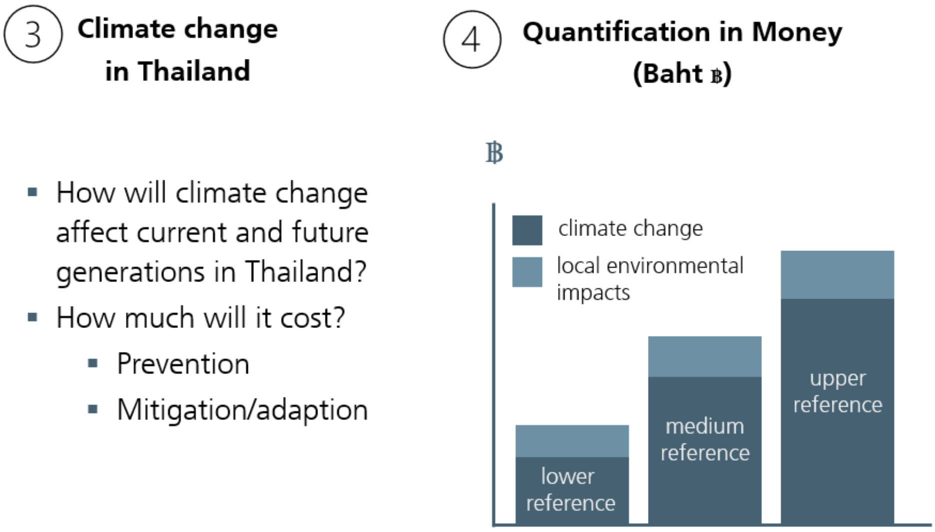

Figure 7: Illustration "From Life Cycle Assessment to the Societal Welfare Gains in Thailand" Step 3 and 4.
Source: Own creation.

In order to put a monetary value on greenhouse gas savings, we have taken a closer look at different approaches to monetize the damage caused by greenhouse gases. Comparing these approaches will lead to a better understanding of the methodology and the actions that have been taken so far worldwide. Finally, we calculate the societal value of each ton of stainless steel scrap, the Scrap Bonus, in Thailand.

5.2 Analysis of the Life Cycle Assessment of Oryx Stainless Thailand Co., Ltd Emission reduction

5.2.1 Background and goal

Back in 2010, researchers from Fraunhofer UMSICHT conducted a study on behalf of the Oryx Stainless Group to examine and quantify the extent to which it contributes to CO_2 savings by providing high-quality raw material blends from stainless steel scrap.
The UMSICHT researchers have updated the greenhouse gas balance of the recycling of stainless steel from the Oryx Stainless Group at the Dordrecht (Netherlands) and Mülheim an der Ruhr (Germany) sites in 2022 for the reference year 2021. The study has now been extended to the Oryx Stainless Group site near Bangkok, Thailand. The scope includes the collection of scrap and turnings, the processing to blend at the Oryx site in Thailand and the transport to customers. Figure 8 shows the process flow chart of Oryx Stainless Thailand and the processes included in the study.

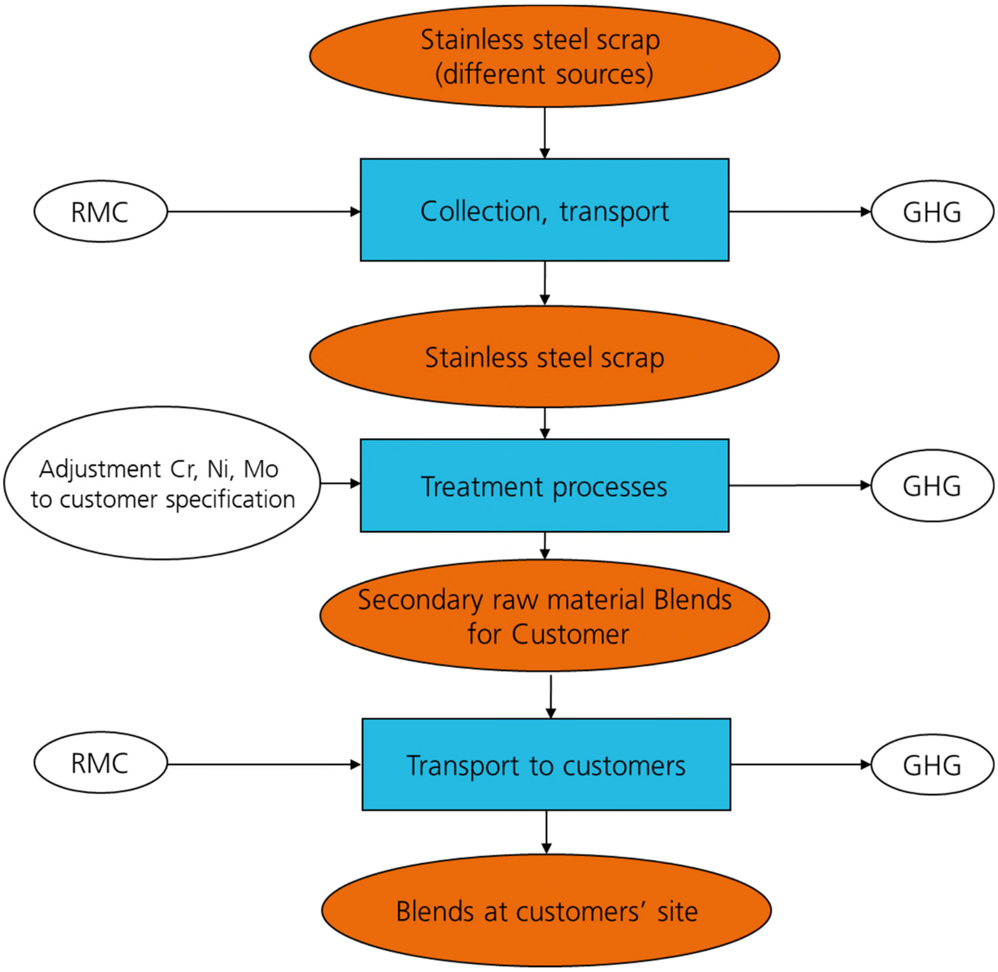

Figure 8: Flow diagram of the investigated system "cradle-to-gate" (RMC = Raw Materials and Consumables, GHG = Greenhouse gases.
Source: Fraunhofer UMSICHT (2023).

A Functional Unit (FU) is a quantitative measure of the function of a process. It provides a reference to which the process inputs and outputs are related. The Functional Unit is defined as one ton blend provided by Oryx Stainless Thailand as a product. The FU is the reference point for calculation of impacts in the Oryx process chain and the GHG savings from substituting primary ferroalloys and pig iron.

To calculate the environmental impacts, the mid-point level or problem-oriented characterization factors of the Environmental Footprint (EF 3.0) is used. The European Union (EU) recommends EF 3.0 methods based upon LCA to quantify the environmental impacts of products (goods or services) and organizations.[39]As the focus of this study is GHG balance, only the impact category climate change is considered.

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[39] European Commission 2024.

5.2.2 Method

As an environmental assessment method, a Life Cycle Assessment is conducted following the ISO standards 14040/44. The LCA software GaBi Version 2022.2 was used to carry out the LCA study focusing on climate change.
The system boundaries for Oryx Stainless Thailand start with the scrap collection and end at the preparation and transport of finished blends to the customer. These steps are calculated as burden of the blends provided by Oryx to replace ferroalloys and pig iron in electric arc furnaces. The greenhouse gas (GHG) savings are calculated through the substitution of Ferro-Cr/Ni/Mo and pig iron on a 1:1 basis.

5.2.3 Results

The results show a total approx. 556,000 t-CO_2e. savings (Figure 9).

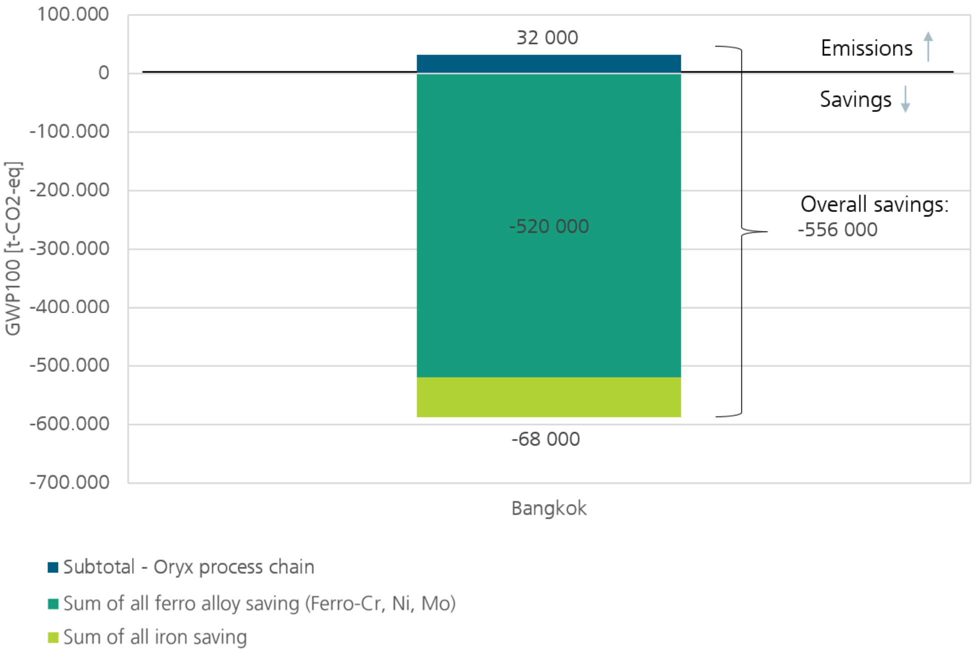

Figure 9: Carbon Footprint of the location.
Source: Fraunhofer UMSICHT (2023).

The average weighted savings of Oryx Stainless Thailand is 6.71 t-CO_2e./t-blend. This number stands between the values of the locations in Europe (6.37 and 6.89 t-CO_2e./t-blend).

5.3 Putting CO_2 emission savings into perspective

Chapter 5.2 reveals that each ton of blend provided by Oryx Stainless Thailand reduces greenhouse gas emissions by 6.71 tons of CO_2 equivalent (t-CO_2e) compared to production from primary raw materials. In the year 2021, Oryx Stainless Thailand’s recycling efforts translated into total CO_2e savings of 556,000 t-CO_2e. This figure emphasizes the magnitude of emissions that have been avoided through stainless steel recycling in the whole value chain. To provide a deeper understanding of these CO_2e figures, it's beneficial to draw tangible comparisons.

6.71 tons of CO_2e is equivalent to the emissions generated by a commercial air conditioner operating on Thailand’s current electricity mix for 22,366.67 hours or 2.55 years.[40] Alternatively, one can compare the 6.71 tons of CO_2e saved with the average individual carbon footprint in Thailand for the year 2021 (approximately 3.89 tons of CO_2e,[41] compared to the world average of 4.66 tons[42]). Thus, the emissions savings of 6.71 tons of CO_2e are equivalent to the annual carbon footprint of approximately 1.73 Thai individuals.

Zooming out to a broader perspective encompassing industrial emissions in Thailand, which include sectors such as mineral and chemical industries, metal production, and non-energy products stemming from fuels and solvent use, we discover that these industries collectively contribute millions of tons of CO_2e to the atmosphere annually.[43]

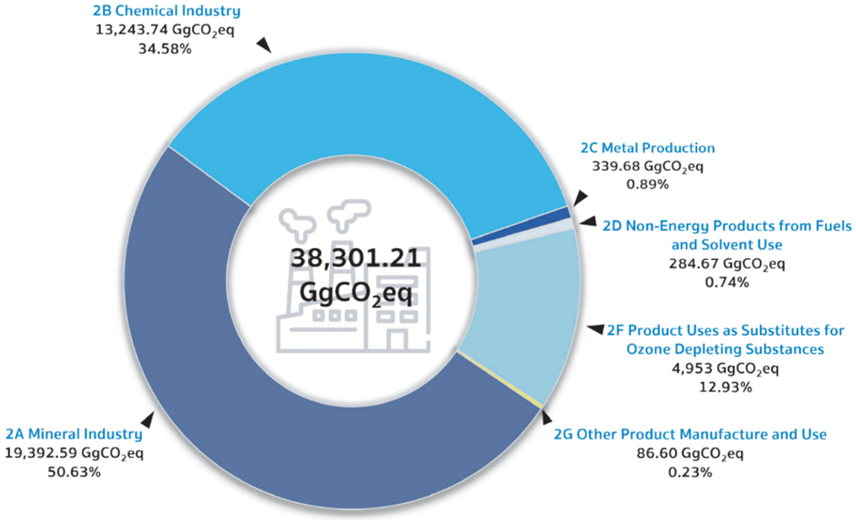

Figure 10: Greenhouse Gas Emission by Industrial Sector.
Source: UNFCCC (2022).

In this context, Oryx Stainless Thailand's annual savings of 556,000 tons of CO_2e represent 1.45 % of the total greenhouse gas emissions originating from all industrial processes within the country. It's important to clarify that these savings are not reflected in official industrial emissions statistics.

Thailand's vulnerability to climate change (Chapter 4.2) emphasizes the necessity of reducing CO_2 emissions. In this context, our study advocates for a monetization approach, quantifying the cost of climate change when CO_2 emissions remain unmitigated. This approach integrates these costs into market structures, offering a clearer understanding of the potential savings that could accrue for entire populations and the world when CO_2 emissions are reduced.

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[40] International Trade Administration | Trade.gov 2024.

[41] Hannah Ritchie et al. 2020.

[42] Global Carbon Project 2023.

[43] UNFCCC | Thailand 2022.

5.4 Value of emission savings

5.4.1 Overview

The study's foundation lies in the Life Cycle Assessment, which serves as the cornerstone for subsequent calculations and implications. The LCA plays a pivotal role in quantifying the substantial societal benefits achieved through emissions avoidance, specifically related to the mining and processing of raw materials in stainless steel production.

While these emissions reduction figures offer valuable insights into the environmental benefits of stainless steel recycling, translating them into monetary terms- the Scrap Bonus -provides a more tangible perspective. This approach allows a broader understanding of the positive societal impact of stainless steel recycling.

The indicator "Social Cost of Carbon" (SCC) is crucial to convert the emission savings from tons of CO_2 into money. Nordhaus (2017) defines the SCC as "the discounted value of economic welfare from an additional unit of CO_2-equivalent emissions" or, less technically, "the economic cost caused by an additional ton of carbon dioxide emissions or its equivalent".[44]

We compare three approaches to quantifying the carbon costs and, thereby, the value of each ton of CO_2e saved by recycling stainless steel. First, we assess the scientific literature to estimate the social costs of carbon. Second, we study carbon prices determined in emissions trading systems. Third, we compare costs of carbon estimated by governments and government agencies around the world. Based upon these analyses, we generate scenarios for the costs of carbon with which we compute the Scrap Bonus.

5.4.2 Scientific estimates of the Social Cost of Carbon

Determining the SCC is a complex calculation process which employs so-called integrated assessment models. These models reflect the coupling between the climate and the world economy. This involves projecting how different levels of emissions could lead to future climate change and the associated economic impacts, which often include damage to infrastructure, agriculture, health, and more.

Discounting future costs plays a critical role in estimating SCC. It reflects the idea that costs incurred in the future are often valued less than the same costs in the present. The applied rate of discounting is called the pure rate of social time preference to distinguish it from interest rates which are determined on markets. This pure rate of social time preference introduces an important normative element into the quantification of the SCC.[45]The lower the pure rate of social time preference, the higher society values damages from climate change in the future. A pure rate of social time preference of 0 implies that a society values damages in the future as much as those in the present. Accordingly, high pure rates of social time preference result in lower SCC values.

A striking feature of SCCs is the wide range of estimates, spanning from negative values (indicating potential benefits of certain emissions in extreme cases) to costs excessing 2,000 US dollars per ton of CO_2e. This wide range reflects the inherent uncertainties in climate science, economics, and assessment of future impacts.

In summary, the social cost of carbon is an important tool for policymakers. Highlighting the costs of climate change increases public awareness. Furthermore, it allows for cost-benefit analyses of climate change. The integration of these costs into current economic activity enables households and firms to make informed choices which reflect the true costs of producing and consuming goods (see section 6).

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[44] Nordhaus 2017.

[45] Parry et al. 2012.

In our study, it is not possible to make a separate calculation for global and national SCC. The already large complexity and uncertainty of estimating global SCC increases drastically when trying to break down the SCC on a national level.

We consider different approaches from the literature to calculate SCC for stainless steel recycling in Thailand. At the country level, there are publications such as Tol[46] which calculates a global SCC and compares it to the national share of greenhouse gas emissions. Since carbon dioxide is a worldwide external factor, a society should always aim to formulate policies based on the global value. Therefore, we consider, but don't use, a country-level social cost of carbon approach.

5.4.3 Emission Trading Systems (ETS)

Emissions trading systems (ETS) create a market for carbon emission allowances, which regulated firms have to submit if they emit CO_2. They work as "cap and trade" systems, where a maximum level of allowable emissions, often referred to as the "cap", is set by a governmental institution. It issues emission allowances of a number corresponding to the cap. Each allowance represents the right to emit a certain amount of greenhouse gases, usually one metric ton of CO_2 equivalent. The cap is set to a level below what regulated firms would emit in the absence of the ETS. This implies that emission allowances are scarce and the scarcity implies a carbon price.

The allowances can be traded. Companies that emit less greenhouse gases than their allocated allowances can sell them. Companies which emit more have to purchase them on the market. This structure ensures that emissions are avoided where it is possible at the least cost, making emission reductions cost effective. Those who can reduce emissions at a lower cost can sell their allowances to those who have a higher cost of reducing emissions. The cap is not affected by trading and follows an emissions reduction plan.[47]Emissions trading systems are established in different countries or regions of the world. The map in Figure 10 shows where emission trading systems are in operation, planned, or under consideration.[48]

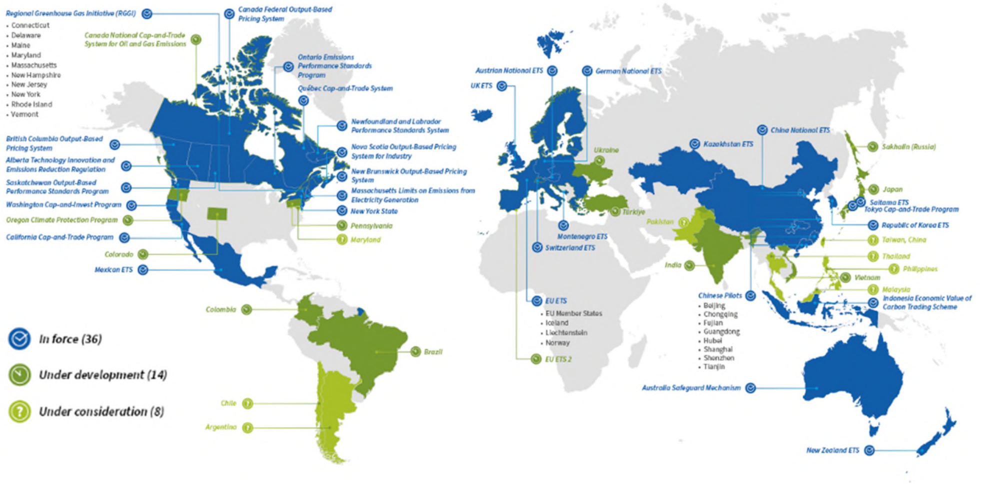

Figure 11: Emission Trading Systems Worldwide.
Source: ICAP (2024).

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[46] Tol 2019.

[47] Climate Action 2024.

[48] International Carbon Action Partnership ICAP 2024.

Established in 2005, the European Union Emissions Trading System (EU ETS) was the first trading system for carbon emissions. It had an average price in 2023 of about 92 US dollars per ton of CO_2e.[49]Table 1 shows the average prices in ETS for different countries and regions when the systems were established and now.

Table 1: ETS of New Zealand, EU and China. Source: ICAP (2024).[50]

Country/Region	First Year	Price	Year	Price
New Zealand/NZ ETS	2009	US$12 tCO_2	2023	US$63 tCO_2
European Union/EU-ETS	2005	US$23 tCO_2	2023	US$92 tCO_2
People's Republic of China/China ETS	2021	US$7 tCO_2	2023	US$9 tCO_2

In addition to cap-and-trade-based emissions trading systems (ETS), there are also voluntary emissions trading platforms through which individuals, organizations and companies can voluntarily trade carbon credits to offset their greenhouse gas emissions. Unlike mandatory systems, participation is voluntary, allowing participants to buy and sell credits without legal obligation. Voluntary systems promote emission reductions beyond regulatory requirements and encourage environmental responsibility through voluntary action. These systems are picking up momentum in Southeast Asia as countries in the region recognize the importance of carbon trading. To address rising carbon emissions, some countries in the region, such as Thailand and Malaysia, have established voluntary carbon trading platforms and exchanges.[51] These systems allow for the generation and trading of voluntary carbon credits, providing an essential tool for many multinational companies to achieve carbon neutrality. The establishment of carbon exchanges can also enhance the potential of national carbon markets,[52] similar to securities markets, by facilitating successful transactions and regulatory settlement. As a result, Southeast Asian countries are actively working to establish carbon exchanges to tap into the growing voluntary carbon market in the region.

The Thailand Greenhouse Gas Management Organization (TGO) initiated the Thailand Voluntary Emissions Trading Scheme called Thailand V-ETS in 2013, aimed at developing and testing Monitoring, Reporting and Verification (MRV) systems, cap-setting procedures, and trading infrastructure across 12 GHG-intensive sectors, covering both direct and indirect emissions.[53]

Prices in emissions trading systems can be employed to quantify the monetary value of greenhouse gas emission reductions from stainless steel recycling. They are, however, not well suited for this task because they reflect the ambition of governments' climate policy and market conditions rather than the costs of climate change. Nevertheless, they form a useful benchmark for the estimated costs of climate change.

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[49] Ember 2024.

[50] Average value of the year and exchange rate February 2024 used.

[51] Rowley 2023.

[52] The Business Times 2023.

[53] International Carbon Action Partnership ICAP.

5.4.4 Fixed prices of CO_2

A fixed price on CO_2 emissions is a policy that sets a specific cost for each ton of carbon dioxide emitted into the atmosphere, usually through carbon taxes or fees. This cost encourages companies to reduce emissions and adopt cleaner technologies by making them financially responsible for the environmental and societal costs of their actions. It provides a predictable way to reduce emissions, generates revenue for climate policy efforts, and can be applied to different sectors. A fixed carbon price also influences consumers to purchase goods that emit less greenhouse gases. An advantage of a fixed carbon price is that costs can be planned in the long term for all parties involved, although it is not clear whether the price chosen in such a way will achieve the intended emission reductions.

Finding the right price is not easy in practice. It involves striking a balance between emission reductions and economic viability, not forgetting social acceptance and feasibility. To solve those challenges in most cases, an increase over time can be observed. This reflects the assumption that the costs of climate change will also increase over time. One example is the Southeast Asian country of Singapore, which introduced a CO_2 tax in January 2019. Singapore's carbon tax increases in several stages. In the introduction between 2019 and 2023, the price was 5 Singapore dollars per tCO_2e. It increased over time as illustrated in Figure 11. From 2028 to 2030, the price for CO_2 will move in a corridor between 50 and 80 Singapore dollars per tCO_2e.[54]

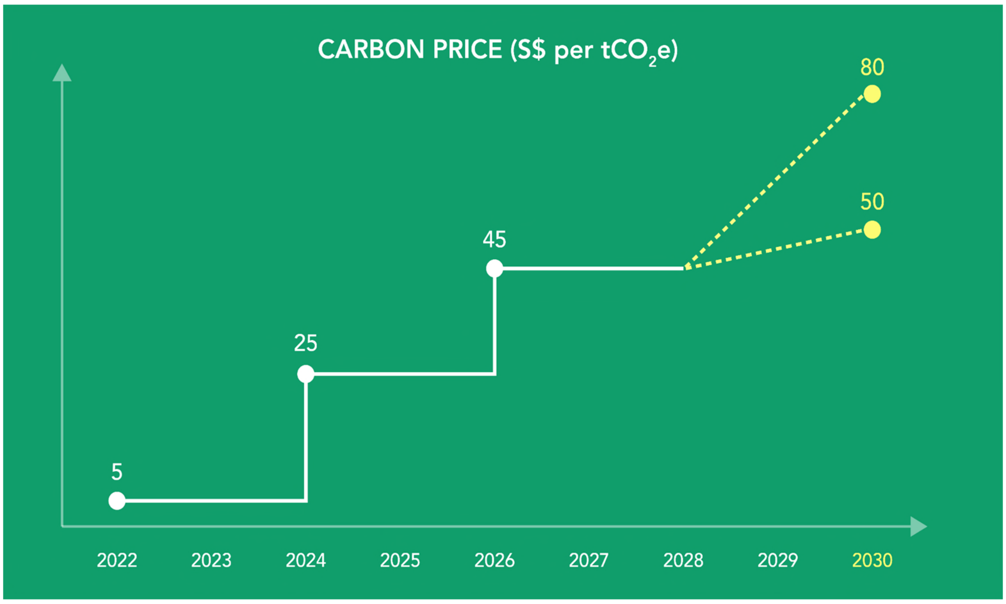

Figure 12: Pathway of Singapore's Carbon Tax.
Source: National Climate Change Secretariat of Singapore (2024).

Before a carbon tax is set, assumptions are made by governments or other organizations. For example, about how high the costs of CO_2 and an associated price would have to be in order to achieve a steering effect. These assumptions are often based on scientific hypotheses and can form the basis for a process to implement a carbon price in a country's economic system. In addition to scientific assumptions, the political agenda can also play a major role. An example of this is the assumption of the United States 51 US dollars per $t\text{-}CO_2e$.[55] But there are also corresponding publications in Thailand. The

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[54] National Climate Change Secretariat of Singapore 2024.

[55] Mindock 2022.

“Thailand's Ministry of Natural Resources and Environment” has published a time related view, between 88–368 dollars per tCO_2e between 2025 and 2050[56] which we will follow up on in the next section.

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[56] The Kingdom of Thailand | Ministry of Natural Resources and Environment - Policy Formulation and National Focal Point 2021.

5.5 Calculation of the Scrap Bonus

Determining a carbon price is complex due to the wide range of assumptions, global uncertainties, and complicated economic models. In addition, Thailand's vulnerability to climate change and its unique economic context play an important role in determining the appropriate range of a carbon price. This is illustrated again in Figure 13 below, which compares observations from the areas of social cost of carbon, emissions trading and carbon tax, and government assumptions. The range here extends from the low single-digit US dollar range to the mid-triple-digit range. This shows that there is a similar trend especially for the market-based price of CO_2, but otherwise there are clear differences that can be attributed to methodology, assumptions, and political agendas.

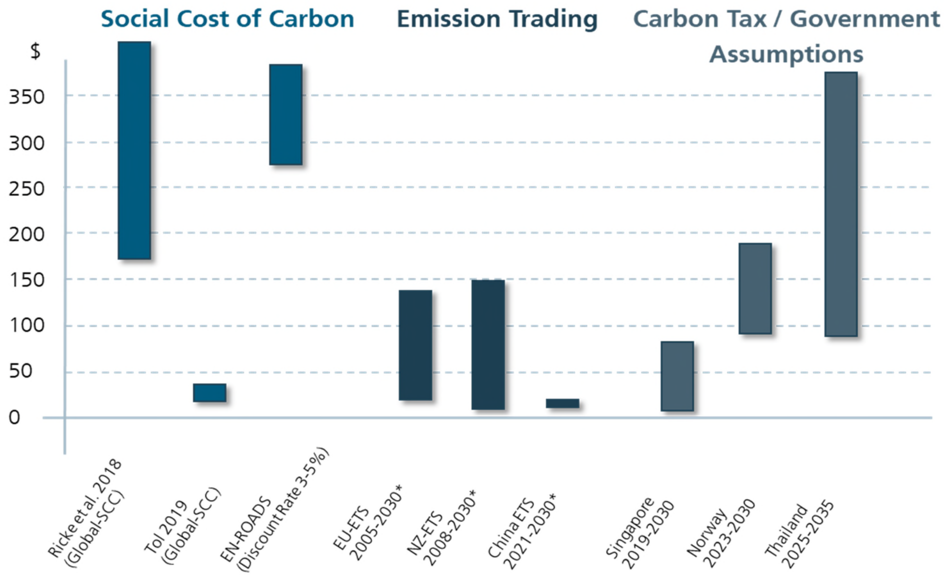

Figure 13: Comparison of different kinds of Carbon Price Estimations.
Source: Own creation from different sources (see Bibliography).

To reflect the uncertainty in the carbon price of CO_2 emissions, we use three different scenarios representing different values respectively. We refer to these as the lower, medium and upper reference points. They address the complexity and uncertainty inherent in climate change projections in a process similar to that used in the Scrap Bonus study.[57]The 2020 Scrap Bonus study used lower, medium and upper benchmarks to monetize the CO_2 emission savings from the use of (stainless) steel scrap. Non-CO_2 emission reductions, local environmental impacts such as acidification and eutrophication, were added to the climate change costs saved. This value remains the same in all scenarios. Table 2 shows the original calculation of the Scrap Bonus in 2020.

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[57] Pothen et al. 2020.

Table 2: Scenarios Scrap Bonus 2020.
Source: Own creation according to Pothen et al. (2020).

Scenario	Carbon Cost per t-CO_2e	Carbon Cost per t blend	Non-CO_2	Total
Scrap Bonus 2020 Low	€30	€135	€29	€164
Scrap Bonus 2020 Medium	€70	€315	€29	€344
Scrap Bonus 2020 Upper	€110	€495	€29	€524

Thailand's current carbon cost expectation range was published by Thailand's Ministry of Natural Resources and Environment in its Thailand Mid-century, Long-term Low Greenhouse Gas Emission Development Strategy. The prices are assumed at 88 US dollars per t-CO_2e in 2025, 109 US dollars per t-CO_2e in 2030 and 368 US dollars per t-CO_2e in 2050, due to the stringent GHG mitigation measures after 2037.[58] The 2020 assumption was lower than the Ministry's current assumptions. In addition, the problems caused by climate change are becoming increasingly apparent, as the chapter on climate change in Thailand shows. The resolution of the COP28 climate conference also sends a clear signal in the process towards a defossilized society. The revised text of the resolution reads: "Transition away from fossil fuels in a just, orderly and equitable manner"[59], which means that efforts need to be intensified and the price signal needs to be adjusted. Based on the national and international CO_2 price correlations and the nation's vulnerability to climate change, and based on the results of our study, we estimate that the savings resulting from avoiding 6.71 tons of CO_2e emissions translates into a value ranging from rounded 14,000 to 48,000 baht per blend stainless steel in CO_2 avoided.
The calculation requires three input variables. The assumed costs for CO_2 which are derived from the international calculations and market developments of ETS systems and taxes, the expected and referenced CO_2 costs in Thailand and Asia and the basis and development of the assumptions from the first scrap bonus report. In the medium reference it reflects the expected CO_2 costs in Thailand, at about 88 US dollars in 2025. Secondly, a stable parameter was selected for the local environmental impact based on the assumptions of the first scrap bonus study. In this adjusted scenario, however, it only plays a subordinate role, as the environmental damage was not examined via the LCA either.

Calculation

$$\left(\begin{array}{c}\text{Estimated carbon cost for one ton } (CO_2e)\\ \mathbf{+}\\ \text{Cost for local environmental factor}\end{array}\right)$$

$$\mathbf{x}$$

$$\text{Avoided emissions } (CO_2e) \text{ per produced blend stainless steel } (6{,}71)$$

$$\mathbf{=}$$

$$\text{Scrap Bonus per ton of blend}$$

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[58] The Kingdom of Thailand | Ministry of Natural Resources and Environment - Policy Formulation and National Focal Point 2021.

[59] Deutschlandfunk.de 2024.

Table 3 shows the figures of the Scrap Bonus Thailand in baht (฿).

Table 3: Scenarios Scrap Bonus Thailand.
Source: Own creation.

Scenario	Carbon Cost per t-CO_2e	Carbon Cost per t blend	Non-CO_2	Total (rounded)
Scrap Bonus Thailand 2024 Low	฿1,938	฿12,981	฿1,356	**฿14,000**
Scrap Bonus Thailand 2024 Medium	฿3,139	฿21,030	฿1,356	**฿22,000**
Scrap Bonus Thailand 2024 Upper	฿6,975	฿46,733	฿1,356	**฿48,000**

Figure 14 displays the Scrap Bonus in baht per ton of stainless steel scrap blend depending on the assumption on the carbon price, i.e., the three references.

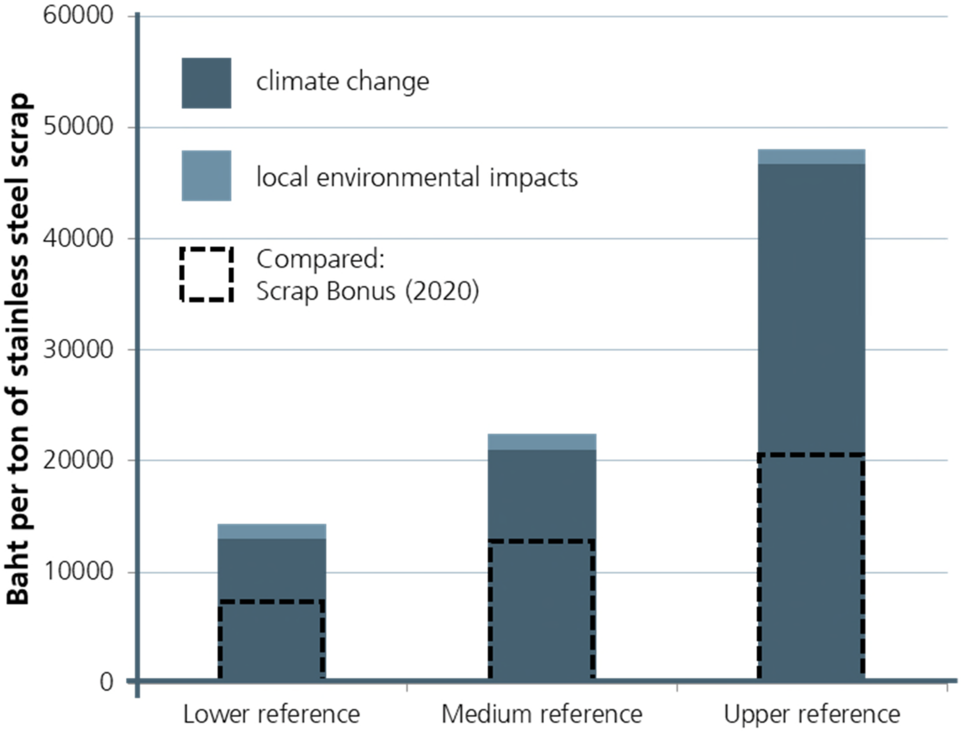

Figure 14: Scrap Bonus in Thailand in baht.
Source: Own creation.

The dark area in the bars reflects social benefits from greenhouse gas emission reduction. The light area represents those from other, local emission reductions. The dashed boxes show the corresponding Scrap Bonus from the 2020 study.[60]
The estimation considers an array of factors, including climate change assumptions and the local environmental context. The graph highlights that the Scrap Bonus is higher than

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[60] Pothen et al. 2020.

under the 2020 assumptions. This is partly due to the increased CO_2 savings of 6.71 tons CO_2 compared to 4.5 tons CO_2. Higher estimates of the cost of carbon further contributed to the higher Scrap Bonus.

The difference of about 114.81 % between the medium and high reference is 56.13 % from low to medium (adjustment of carbon costs over the last 4 years, e.g., EU-ETS) and upper reference is intended to clarify that the effort to mitigate climate change will be greater if targets such as the 1.5 °C target are not met.[61]So each ton of CO_2 saved contributes more because the “budget” gets smaller. A theoretical shortage is created, as mentioned in the study of Thailand’s Ministry of Natural Resources and Environment. Even if we work with low, medium and high reference points and not with time-based assumptions, it can be assumed that Thailand, because of its vulnerability to climate change, saves a disproportionately higher amounts of CO_2 now and over time.

A smaller part in the calculation of the Scrap Bonus is the local environmental impact of stainless steel recycling. Oryx Stainless Thailand’s plant operates with minimal local emissions, making it exempt from consideration in the Life Cycle Assessment. However, the plant contributes to emissions reduction by facilitating recycling processes at alternative locations, thereby circumventing activities like nickel mining and refining in Indonesia. This strategy is particularly relevant in Southeast Asia, where industries like nickel mining and processing in Indonesia face heightened scrutiny for their environmental impact.

Box 1: Nickel mining in Indonesia

Nickel mining and refining in Indonesia have significant environmental impacts, including deforestation, air and water pollution and greenhouse gas emissions. The production of nickel in Indonesia is particularly carbon-intensive, with every ton of the metal-equivalent produced emitting an average of 58.6 tons of carbon which is higher than the global average of 48 tons.[62]Nickel mining plays a crucial role in deforestation and the depletion of biodiversity. Within nickel mining concessions, a minimum of 5,331 hectares of tropical forests have been cleared, resulting in the release of around 2.04 million metric tons of greenhouse gases formerly sequestered as carbon within these forests.[63]The mining activities lead to large-scale pollution of coastal waters, the death of coral reefs, and the death of fish, impacting the livelihoods of local communities. The energy required for processing nickel ore is provided by coal-fired power plants, further contributing to environmental harm.[64]The environmental impact of nickel mining in Indonesia is a matter of concern and requires sustainable practices to mitigate its consequences.[65]This issue is therefore not just a local challenge, as nickel is used in the manufacture of batteries for electric cars with lithium-ion technology, for example, and demand continues to rise in other areas of application too.

By being part of the recycling value chain, Oryx Stainless Thailand sets a positive example for sustainable industrial practices in the region. In order to monetize this qualitative factor, an approach was chosen that is based on the 2020 Scrap Bonus and quantifies an approximate added value of recycling in the area of local emissions at 1.356 baht in Thailand. Our analysis focused on the climate impact and not on the environmental

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[61] IPCC 2016.

[62] Lee 2023.

[63] Climate Rights International 2024.

[64] IUCN NL 2024.

[65] Joe 2021.

impact due to a lack of data, a notable challenge in the region. This challenge is exemplified by the ecological damages caused by nickel mining in Indonesia (see box 1). If we look beyond the Scrap Bonus per ton of stainless steel scrap and consider Oryx Stainless Thailand's plant's annual savings of 556,000 t-CO_2e, we calculate a social added value of approximately 1.9 billion baht per year.

6 Policy implications and recommendations

6.1 Ecological implications

Using raw materials from recycling instead of primary raw materials can reduce greenhouse gas emissions in stainless steel production substantially. Each ton of stainless steel scrap processed by Oryx Stainless Thailand saves 6.71 tons of CO_2e. These gains stem primarily from replacing carbon intensive ferroalloys. CO_2 emission reductions due to using stainless steel scrap mitigate climate change and, thereby, save social costs of carbon. The indicator Scrap Bonus quantifies these positive effects in monetary terms.

Thailand, a nation particularly threatened by climate change, benefits disproportionately from greenhouse gas mitigation. Further positive ecological effects of stainless steel scrap use are considered qualitatively in this study. They include the conservation of exhaustible resources and the protection of biodiversity, in particular in nickel and chrome mining.

6.2 Economic implications

A flourishing circular economy not only creates ecological advantages, but also economic benefits for Thailand. (Stainless) steel recycling can serve as an example for these benefits. Three of these benefits are highlighted in this section.

First, the recycling industry directly creates jobs and value added for the Thai economy. Therefore, it contributes to Thailand's economic growth. In Germany, for comparison, the steel recycling industry provides approximately 37,000 jobs.[66]

Second, the steel recycling industry provides domestic raw materials from recycling to downstream industries. Therefore, it reduces Thailand's dependency on imported raw materials and provides a domestic resource to support Thai industries' international competitiveness. Stainless steel recycling in particular enables domestic supply of high-value materials such as nickel and chrome. The domestic availability of raw materials from recycling, such as stainless steel scrap, will grow as Thailand develops economically because the stocks of recyclable materials accumulated in a nation increase with the size of its economy.[67]

Third, raw materials from recycling allow firms in Thailand to produce low carbon materials. These materials can be sold to customers exhibiting willingness to pay for low carbon products. Being able to produce low-carbon or even carbon-neutral products can constitute a competitive advantage in the presence of carbon border adjustment mechanisms such as the EU's Carbon Border Adjustment Mechanism (CBAM).[68]The more comprehensive these mechanisms become and the more nations introduce them, the bigger the competitive advantage.

6.3 Policy recommendations

Strengthening the domestic recycling industry creates both economic and ecological advantages for Thai society. To fully realize these benefits, policy makers should ensure a level playing field for raw materials and provide favorable operating conditions to recycling industries. We derive five recommendations from the results of this study.

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[66] Hiebel and Nühlen 2016.

[67] Pauliuk et al. 2013.

[68] Taxation and Customs Union 2024.

Strengthen carbon pricing

In the absence of climate policy, emitters do not pay a price for releasing greenhouse gases into the atmosphere. In economic terms, they generate an external effect or externality. Emitters reap the benefits of burning fossil fuels, while the negative effects -climate change- harm others. These damages are not reflected in the price mechanism. Therefore, too much CO_2 is emitted and fossil fuels as well as carbon-intensive products are too cheap compared to low carbon products. The absence of a price on carbon emissions thus creates unfair advantages for dirty goods.

A sufficiently high price on CO_2 emissions "internalizes" the Scrap Bonus into the price mechanism. In the case of stainless steel production, it lowers the cost of using scrap compared to that of using ferroalloys. In other words: Carbon pricing makes climate neutral products more competitive by ensuring that prices reflect the true social costs. Box 2 illustrates the underlying economic mechanisms.

Box 2: External effects and their internalization

This box illustrates how negative externalities such as greenhouse gas emissions distort market outcomes and how internalizing them corrects these distortions.

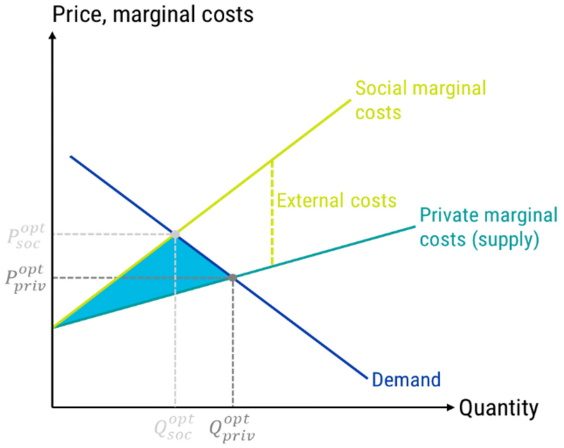

Figure 15: Markets & External Costs.
Source: Own creation.

Figure 15 displays supply and demand on a market, for instance that for ferronickel, in a stylized fashion. The horizontal axis reflects the quantity of ferronickel, the vertical axis the price and the marginal costs of manufacturing it. Marginal costs are the costs of making the next unit of ferronickel. The blue line represents the demand for ferronickel. It is falling in price: The higher the price, the less ferronickel is used. The dark green line represents the private marginal costs which producers face when manufacturing ferronickel (e.g., costs of labor and intermediate inputs). In a competitive market, private marginal costs correspond to the supply. Firms supply as long as their marginal costs are covered.

Manufacturing ferronickel is associated with greenhouse gas emissions. In the absence of climate policy, these emissions are not accounted for by the producers. From a societal standpoint, however, the damages caused by the emissions are as relevant as the private costs. For society, the social marginal costs (light green line) matter. They encompass both private marginal costs and the costs of climate change. The difference between these two are the external costs (dashed line).

The intersection of supply and demand determines price and quantity at the market equilibrium. Figure 15 highlights the difference between the social optimal outcomes and the outcomes in the absence of climate policy. Without climate policy, the price of ferronickel is too low and the quantity produced too high. The blue triangle reflects the societal welfare loss due to the externality.

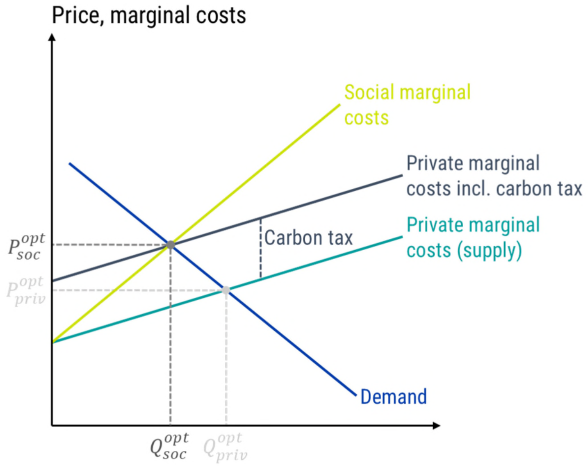

Figure 16: Market and Carbon price (tax).
Source: Own creation.

Figure 16 shows how a carbon price, e.g., a carbon tax (dashed grey line), corrects the externality. The tax puts a price on greenhouse gas emissions which now has to be taken into consideration by the producers. It internalizes the emissions in the price mechanism. In this simple example, the carbon tax enables reaching the socially optimal price and quantity.
This example illustrates: In the absence of climate policy, carbon intensive primary raw materials enjoy an unfair advantage compared to raw materials from recycling. Carbon prices level the playing field by internalizing the costs of climate change, making raw materials from recycling comparatively cheaper and more economically attractive.

Prices on greenhouse gas emissions can be introduced through carbon taxes or through emissions trading systems. Carbon taxes determine a price on greenhouse gas emissions directly. Emissions trading systems such as the European Union Emissions Trading System (EU ETS).
Currently, the Voluntary Thailand V-ETS (see Chapter 5.4.3) is established and will be improved within the process. The experience gained in this program should be used to implement a suitable carbon pricing model that includes as much of the emissions as possible. We recommend advancing the current climate policy efforts in Thailand and to strive for a comprehensive and ambitious approach to carbon pricing. As a positive side effect, this would also ease exporting to the European Union once the CBAM is in force. Furthermore, carbon pricing should not only be strengthened in Thailand but globally. Climate change is a global challenge and thus should be tackled globally. Furthermore, the absence of CO_2 prices also distorts international competition.

Extend the Bio-Circular-Green Economic Model to scrap metals

The Bio-Circular-Green (BCG) Economy Model is a comprehensive approach aimed at fostering sustainable economic growth through the integration of three distinct policies: Bio-Economy, Circular Economy and Green Economy.
In particular, the Economic Transformation with BCG Model, Thailand’s post-COVID sustainable development strategy, emphasizes the exploitation of knowledge, technology and innovation to create economic value to its strength and potential in natural resource wealth, cultural diversity and nurturing spirit. The BCG model has been introduced to enable sustainable and inclusive growth in line with the UN Sustainable Development Goals (SDGs) and the Sufficiency Economy Philosophy (SEP). The model aims at applying the concepts of bioeconomy, circular economy and green economy to develop high value products and services that are eco-friendly and require less resource input, while conserving natural and biological resources.[69]
Stainless steel scrap in general and austenitic stainless steel scrap in particular are forerunners of closed material loops. According to a study conducted by the Karlsruhe Institute of Technology, approximately 95 % of stainless steel is recycled at the end of

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[69] National Science and Technology Development Agency 2024.

its lifetime.[70]As the study shows, the recycling of (stainless) steel prevents local and global damage to nature and people. It can therefore contribute to the BCG and, above all, strengthen the circular economy beyond stainless steel.

Provide efficient operational conditions for recycling industries

As any other sector of an economy, recycling industries depend on an efficient regulatory environment and a well-developed infrastructure. Providing good operational conditions for the recycling sector facilitates achieving the ecological and economic benefits of a circular economy.

The Thailand Board of Investment (BOI) should put more focus on its support for recycling activities and the provision of high-value raw materials from recycling. The current list of activities eligible for investment promotion includes the activities "recycling and reuse of unwanted materials", "sorting/separation service of unwanted materials, which is located in an industrial estate or promoted industrial zone" and "sorting/separation service of unwanted materials"[71]. Facilitating activities which separate and process raw materials from recycling to increase their economic and ecological value would complement these existing activities.

Furthermore, stainless steel and many other recycling companies could be seen as "pure play" green companies. In other words, they derive their revenues from the ecologically beneficial activity of providing raw materials from recycling. These ecological benefits should be reflected in financing conditions in a similar fashion as for other sustainable sectors.

More generally, it is important to be aware of the role of the circular economy within a sustainable economy. Closing material cycles is a crucial part of the transformation towards climate neutrality and highly complementary to other parts of this transformation such as the shift towards green energy.[72]

A well-developed and well-checked regulatory framework is important to keep non-compliant (environment, tax, regulations, etc.) market participants out of the recycling industry. Over-regulation, however, hampers the provision of raw materials from recycling and reduces the benefits for the Thai economy. Therefore, regulatory bodies should aim to balance the benefits of regulation with the danger of over-regulation.

Support research, development and education

Recycling industries depend on a well-trained workforce and innovative processes to maximize the benefits they provide for the circular economy in Thailand.

Workers' training and experience are crucial ingredients for (steel) recycling. Training should include both university education in dedicated degrees and on the job training. Initiatives by the recycling industry could complement public education programs. Recent developments include enhanced educational programs that focus on upskilling professionals with specialized knowledge in various aspects of recycling operations. An example of current development is the Thailand Waste Management & Recycling Academy, offering guidance to eleven startups tackling recycling issues from varying standpoints.[73]Providing practical training for workers in the steel recycling sector, the German steel recycling industry's Institute for Scrap and Metals (ISM, Institut für Schrott und Metalle) could serve as a prototype for Thailand.

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[70] Stainless Steel World Publisher 2023.

[71] The Office of the Thailand Board of Investment 2023.

[72] Ellen Macarthur Foundation 2021.

[73] SecondMuse 2023.

High-quality raw materials from recycling will be in particularly high demand in the future. Yet contaminants in scrap are likely to be a major challenge for recycling sectors in the future.[74]Therefore, support for developing innovative approaches to sorting and processing scrap is an important element in a comprehensive strategy to facilitate the circular economy. Providing high-quality tailored blends of raw materials from recycling to its customers, the stainless steel recycling sector can serve as a forerunner.

Supporting research, development and training also encompasses the economic as well as business side of the circular economy. Instruments such as providing data on raw materials from recycling or training experts (e.g., for life cycle assessments) complement the aforementioned measures.

Facilitate free trade with raw materials from recycling

Raw materials from recycling in general and stainless steel scrap in particular are globally traded commodities. In 2022, approximately 4.3 million tons of stainless steel scrap were sold across borders.[75]Stainless steel scrap exhibits a high value-to-weight ratio. Therefore, transportation costs obstruct trade less than in the case of carbon steel scrap.

Greenhouse gas emissions are global pollutants. Their effect on climate change does not depend on where they are emitted. Conversely, the positive effects measured by the Scrap Bonus in this study do not depend on where stainless steel scrap is used.

Free international trade ensures that raw materials from recycling are used where they generate the highest benefits. Trade barriers distort this process and lead to undesirable side effects. Consider the case of an export tariff introduced by a scrap-exporting nation as an example:

The export tariff makes scrap more expensive for foreign customers. Higher scrap prices reduce the use of raw material from recycling abroad along with the associated emission savings. The domestic recycling industry is, at least partially, cut off from their foreign customers. Reduced scrap demand lowers the domestic scrap price. A lower price of raw materials from recycling makes collecting and processing scrap less profitable, reducing the domestic supply, in particular if the domestic industry is unable to uptake the additional scrap not exported any more. Trade barriers, thus, distort prices and can reduce scrap collection and processing, eventually reducing scrap use and harming global climate policy ambitions.

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[74] Daehn et al. 2017.

[75] United Nations 2022.

7 Conclusion and outlook

The transformation of the current linear economic model of "take-make-use-dispose" into a circular economy in which inputs are reduced, products are reused, and materials are recycled is a crucial prerequisite for any carbon neutral society. The circular economy also reduces the need to extract and process primary raw materials. Thereby, it not only prevents local pollution and loss of biodiversity but also mitigates the dependency on imported raw materials for resource-scarce countries.

Located in Southeast Asia, the Kingdom of Thailand is particularly vulnerable to climate change. According to the Global Climate Risk Index 2021, Thailand was the ninth most affected country by human impacts and direct economic losses from weather-related loss events between 2000 and 2019. Thailand is also dependent on imports of many raw materials to fuel its growing economy. Embracing the circular economy's opportunities, the Thai government adopted its Bio-Circular-Green Economic Model in 2021.

Stainless steel is a type of steel particularly resistant to corrosion. Its versatility, durability, and its visual appeal have made it a sought-after material in applications ranging from industrial machinery over kitchenware to architecture. Its attractiveness is reflected in its growing production. Global stainless steel production rose from about one million tons in 1950 to 58.4 million tons in 2023.[76]

Stainless steel can be recycled without a loss of quality and is, in fact, recycled almost completely. Re-melting stainless steel scrap leads to substantial reductions in greenhouse gas emissions compared to production from primary raw materials such as iron, chrome, and nickel. It furthermore reduces dependency on scarce raw materials, in particular nickel. Stainless steel recycling, thus, can be seen as an excellent example to showcase the benefits of the circular economy.

This study quantifies the societal benefits of stainless steel recycling in Thailand based on the example of the stainless steel recycling company Oryx Stainless Thailand and its operations near Bangkok. To this end, it quantifies the Scrap Bonus for stainless steel scrap in Thailand. The indicator Scrap Bonus measures "the social cost savings due to the environmental burdens avoided when using one ton of steel scrap" (Fraunhofer IMW 2022[77], Fraunhofer IMWS 2020[78]). Transforming emission savings from tons of CO_2 into money, the Scrap Bonus allows for an intuitive understanding of recycling's benefits for climate and society.

Each ton of stainless steel scrap collected, processed, and shipped to its customers by Oryx Stainless Thailand saves approximately 6.71 tons of CO_2e. The same amount of greenhouse gases is emitted when operating a commercial air conditioner in Thailand for 2.55 years. In 2021, Oryx Stainless Thailand saved 556,000 t-CO_2e in total.

Converted into money, one ton of stainless steel scrap blend provided by Oryx Stainless Thailand generates a Scrap Bonus of between 14,338 baht and 48,089 baht. In other words: Each ton of recycled stainless steel scrap saves environmental costs of up to almost 50,000 baht. The range of these values reflects the uncertainty about the costs of climate change. Following the Thai government's estimates, we employ social costs of carbon between 88 US dollars per t-CO_2e and 368 US dollars per t-CO_2e to compute the Scrap Bonus.

A number of policy recommendations are identified which support reaping the ecologic as well as the economic benefits promised by the circular economy of stainless steel. A comprehensive pricing of carbon emissions, both in Thailand and beyond, is not only essential for successful climate policy but also generates economic incentives for the

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[76] worldstainless 2023.

[77] Pothen and Brock 2022.

[78] Pothen et al. 2020.

circular economy. Consequently, we recommend integrating metal recycling more deeply in the Bio-Circular-Green Economic Model.

Efficient operational conditions for recycling industries, ranging from infrastructure to financing opportunities, foster the success of the circular economy in Thailand. Supporting research and development as well as the training of workers helps the recycling sector to provide high-quality raw materials from recycling. Free trade with raw materials ensures that these raw materials from recycling are used as efficiently as possible to reduce CO_2e emissions.

Beyond illustrating the positive effects of stainless steel recycling for Thai society, the study also emphasizes the potential for international cooperation. Thailand is a forerunner of the circular economy in Southeast Asia. Thailand and Europe can benefit from sharing their experiences in setting up value chains for raw materials from recycling and conducting joint research. This cooperation helps both sides in achieving ambitious climate policy goals and generating new sources for sustainable raw materials.

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