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Greening the Scrap Metal Value Chain through Promotion of BAT/BEP to Reduce U-POP Releases from Recycling Facilities: Policy and Regulatory Framework

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Abstract

Thailand has implemented a strong and comprehensive system of regulations to effectively handle substances that pose threats to health and the environment. This includes specific legislation that clearly defines the roles of the various entities involved. Nevertheless, although there are extensive rules that cover a wide range of pollution sources, there is a noticeable lack of legislation specifically aimed at controlling dioxin and furan emissions from scrap metal smelters, which have a considerable impact on pollution levels. In order to address this disparity, suggested legislative actions aim to classify scrap metal smelters as controlled sources of contamination and establish criteria for dioxin and furan discharges. The objective of these measures, which consist of three proposed legislations, is to implement stringent emission restrictions and encourage the use of Best Available Techniques and Best Environmental Practices (BAT/BEP) to effectively reduce the impact of emissions. The proposed laws have been refined through stakeholder engagements, which included representatives from the public and corporate sectors, academics, and NGOs. These consultations aimed to ensure that the laws conform with international norms and commitments outlined in the Stockholm Convention. Thailand has conducted thorough evaluations of laws and regulations related to the accidental release of unintentionally produced persistent organic pollutants (U-POPs) emissions, in addition to legislative initiatives. As a result, proposed PCDD/PCDF emissions standards have been developed based on extensive analysis of existing literature. The first step in managing PCDD/PCDFs in secondary metal production is to set emission standards for different types of metals. This is done to encourage scrap metal recycling facilities to report the presence of PCDD/PCDFs in flue gas emissions. In addition, it is recommended that the government encourage the utilization of BAT and BEP for industrial waste recycling in order to decrease the presence of PCDD/PCDFs in the remaining waste. The involvement of stakeholders has played a crucial role in improving the proposed emission limits, guaranteeing more stringent regulation and alignment with health risk evaluations. Furthermore, financial incentives are essential in stimulating efforts to reduce PCDD/PCDFs, and industrialized countries such as the EU provide low-interest loans and credit guarantees to encourage the adoption of cleaner production processes. In Thailand, effective methods like subsidies, fiscal incentives, and eco-labeling programs have been recommended as ways to encourage the adoption of BAT and BEP in different industrial sectors. In this study, the most favorable strategy aims to offer customized incentives to businesses in order to promote the adoption of BAT/BEP practices. These incentives include financial support, subsidies for certification, and training

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programs. These activities demonstrate Thailand's dedication to reducing PCDD/PCDF emissions and adhering to global norms, thereby promoting environmental sustainability and safeguarding public health.

Keywords: *BAT/BEP, U-POPs, PCDD/PCDFs, Stockholm Convention, Scrap Metal, Economic Incentives, Emission Standards, Legal & Administrative Measures.*

Introduction

The economic structure of Thailand is strongly reliant on foreign trade, with exports accounting for over 58% of the country's gross domestic product (GDP) in 2021 (https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=TH). Although the delta version of COVID-19 has presented difficulties, Thailand's GDP growth rates for the years 2019 to 2022 depict a fluctuating economic trajectory (https://www.macrotrends.net/global-metrics/countries/THA/thailand/gdp-growth-rate). In 2022, the GDP growth rate reached 2.60%, marking a 1.11% increase from the previous year. In 2021, the growth rate stood at 1.49%, exhibiting a significant 7.56% increase compared to 2020, when the economy experienced a notable decline with a GDP growth rate of -6.07%. The growth rate for 2019 was 2.11%, indicating a 2.11% decline from the preceding year due to the global pandemic. The industrial and service sectors make a substantial contribution to the GDP, with important exports such as automotive parts, food processing, electrical components, and agricultural products (Bhongchirawattana, 2021). Millions of migrant laborers, mainly from neighboring countries, have been drawn to this economic activity (Mortensen, 2024). The mining sector, under the regulation of the Ministry of Industry (MI), the Ministry of Natural Resources and Environment (MNRE), and the Department of Primary Industries and Mines (DPIM), performs a crucial role, consistently producing more than 40 minerals.

Despite challenges like the US-China trade war and fluctuations in domestic consumption, the metallurgical sector significantly contributes to Thailand's economy (Juntueng et al., 2014). The presence of unintentionally produced persistent organic pollutants (U-POPs) in the environment raises concerns and emphasizes the necessity of regulatory intervention in Thailand (Choo Chuay et al., 2020a,b, 2022). Research indicates substantial emissions of U-POPs from industrial sources, such as boilers that utilize different types of fuels (Pongpiachan et al., 2013, 2016, 2021). Studies have shown that micro-emulsion technology is highly effective in decreasing U-POP emissions, highlighting the significance of clean technologies in reducing pollution (Pongpiachan et al., 2016). Occupational exposure to U-POPs (unintentional persistent organic pollutants) from industrial activities emphasizes the need for regulatory measures to protect public health (Pongpiachan et al., 2013, 2016, 2021). Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are extremely poisonous pollutants found in the environment (Fernandez-Gonzalez et al., 2015). They are classified as chlorinated organic compounds (Hutzinger et al., 1985). These substances are recognized for their ability to remain in the environment, accumulate in the food chain, and have the potential to create significant health issues in both humans and wildlife (Naito et al., 2003; Okumura et al., 2004). These health impacts include cancer, harm to the immune system, and problems with reproduction and development (Fernandez-Gonzalez et al., 2015).

The scrap metal industry is a sector that contributes to the emission of PCDDs and PCDFs into the environment (Tysklind et al., 1989). This sector includes the gathering, transformation, and reutilization of metallic refuse, which may encompass diverse chlorinated substances like

plastics, paints, and coatings. PCDDs and PCDFs can be unintentionally produced as by-products during metal recycling processes, particularly when high temperatures are used for melting and refining (Hung et al., 2015). PCDDs and PCDFs can be formed in the scrap metal sector through many pathways. The heat breakdown of chlorine-containing organic compounds found in the scrap material is a significant pathway. When waste metal containing PVC (polyvinyl chloride) or other chlorinated compounds is exposed to high temperatures, chlorine atoms can be liberated and combine with organic carbon sources, resulting in the creation of these harmful chemicals. In order to reduce the emission of PCDDs and PCDFs, the scrap metal sector has established a range of control measures. These measures consist of eliminating chlorinated materials from scrap prior to processing, employing advanced combustion technologies to reduce the production of PCDDs and PCDFs, and implementing pollution control devices like bag filters, electrostatic precipitators, and activated carbon adsorption systems to capture and eliminate these compounds before they are discharged into the air (Dias-Ferreira et al., 2016). Regulatory frameworks have been implemented at both national and international levels to oversee and restrict the release of PCDDs and PCDFs from industrial operations, particularly the scrap metal industry. The purpose of these laws is to safeguard human health and the environment by requiring industries to implement optimal methods and technologies to minimize the production and emission of certain hazardous substances.

In line with the Stockholm Convention, the goal of the "Greening the Scrap Metal Value Chain through Promotion of Best Available Techniques and Best Environmental Practices to Reduce Unintentional Persistent Organic Pollutant Releases from Recycling Facilities" initiative is to cut down on U-POP emissions from the metalworking industry. The initiative aims to improve environmental compliance and sustainability by assessing the scrap metal value chain and utilizing cutting-edge technologies. The collaboration between national legal frameworks and the mandates of the Stockholm Convention is crucial. This study aims to improve regulations, raise awareness, and strengthen the capability of the metallurgical sector. The project encompasses many elements, such as policy formulation, enhancing capabilities, conducting pilot demonstrations, and monitoring and evaluating progress. Its objective is to facilitate the spread of information and encourage the adoption of sustainable practices in the metallurgical industry.

Research Methodology

Definition of Stakeholders

The stakeholders in Thailand's metallurgical/scrap metal recycling industry are categorized into five groups: (A) collectors, (B) foundries, (C) downstream industries, (D) sellers, and (E) regulators. Table 1 has descriptions for every group. There are several parties involved in the scrap metal supply chain in Thailand. Accurately determining the numbers, particularly for groups A, C, and D, is challenging. Specifically, the majority of operators in groups A and D are typically tiny or medium-sized businesses, making it extremely difficult to accurately determine their true numbers. This is due to the fact that they generally operate without licenses and can easily engage in scrap metal activities without attracting attention. Estimating the precise numbers of individuals belonging to group C is challenging because there are many items available on the market that contain metals. It is only possible to make a decent estimation of the number of individuals in group B. Group E members control or exert influence on the environment in which groups A-D work in order to meet the demands of end users or customers and manage the inclusion or reintroduction of metal scraps into the supply chain. Figure 1 depicts

the relationship between each group. In addition, the relevant stakeholders within the supply chain of the scrap metal recycling industry were cross-checked with the databases of the Department of Business Development (DBD) and the Department of Industrial Works (DIW), as well as from other sources and on-site visits. Most stakeholders are business operators or the private sectors, which make up each sector or tier of the supply chain, referred to as Groups A–D, while the public sector is referred to as Group E, including authorities, local governments, foundations, Non-Governmental Organizations (NGOs), Congressional Budget Office (CBOs), associations, academia, etc. The numbers of stakeholders were identified with all sectors totaling 2,053 as classified in Table 2 and had been used as the population to determine the appropriate sample sizes.

Sample Size Determination

Taro Yamane's methodology and stratified random sampling were used to accurately determine the population size and choose stakeholders in Thailand's metallurgical and scrap metal recycling businesses. This process guarantees that the data gathered will be both representative and reliable, establishing a strong basis for further analysis and suggestions. Taro Yamane developed a formula that is a commonly employed statistical technique for calculating the appropriate sample sizes in survey research (Glenn, 1992; Yamane, 1973). The formula assists researchers in determining the required sample size to get a specific level of accuracy and confidence in their findings. The formula is stated as follows:

$$n = \frac{N}{1 + N(e^2)}$$

Equation (1)

Where *n*, N, and *e* stand for the sample size, the population size, and the level of precision, respectively. It is crucial to underline that N is the total number of stakeholders in each category (i.e. collectors, foundries, downstream industries, sellers, and regulators). Generally, *e* is typically expressed as a decimal. In this study, a 5% margin of error (i.e. $e = 0.05$) was selected as the margin of error reflects the maximum expected difference between the true population parameter and the sample estimate.

Survey Summary

The findings of the quantitative survey indicate a greater level of knowledge and increased awareness of the Stockholm convention, U-POPs, and BAT/BEP (see Table 3-4). Additionally, there is a more favorable attitude towards environmental inspections. Conducting comprehensive interviews provides numerous practical insights for the formulation of the new policy. The U-POP emission requirements can be attainable objectives, given the reasonable expenses associated with sample collection and analysis. Enforcement of legal and administrative measures can be achieved by allowing sufficient time for transition, providing knowledge support to stakeholders, and ensuring the integration of relevant authorities. Economic incentives, when properly combined, will encourage investments in BAT/BEP practices to decrease the release of U-POPs in the scrap metal recycling sector.

Group A/Collectors

The survey results indicate that Group A/Collectors exhibit a notably greater lack of information about the Stockholm Convention, U-POPs, and BAT/BEP in comparison to other stakeholder groups (see Table 3). Although Group D/Sellers also had comparable findings, collectors have a greater influence on minimizing U-POP releases due to their provision of raw materials to Group B/Foundries. Collectors typically address concerns such as dust or odors emitted by metal cutters, although the use of air filters is not necessary as dangerous waste is typically not present. Although it is not mandatory for collectors and sorters to measure U-POPs, they are well recognized for their vital contribution to reducing U-POP emissions in the metal recycling sector. Certain experienced collectors strictly follow rigorous environmental guidelines, employing BAT/BEP such as shredders, pressers, and cord-peeling devices instead of incinerating electrical wires.

The implementation of new laws and regulations will primarily have a significant influence on foundries while having a negligible effect on collectors or other participants in the metal recycling industry's supply chain. Nevertheless, it is imperative to impose explicit restrictions and controls on collectors to ensure compliance. At present, the issuance of licenses and permits for collectors is handled by numerous government bodies, resulting in a complex and convoluted process. Consolidating this into a comprehensive service could improve efficiency. Government assistance is crucial in providing expertise, promoting innovation, and offering extensive training to unlicensed collectors, their employees, and the communities around them. To promote investment in modern equipment, BAT/BEP, and dust avoidance measures, it is advisable to offer economic incentives such as subsidies, low-interest loans, and tax savings to collectors. Although these prospective technologies exist, they have not yet been fully realized or implemented.

Group B/Foundries

The survey findings reveal that stakeholders in Group B/Foundries exhibit a notable level of familiarity with the Stockholm Convention, U-POPs, and BAT/BEP (see Table 3). Furthermore, a significant number of them already comply with stringent environmental requirements, hence upholding elevated environmental standards. Foundries often have few concerns about new laws mandating regular measurement of U-POPs because of the existing rules imposed by DIW, Environmental Impact Assessment (EIA), and international audit standards. Nevertheless, the significant expenditure on measuring dioxin and furan necessitates the provision of subsidies for additional costs. It is necessary to classify foundries based on their size in order to choose the suitable technology, and emission regulations should be based on worldwide benchmarks. Stakeholder engagement is essential to establishing attainable emission standards. Before new rules come into effect, it is crucial to provide training and a transitional phase to ensure that foundry operators comply with and fully understand the laws. Government assistance, such as investment promotions, tax incentives, and funding, is essential to alleviate the financial strain associated with compliance.

The initial implementation of new regulations could be targeted at pilot foundries in order to establish precedents. The interaction between operators and enforcing agencies should be characterized by a consultative approach where guidance and help are provided. It is proposed to provide academic support to older foundries by implementing appropriate "add-on" technology and enhancing the skills of their workforce. Integration and online accessibility of data pertaining to regulations, technology, best practices, and trade barriers are crucial. Diverse

groups should be targeted by economic instruments and incentives; subsidies and tax incentives are suitable for large firms, while low-interest loans are advantageous for small enterprises. By utilizing a combination of mechanisms, such as a 70% loan paired with a 30% subsidy or tax exemptions along with low-cost measurement, it is possible to incentivize investment in BAT/BEP. Implementing tax incentives for environmental investments and streamlining application processes will facilitate prompt decision-making. While the concept of a "green metal" label may not have widespread recognition in Thailand, it has the potential to be incorporated into MIT (Made in Thailand) programs. Additional efforts encompass streamlining bureaucratic procedures, establishing a connection between U-POPs and carbon credit, and incentivizing environmentally sustainable industries to have access to privileges.

Group C/Downstream Industries

The survey results for Group C, which represents downstream industries, were inadequate because the stakeholders believed that the project's outputs had little impact on them. This perception resulted in limited participation in the survey. Nevertheless, the individuals who did take part contributed significant perspectives. Downstream companies, which produce goods that contain metal, procure raw materials from foundries and are already in adherence to EIA requirements and many ISO standards. Their manufacturing procedures release negligible amounts of U-POPs, prioritizing the management of other pollutants. Stringent implementation of environmental rules in foundries is essential, yet it may result in elevated environmental expenses for downstream businesses. The incorporation of U-POP reduction into the Thai Industrial Standard by the Thai Industrial Standard Institute (TISI) could yield advantageous outcomes. Green metal labels are deemed superfluous unless specifically requested by customers. Economic instruments and incentives tailored for these sectors should be uncomplicated and minimize superfluous bureaucracy. In the end, initiatives should strive to enable operators to achieve sustainability on their own, for example, by obtaining ISO certifications or other applicable standards.

Group D/Sellers

A multitude of samples were gathered from this particular set of stakeholders, as indicated by the survey. The results indicate that they have the lowest level of concern over the Stockholm convention, U-POPs, and BAT/BEP (see Table 3). There is no obligation for sellers of metal products to measure U-POPs. They will not be impacted by the enactment of laws and regulations. They serve as intermediaries between foundries, downstream industries, and end customers, thereby following the principle of "Buy Cheap, Sell Cheap, or Buy Expensive, Sell Expensive." Government assistance is unnecessary for sellers of metal items.

Group E/Regulators

Based on the social survey, non-business stakeholders in this group possess a strong understanding of the significance of the Stockholm Convention, U-POPs, and BAT/BEP (see Table 3). They offered useful recommendations throughout the comprehensive interviews. The Ministry of Industry has the authority to establish emission guidelines for U-POPs and make relevant notifications. The public and commercial sectors can conduct U-POP measurements depending on the preparedness and technological capabilities of their laboratories. However, Thailand currently does not have enough certified laboratories to perform large-scale measurements. There is a need to design measurement methods that are innovative, safe, and cost-efficient. It is essential for new policies to be in accordance with the 20-year National

Strategy, the National Economic and Social Development Plan, and the BCG Economic Model. Communities residing in close proximity to industrial zones regularly encounter issues related to unpleasant odors and excessive noise. However, the occurrence of chemical leaks is somewhat less worrisome, thanks to efficient communication and corporate social responsibility (CSR) initiatives. It is necessary to customize new measures according to Thailand's specific circumstances, offering explicit instructions for operators and taking into account the varying sizes and capacities of plants.

Operators must be provided with explicit instructions about the selection and utilization of BAT/BEP technologies. These guidelines should include a comprehensive work plan that outlines the expected results for different sub-groups and sizes and involve the participation of various government bodies. It is essential to have a digital platform that combines all agencies and creates complete Key Performance Indicators (KPIs). The new legislation should adopt a more permissive stance towards operators who currently comply with international standards such as ISO. The government should provide educational services, particularly tailored for small businesses. The use of economic methods and incentives should be combined with the current Green Label regulations. Subsidizing funds should be accompanied by explicit criteria that take into account repayment periods, net present value, and return on investment to guarantee long-term viability and feasibility.

According to the survey results as illustrated in Table 4, Group E (Regulators) encounters the most significant challenges and responsibilities in comparison to Group A (Collectors), Group B (Foundries), Group C (Downstream Industries), and Group D (Sellers). Regulators have the duty of supervising compliance, enforcing environmental standards, and promoting sustainable practices, which adds to the difficulties they face. The primary obstacles involve compelling enterprises to make substantial investments in enhancing production capacity and efficiency (rated at 4.45), allocating resources towards adopting innovative technology to minimize the release of U-POPs (4.27), and closely monitoring U-POP emissions to uphold acceptable levels (4.30) (see Table 4). In addition, authorities encounter significant challenges when it comes to mandating industries invest in enhancing their production processes and adopting new technologies that align with their production capacity (4.36). They also confront difficulties in promoting customer acceptance and preference for environmentally sustainable products (4.10). The elevated levels of perceived hurdles arise from the necessity for comprehensive regulatory frameworks, significant initial investments, and continuous support to ensure industries adhere to environmental requirements. Regulators must establish and execute efficient surveillance systems, even in the presence of financial and technical constraints encountered by smaller businesses. In addition, it is crucial for them to guarantee that investments made in technical advancements result in measurable environmental advantages, all while maintaining economic feasibility for organizations. Facilitating customer endorsement for environmentally friendly products necessitates the synchronized endeavors of manufacturers, consumers, and policymakers. To tackle these difficulties, a comprehensive strategy is required that includes financial incentives, strong monitoring systems, and collaboration among all industrial sectors to promote lasting improvements throughout the industry.

Health Risk Assessment of PCDD/PCDFs

Evaluation of Suitable Emission Concentration Using Health Risk Assessment was suggested to be added to the study for Thailand’s emission standard values. The incremental lifetime cancer

risk (ILCR) for the inhalation pathway were calculated using USEPA's methodology as following equation (Ajay et al., 2022);

$$DED_{inh} = \frac{C_{air} \times IR \times F \times ED}{BW \times AT}$$

Equation (2)

$$ILCR_{inh} = \frac{DED_{inh} \times IUR \times BW}{IR}$$

Equation (3)

Where DED_{inh} is Daily exposure dose through inhalation (ng kg^{-1} day^{-1}), C_{air} is concentration observed in the air (ng-TEQ m^{-3}), IR is inhalation rate (m^3 day^{-1}), F is frequency of exposure (day $year^{-1}$), ED is Exposure Duration (year), BW is Body weight (kg), AT is Average Time (day), IUR is Inhalation Unit Risk factor (m^3 ng-TEQ^{-1}), and $ILCR_{inh}$ is the incremental lifetime cancer risk for the inhalation pathway which is dimensionless.Combining the two equations yields

$$ILCR_{inh} = \frac{C_{air} \times IUR \times F \times ED}{AT}$$

Equation (4)

Rearrange to get C_{air} yields

$$C_{air} = \frac{ILCR_{Inh} \times AT}{IUR \times F \times ED}$$

Equation (5)

The $ILCR_{inh}$ was set the 10^{-4} for the probably highest chance to get the cancer throughout the 70 years. AT is 25,550 days. However, US-EPA has evaluated the IUR of 0.033 m^3 ng-TEQ^{-1} for 2,3,7,8-Tetrachlorodibenzodioxin (TCDD). The frequency of exposure was estimated to 350 day $year^{-1}$ with the exposure duration of 30 years. Substitute these values to Eq (5) obtain the maximum emitted concentration of 0.007374 ng-TEQ m^{-3} for TCDD. For all interested 17 PCDD/PCDFs, the equivalent toxic concentrations were estimated to by 17 times higher than that of TCDD which is about 0.125 ng-TEQ m^{-3} or 0.1 ng-TEQ m^{-3} for the first digit decimal application.

Methodology to Establish Thailand Dioxin Standards for Air Emission Control from Scrap Metal Recycling Facilities

Thailand does not have an adequate database on the quantification of PCDD/PCDFs originating from the scrap metal business. At present, the available data is limited to the records of the Pollution Control Department (PCD), which conducted measurements on 17 factories a decade ago. Additionally, the expense associated with measuring PCDDs and PCDFs is also considerable. In order to fill this lack of data, a method was selected that involved using PCDD/PCDF values from worldwide standards in different nations as a reference. While there may be variations in these values among different countries (see Table S6-S10), it is necessary

to organize them in ascending order of concentration and designate them as quartiles (Q1–Q4), splitting them into four intervals. The policy establishes the value in Q1, which corresponds to the first 25% of the data, as the standard value. This is regarded as the most rigorous measurement value.

The proposed policy utilizes the concept of quartile range to determine the position of data and establish the ranges for National Dioxin Emission Standards (NDES) in different types of scrap metal industries, including metal and steel smelting plants, steel foundries, copper smelters that use secondary copper as raw materials, and aluminum smelters that use secondary aluminum as raw materials. The NDES of Thailand can be derived from the following four processes:.

Step 1: Gathering Current Emission Regulations

The literature was reviewed to collect the current PCDD/PCDF emission limits for the metal industry in various nations. The data sources may consist of published studies in international academic journals or official documents from government agencies, such as the National Implementation Plan or National Action Plan, as well as laws, regulations, and pertinent reports (see Table S6-S10). Nevertheless, each country has its own unique unit of measurement for concentrations, which may vary slightly in specific aspects. Therefore, the emission standard that has been gathered shall be reported as ng-TEQ m^{-3}, regardless of specific technical terms such as WHO-TEQ or I-TEQ for the mass of PCDDs or PCDFs and Nm^3 (normal cubic meter), Rm^3 (reference cubic meter), or Sm^3 (standard cubic meter) for the air volume. However, it is important to mention that the prior measurement unit for PCDD/PCDFs from other sources used in Thailand was I-TEQ Sm^{-3}.

Step 2: Arrange the Values in a Specific Order

The collected emission standards will be sorted and ranked in ascending order, with the lower rank indicating a lower value of the standard.

Step 3: Partitioning the Data into Four Equal Segments

The PCDD/PCDF emission standards will be divided into four equal sections based on the idea of quadrile rank. The three quartile ranks, specifically Rank Q1, Rank Q2, and Rank Q3, serve as the dividing points for the partition. The calculation of these ranks is based on the inclusive quartile idea, which is defined as follows:

$$RankQ_r = 1 + \frac{r(N-1)}{4}$$

Equation(6)

The variable "*r*" represents the rank number, whereas "*N*" represents the total amount of data. Once the quartile ranks are calculated, the value corresponding to each rank will be established utilizing the notion of proportionality. These numbers are referred to as quartile points, specifically Q1, Q2, and Q3.

Step 4: Calculating the Quartile Ranges

The data is divided into four equal parts, with each part being referred to as a quartile range. The 1st quartile range, often known as the Q1 range, refers to the range of the lowest 25% of values

in the emission standard. The second, third, and fourth quartile ranges, also known as Q2 range, Q3 range, and Q4 range, respectively, are defined as the intervals of the emission standard that encompass 25% to 50%, 50% to 75%, and greater than 75% of the sorted data, respectively.Once the quartile ranges for PCDD/PCDF emission requirements are established, industrial facilities must provide reports on their PCDD/PCDF emission concentrations together with the corresponding quartile ranges. The proposed policy aims to enforce the use of BAT/BEP in existing industrial plants. This would effectively reduce the concentration of U-POP emissions within the specified range (Q1) within a specific timeframe as mandated by the legislation or regulation (e.g., within five years). The regulatory measure could potentially take the form of a notification issued by the Ministry of Industry. Nevertheless, it is anticipated that the recently established plants, following the enactment of the rule or regulation, will be able to attain the Q1 range.

Results & Discussion

Establishment of National Emission Standards of PCDD/PCDFs

This study involved a review of the international standards for PCDD and PCDF emissions from metal recycling facilities in different nations. These standards were then used as a foundation for formulating requirements specifically for Thailand. The gathered criteria were systematically evaluated and subjected to statistical analysis in order to establish the national emission standards for PCDD and PCDFs (see Table 6). The quartile ranking method, as recommended in Section 2.5, was employed for this purpose. Data on the precise levels of PCDD/PCDFs in the air released by 17 iron and steel recycling operations were collected. The study found that 13 out of the 17 metal recycling plants, or 76.4%, had emissions of PCDDs and PCDFs into the air that were below the threshold value of 0.2 ng I-TEQ m^{-3}, which is the standard for setting regulations. This indicates that the suggested standards have both theoretical soundness and practical feasibility. Nevertheless, it is important to acknowledge that several facilities currently fail to meet these criteria. Furthermore, it is essential to acknowledge that the narrow range of samples, which includes only 17 facilities, is insufficient to establish a strong basis for the formulation of national policies in Thailand. Therefore, it is not recommended to promptly enforce emissions regulations for PCDDs and PCDFs originating from metal recycling operations in Thailand. Instead, it is advisable to consider a transitional period, allowing businesses sufficient time to prepare for future legislative and regulatory measures. Operators must make the appropriate arrangements for collecting and analyzing samples in order to create a thorough database on PCDD and PCDF emissions from metal recycling operations in Thailand. The study additionally included a health risk evaluation to establish suitable emission values for decision-making, as explicitly demonstrated in Section 2.4. The inhalation pathway's incremental lifetime cancer risk (ILCR) was determined using the methods provided by the United States Environmental Protection Agency (US-EPA), as outlined in equations 2 to 5. The exposure data is derived from the Inhalation Unit Risk (IUR) of 0.033 ng-TEQ m^{-3} for TCDD, with a frequency of 350 days per year over a period of 30 years. The risk value was determined based on the maximum emission concentration of 0.007374 ng-TEQ m^{-3} for TCDD, while the estimated concentration for the overall 17 PCDDs and PCDFs was 0.1 ng-TEQ m^{-3}.

The establishment of new standards will require the development of further regulatory measures. DIW or DPIM must create comprehensive guidelines or manuals to assist metal recycling facilities in transitioning to compliance with BAT/BEP. This will ensure that they meet the prescribed pollution emission standard. Furthermore, it is crucial for the DIW or DPIM to create

clear mechanisms within the regulatory framework to deal with situations where emission levels from industries exceed the set limitations. This technique will offer a thorough and inclusive assessment of the pollution capacity of these facilities across the entire country. Furthermore, it is imperative to devise strategies to enhance awareness of BAT and BEP in order to aid facilities in meeting forthcoming legal obligations. This will enable them to enhance their production methods and pollution control systems, thereby ensuring compliance with upcoming emission standards. The emissions of PCDDs and PCDFs from metal recycling operations into the environment occurs through three main routes: airborne emissions, discharge of wastewater, and accumulation in industrial residues. Multiple nations have implemented regulations to regulate air pollution from these types of installations. Nevertheless, only South Korea and Japan have established supplementary regulations to manage dioxins and furans in wastewater. In Thailand, there is insufficient information available on the presence of PCDDs and PCDFs in the effluent of both ferrous and non-ferrous facilities. Furthermore, there is a lack of evaluation and recommendations for setting an appropriate effluent standard for these substances. As previously stated, the PCD should initiate a project to examine the practicality of implementing PCDD and PCDF regulations in waste water from both ferrous and non-ferrous businesses. This can be accomplished by requesting financial support from Global Environment Facility (GEF). The Ministry of Industry can establish a notification to enforce a norm for PCDD and PCDF levels in effluent.

Two specific categories of enterprises, iron scrap recycling factories and non-steel or iron scrap recycling factories, were subject to the national emission regulations PCDD/PCDFs. Nevertheless, small (S) or medium (M)-sized factories may have lower potential compared to large (L)-sized factories. Factors to examine include the appropriateness of existing technology and the provision of readiness information to operators. We categorize factories into three sizes: S, M, and L, with the aim of implementing economic support measures. The statistical principles use the 33^{th} and 66^{th} percentile values as the criteria for categorizing sizes (S, M, and L) according to the factories' machinery power, measured in horsepower units, as shown in Figure 2. Figure 2 illustrates the distribution of total machine horsepower (HP) for two categories of recycling plants: ferrous (Group No. 59 and its affiliates) and non-ferrous (Group No. 60 and its affiliates) facilities. The group of ferrous recycling plants' median horsepower was 1,056 HP. Meanwhile, the cluster of non-ferrous recycling facilities had a median value of 324 horsepower. Figure 3 illustrates the distribution of total machine horsepower (HP) in two separate groups of recycling plants: ferrous plants (factory group no. 59 and associates) and non-ferrous plants (factory group no. 60 and associates). Each bar in the graph represents a range of 100 HP. Both histograms display data in the range of 0 to 5,000 HP to enable a direct comparison. The 66^{th} percentile values of 2,082 horsepower (HP) for ferrous recycling plants and 495 HP for non-ferrous recycling plants will serve as benchmarks for categorizing each kind of facility. Consequently, we categorize 115 of the 173 ferrous plants assessed as SM and 58 as L. In contrast, non-ferrous recycling facilities possess a more extensive collection of 475 plants. Out of them, there are 317 plants designated as SM, each having a horsepower equal to or less the 66^{th} percentile value of 495 HP. Additionally, there are 158 vehicles categorized as L, each with horsepower beyond this 66^{th} percentile value. Nevertheless, quantifying the output of products and the pollution caused by the plant solely based on machine power measured in horsepower may not provide an accurate representation. Practically, it would be more appropriate to use the production capacity measured in tons per day as a standard for categorizing a plant's size. Because there is limited information on production capacity in the DIW's database, this study has temporarily relied on machine power to categorize plant size. If adequate data on plant

production capacity becomes available in the future, the relevant agencies can use this information to identify plant size more accurately, potentially making it a criterion for classification.

Legal and Administrative Measures

Ferrous and non-ferrous metal manufacturing are designated by the United Nations Environment Programme (UNEP) as major contributors of dioxins, which are explicitly recognized by the Stockholm Convention as U-POPs. The 2nd National Implementation Plan for Persistent Organic Pollutants (NIP/POPs) in Thailand highlights that metal manufacturing is a significant contributor to U-POPs, accounting for roughly 277.8 g-TEQ every year. This amount represents 21% of the country's total dioxin emissions in 2017. This places the industry in the third position, trailing behind garbage incinerators and open-air incineration. Nevertheless, the metal industry in Thailand currently lacks clear U-POP guidelines, even though criteria for dioxin and furan have been created for other facilities, including waste incinerators and cement plants. Hence, it is imperative to establish precise criteria for regulating the release of PCDDs and PCDFs during metal manufacturing, specifically from exhaust outlets in scrap metal facilities, in order to effectively manage dioxin emissions originating from this principal source.

The second NIP/POPs plan (2023-2027) is designed to match Thailand's 13th National Economic and Social Development Plan. Its objective is to develop complete environmental quality standards, which include setting release requirements for POPs emitted from pollution sources as well as contamination standards for food and drinking water. To minimize the emission of PCDDs and PCDFs, it is crucial to regulate pollution at the primary source due to the significant impact of scrap metal facilities on air pollution and the food chain. Therefore, it is crucial to implement legislation within the next 1-2 years that establishes specific limits for dioxin and furan levels in metal melting, smelting, and scrap metal facilities. This is necessary in order to effectively regulate pollution and safeguard the environment.

Two Approaches for Implementing the Notification of PCDD/PCDFs Standard

Two techniques, namely the Single Notification Approach (SNA) and the Dual Notification Approach (DNA), were suggested to set standards for the release of PCDD/PCDFs from scrap metal smelting facilities. The Single Notification Approach entails the issuance of a singular notification that establishes both emission regulations and requirements for data reporting. The Royal Gazette requires factories to promptly disclose data. Furthermore, they must adhere to emission requirements for three years and achieve complete compliance within five years. This methodology enables immediate recognition of standards and offers a five-year grace period for factories to adapt their procedures. The DNA divides standards into two independent notifications over a five-year period. The initial notification necessitates the submission of PCDD/PCDF emissions data to create a database for norm reevaluation. The subsequent notification, given after a span of five years, defines the precise emission standards. This technique provides factories with extra time to adapt their operations, but it could potentially postpone the implementation of standards. Moreover, the detection of PCDD/PCDF emissions from metal recycling facilities, using financial support to create a comprehensive database was also recommended. This data will assist in establishing legislative benchmarks and is in line with the DIW recommendation to utilize UNIDO financial support for representative factory measurements.

On October 27, 2023, during consultations with the Board of Investment (BOI), the advice was to seek BOI promotion for the development of dioxin standards. The importance of adopting a comprehensive strategy to reduce environmental consequences was underlined. The SNA is considered appropriate for aligning with BOI measures since it promotes timely establishment and knowledge of standards while allowing for a transition period to achieve compliance. This strategy also facilitates the creation of a valuable emissions database that can provide information for future legislative actions and modifications to standards.

Entrepreneurs' Readiness to Comply with Laws

In the present context of the iron and steel business, there are price swings caused by economic and investment challenges. In the Chinese market, there is also competition in terms of price and technology. This requires the sector to adapt to global and national trends. These trends encompass a movement towards alternate energy sources in order to mitigate carbon dioxide emissions, hence necessitating the adoption of ecologically sustainable business practices. Transition during this period is critical and appropriate, particularly with government assistance in promoting policies from the BOI and credit-granting policies from the banking sector. Furthermore, Western nations, such as Europe and America, implement trade policies like the Carbon Border Adjustment Mechanism (CBAM) and Carbon Capture and Utilization (CCU), which play a crucial role in incentivizing and driving the adaptation and transformation of economic operations. This trend is not limited to the iron and steel industry but also extends to other areas. Entrepreneurs who are interested in making improvements in the iron and steel business receive aid from both the government and private sector, recognizing the significant role this industry plays in propelling the country's economy. This assistance has a positive effect, fostering entrepreneurs' confidence and equipping them to transition towards making their enterprises more ecologically sustainable.

Evaluating the Potential of Analytical Laboratories to Support the PCDD/PCDF Measurements

According to the DIW database, as of July 2023, there are 648 industrial recycling operations that must adhere to legal requirements. There are a total of 173 scrap iron recycling factories and 475 recycling plants for other non-ferrous metals. If these factories are mandated to perform annual measurements, it implies that the need for testing will also rise by 648 samples per year. According to an interview with officials from UIA Company, a company in Thailand that offers PCDD/PCDF analytical services, it was disclosed that the company has the ability to analyze approximately 500 samples per year for each client. Currently, they are already conducting regular analyses on around 220 samples per year. Hence, if there is a need to process more samples, the organization can only handle a maximum increase of 280 samples per year. Nevertheless, the laboratory may enhance its capacity to process 1,000 samples annually by acquiring supplementary sets of glassware for sample extraction and employing more chemists. However, Thailand has two additional businesses, ALS Company and SGS Company, that offer PCDD/PCDF analytical services identical to UIA Company. The National Institute of Dioxin, operating under the Department of Climate Change and Environment (DCCE) within the Ministry of Natural Resources and Environment, is the sole government agency equipped to do PCDD/PCDF analysis. By aggregating the overall capacity for additional PCDD and PCDF analyses, it is determined that they can process approximately 1,000 extra samples annually. This capacity is enough to accommodate the testing of samples from all 648 industrial recycling plants that are legally obligated to conduct yearly testing.

The Challenges for Thai Steel Industry toward EU-CBAM Measurement

The Carbon Border Adjustment Mechanism (CBAM) is an essential component of the EU's Fit for 55 Agenda (https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55/). Its purpose is to address carbon leakage by ensuring that the carbon cost is the same for both domestic products and imports. This strategy seeks to deter the transfer of production to countries with less rigorous environmental rules and the substitution of EU products with imports that have higher carbon emissions (Lim et al., 2021; Perdana et al., 2022). The minimal effects on the Thai sector in the near future was anticipated from the implementation of the EU-CBAM, as the export of items subject to CBAM to the EU does not represent a substantial proportion of overall sales. Nevertheless, Thai manufacturers and exporters may have difficulties concerning the quantification, authentication, and documentation of emissions, specifically in the steel and aluminium industries, which have a more substantial impact on sales to the EU. The imperative to decrease carbon intensity in order to mitigate expenses linked to CBAM exports will introduce further obstacles. Anticipated difficulties are likely to increase. Despite its challenges, this situation has the potential to compel both the public and commercial sectors in Thailand to adjust their operations and accelerate the shift towards a low-carbon economy, thereby creating new opportunities for low-carbon businesses.

The European Union's implementation of the CBAM has served as a catalyst for other nations to formulate comparable measures. The United States, for example, introduced the Clean Competition Act (CCA), which incorporates a carbon price mechanism for domestically produced goods and a carbon border adjustment for imports that require significant energy consumption (https://www.whitehouse.senate.gov/news/release/whitehouse-and-delbene-reintroduce-carbon-border-adjustment-bill-to-boost-domestic-manufacturers-and-tackle-climate-change/). The previous study suggests that the following nations are most likely to mount opposition to CBAM: Iran, Ukraine, the USA, the United Arab Emirates, Egypt, China, India, Kazakhstan, Russia, and Belarus (Overland and Sabyrbekov, 2022). The increasing implementation of these restrictions on a global scale will have a substantial effect on manufacturing and commerce, specifically placing pressure on companies in countries with less eco-friendly practices to conform to evolving environmentally conscious production patterns. Starting in October 2023, the CBAM will introduce reporting obligations without making any financial changes, resulting in additional expenses for emissions verification and administrative tasks. If Thai manufacturers do not satisfy new global standards, it is probable that there will be a rise in long-term expenses.

The anticipated effects of the CBAM on the Thai sector include higher export expenses and reduced competitiveness. Manufacturers and exporters may face increased export costs to the EU since importers have the ability to transfer CBAM charges to them. Although the immediate consequences may be minor, the potential long-term ramifications could be substantial if other nations implement similar policies, thus diminishing the competitive edge of Thai exports. Exports of iron, steel, and aluminium, which have been experiencing an increase in value, may encounter difficulties in sustaining their progress against more well-prepared rivals such as South Korea, China, and India. CBAM has the potential to expedite Thailand's shift towards a low-carbon economy and provide prospects in environmentally friendly sectors. The iron and steel industry, which relies largely on the EU market and has a high carbon footprint, will have the greatest impact, with the aluminium industry following suit. Industries such as cement, fertilizer, power, and hydrogen will experience negligible effects as a result of limited or non-existent exports to the European Union.

Proposed Framework Economic Incentives

In order to encourage private firms willing to reduce PCDD/PCDF emissions, there are at least three options for implementing economic incentives, which include both fiscal and financial measures (see Table 7). These three policy options are needed to work with or collaborate with other related agencies.

Option A

Option A should give businesses a variety of measures, allowing them to choose and apply for more than one economic incentive. Economic incentives for reducing PCDD/PCDF emissions include various measures. Firstly, government agencies in charge of the ferrous and non-ferrous sectors can offer fiscal measures that aim to reduce PCDD/PCDF emissions. Secondly, private financial institutions or banks can provide financial measures, such as business loans, with the condition that PCDD/PCDF emission reduction is one of their targets. Thirdly, there is the option of financial support or subsidies specifically for PCDD/PCDF emission reduction projects in the ferrous and non-ferrous sectors. Lastly, by meeting the criteria for PCDD/PCDF emission reduction, one can obtain certification for PCDD/PCDF emission reduction and green procurement. Figure 4 illustrate the depicted metrics.

Fiscal interventions can take various forms, including (*a*) lowering import tariffs on efficient steel melting machinery, (*b*) providing tax exemptions for expenses related to PCDD/PCDF emission reduction, and (*c*) decreasing corporate income tax for companies that comply with legal emission regulations by reducing PCDD/PCDF emissions.

Financial measures in conjunction with commercial banks can take several forms, including: (*a*) increasing loan limits, specifically Y% of the budget or expense for PCDD/PCDF emission reduction; (*b*) reducing the lending interest rate for PCDD/PCDF emission reduction projects; and (*c*) extending the loan repayment period.

Financial assistance for investment in projects aimed at reducing PCDD/PCDF emissions can take on different forms, including a subsidy. The Environmental Fund, under the Office of Natural Resources and Environment Policy and Planning (ONEP), MNRE, may provide this subsidy, covering a certain percentage of expenses. (*b*) Establish a BAT/BEP Fund by securing initial funding, specifically Z million baht, from the government budget, subject to project-based approval. (*c*) Upon request, allot the Ministry of Industry's government budget to private firms. We will allocate the budget under this program until we reach the target of PCDD/PCDF emission reduction. One can obtain certification for reducing PCDD/PCDF emissions and implementing green procurement through either Eco-label Certification or by establishing a PCDD/PCDF reduction program. Specifically, the DIW's Green Industry Verification (GIV) program should include a requirement for reducing PCDD/PCDF emissions, and the DCCE's Green Basket program under the MNRE should list it. Option A is predicated on a voluntary basis. A project appraisal can help entrepreneurs determine the most appropriate metric for their business. Nevertheless, project approval necessitates the creation of a dedicated government agency or committee to oversee it.

Notwithstanding, option A exhibits two vulnerabilities. Initially, the government lacks the ability to accurately predict the required budget and anticipate the specific actions taken by private enterprises, which vary in size and scope. Therefore, the constrained budget and staff shortage make it unclear which projects receive priority for support. Furthermore, allocating fair assistance among various groups poses a challenge. For instance, Group A Collectors comprises

597 organizations, Group B Facilities consists of 321 sites, Group C Downstream Industries includes 499 installations, and Group D End Users encompasses 428 companies. In other words, government agencies must determine which groups and how much support they should receive.

Option B

Option B should provide economic incentives based on a decrease in PCDD/PCDF emissions, subject to specific conditions. This option aims to categorize entrepreneurs into three distinct groups: one group consists of those who emit higher than the standard level; another group consists of individuals who emit equal to or less than the normal level; and the last group consists of scrap collectors. This option specifically targets the sources of PCDD/PCDF emissions, which include Group A collectors and Group B facilities. Figure 5 illustrate the economic advantages offered by this alternative. Figure 5 lists the economic incentives for various types of entrepreneurs.
(*i*) Incentives for SMEs that exceed the emission standards (assuming the legal standards are established) include: (*a*) financial measures such as loan limits (i.e. a percentage of emission reduction expenses), lower interest rates, and longer loan repayment periods; (*b*) financial support from the Environmental Fund (if applicable to emissions of PCDD/PCDF) or the BAT/BEP Fund (a new measure) in the form of subsidies based on a percentage of expenses (as determined by the ministry or committee); and (*c*) a specified time frame for entrepreneurs to adjust their business, technology, or production processes to reduce emissions of PCDD/PCDFs.
(*ii*) To provide incentives for SMEs that emit emissions equal to or less than the legal standards, we can modify the criteria for eco-label certification or establish standards for products related to ferrous and non-ferrous materials, incorporating a condition on the reduction of PCDD/PCDF emissions, particularly during the melting process. (*b*) Including activities that reduce PCDD/PCDF emissions in the criteria for Green Industry Certification (GIC), or enhancing the GIV if a firm successfully achieves this reduction. (*c*) The certification of businesses that reduce PCDD/PCDF emissions should be implemented throughout their supply chain. If the process of melting steel reduces PCDD/PCDF emissions or emits at the legal standard, then products that use steel materials should indicate or display an eco-mark, signifying the reduction of PCDD/PCDF emissions throughout the entire supply chain.

(*iii*) Incentives for collecting ferrous and non-ferrous scrap materials consist of (*a*) a financial assistance program that provides free training courses or subsidies for entrepreneurs and workers; and (*b*) certification for the supply chain of products that utilize ferrous or non-ferrous materials, ensuring appropriate recycling practices or the use of properly recycled materials. The primary distinction between Option B and Option A is the superior efficacy of incentives provided by Option B, particularly for entrepreneurs facing financial constraints in their efforts to minimize PCDD/PCDF emissions.

However, Option B still has limitations in terms of the measure's effectiveness at the national or sectoral level. Due to variations in business size, kind, technology used for melting processes, and customer base (including end users and downstream sectors), the decision to participate in the PCDD/PCDF reduction program also varies. Hence, Option B has proven to be less effective than anticipated in attaining the desired reduction of PCDD/PCDFs in both the ferrous and non-ferrous sectors. This is because Option B provides less incentive to decrease PCDD/PCDFs below the legally established thresholds. Companies may choose to pay a penalty for emitting PCDD/PCDFs that exceed legal guidelines, as the expenses associated with obtaining eco-label certification or conducting PCDD/PCDF tests may be prohibitively high for SME. This may

result in an inequitable distribution of responsibility for environmental protection between larger corporations and SME.

Option C

Option C should offer targeted economic incentives to different groups of entrepreneurs to ensure equitable access to financial incentives and accessible technology for reaching the industrial sector's PCDD/PCDF reduction target. Economic incentives encompass various financial measures, such as increasing loan limits, offering low interest rates, and extending the pay-off period. Additionally, incentives may include PCDD/PCDF emission reduction certification, upgrading product or eco-label standards, and implementing green industry standards. Furthermore, economic incentives may include providing a time frame for businesses to adjust, as well as offering financial support to entrepreneurs and workers in melting and collection firms who attend training programs. Figure 6 depicts the economic incentives associated with different sorts of entrepreneurs or business models, specifically focusing on point-source entities such as Group A collectors and Group B facilities. The following are descriptions of economic incentives.

(*i*) Incentives for small and medium-sized firms that emit PCDD/PCDFs above legal standards include: (*a*) financial measures from financial institutions, such as a loan limit equal to Y% of the PCDD/PCDFs reduction expense, a low interest rate, and an extended pay-off period; (*b*) financial support from the Environmental Fund or BAT/BEP Fund, such as a subsidy of X% of the PCDD/PCDF reduction expense (subject to conditions set by the committee); (*c*) financial support or subsidy for obtaining eco-label certification related to PCDD/PCDF reduction; (*d*) support for training programs for entrepreneurs and workers involved in melting and collections, which may include free training or partial subsidy; and (*e*) a specified time frame for business adjustment to reduce PCDD/PCDF emissions. These methods are equivalent to Option B, or potentially more incentivizing than Option B.

(*ii*) Incentives for medium-and-large firms exceeding legal standards for PCDD/PCDF emissions include (*a*) financial measures from financial institutions such as a loan limit (i.e. 0.5Y% of PCDD/PCDF reduction expense), low interest rates, and extended pay-off periods; (*b*) financial support from the Environmental Fund or BAT/BEP Fund such as a 0.5X% subsidy of PCDD/PCDF reduction expenses (subject to conditions set by the committee); (*c*) financial support or subsidies for eco-label certification related to PCDD/PCDF reduction; (*d*) subsidies for training programs for entrepreneurs and workers involved in melting and collections; and (*e*) a designated time frame for business adjustment to reduce PCDD/PCDF emissions. These measures may be less motivating than Option B.

Three types of incentives are available for small, medium, and large companies that emit PCDD/PCDFs at or below legal levels. These include (*a*) changing the requirements for lowering PCDD/PCDF emissions for eco-label certification or product standards for ferrous and non-ferrous materials; (*b*) changing the requirements for lowering PCDD/PCDF emissions for GIV or giving firms that reduce PCDD/PCDF emissions a higher GI rating; and (*c*) recognizing companies that lower PCDD/PCDF emissions in the supply chain of products made from ferrous or non-ferrous materials. These measures are identical to Option B.

(*iii*) Incentives for collectors of ferrous and non-ferrous scrap include (*a*) a training program to support entrepreneurs and workers involved in melting and collection (with free training or some form of subsidy); and (*b*) certification for businesses that reduce the presence of PCDD/PCDFs

in the supply chain of products made from ferrous or non-ferrous materials. These measures are identical to Option B.

Option C possesses a minimum of three compelling advantages. This alternative posits the allocation of distinct responsibilities among various firm sizes and types of businesses, particularly melting firms and scrap collectors, as a means to reduce PCDD/PCDF emissions and comply with regulatory requirements. It suggests that larger corporations have a greater responsibility towards society and the environment compared to smaller firms. A cluster of small enterprises should have equal or almost equal responsibility as a cluster of medium and large firms. Furthermore, the government can predict the budget allocation for PCDD/PCDF reduction programs and provide specific guidance to support various types of businesses (including large, medium, and small firms), while also setting clear targets for PCDD/PCDF reduction measures. Furthermore, these support programs should be better monitored and evaluated to improve future economic incentives.
The main drawback of Option C is the elevated transaction cost associated with coordinating efforts across government agencies, private enterprises, and other ministries. This coordination is necessary for proposing improved policies or economic incentives.

Key Takeaways from Stakeholders' Engagement and their Verification

The proposed three policies aim to decrease emissions of PCDD/PCDFs by implementing a range of economic incentives that will assist industries in adopting cleaner technologies and sustainable practices. Option C was selected as the preferred choice during consultation meetings for three primary reasons: its efficacy in promoting the adoption of BAT/BEP by both small and large companies, the provision of financial incentives and subsidies for green certifications, and its compatibility with current initiatives in commercial banks and government agencies. This option also provides a grace time of approximately three years for industries to make the necessary changes to comply with PCDD/PCDF emission guidelines. Minor adjustments were made to Option C based on the key comments gathered from the consultation workshops. The adjustments encompass providing non-economic assistance to SMEs that comply with PCDD/PCDF regulations to collaborate with those that do not, as well as offering technical support to scrap collectors to access cleaner technologies. The policy emphasizes the requirement for a significant allocation of funds for the BAT/BEP fund because there are more than 100 firms involved in the scrap business. This necessitates verifying and categorizing the companies based on their adherence to PCDD/PCDF emission limits. In addition, private enterprises have the option to seek for subsidies through the Environmental Fund, which is backed by either the Department of Mineral Industries and Mines or the DIW.

It is advised to provide fiscal incentives, such as tax deductions for investments in BAT/BEP and exemptions from import tariffs for essential equipment. However, these incentives can only be implemented with the agreement of the cabinet. These fiscal measures are intended to be impartial, encompassing additional emissions and sectors outside PCDD/PCDFs and the scrap business. The policy also recognizes the diverse capacities of SMEs in comparison to large manufacturers, resulting in the categorization of enterprises into small, medium, and large classifications. Out of the 173 ferrous factories that were assessed, 115 of them are categorized as small and medium-sized and the remaining 58 are classed as medium and large-sized. Out of the total 475 non-ferrous recycling facilities, 317 are categorized as small and medium and 158 are categorized as large, providing customized assistance based on the size of the factories.

Conclusions

*This study conducted a comprehensive assessment of global regulations pertaining to the emissions of PCDD and PCDF from metal recycling facilities. We then used these standards to determine Thailand's specific requirements. After examining data from 17 iron and steel recycling operations, we discovered that 76.4% of these facilities had emissions that were lower than the threshold value of 0.2 ng I-TEQ m^{-3}. This suggests that the proposed requirements are achievable. Nevertheless, we advise against promptly implementing these guidelines because of the limited size of the sample. Instead, it is advisable to consider implementing a transitional phase, which would provide firms with sufficient time to adhere to the requirements. An evaluation of health risks using procedures approved by the US-EPA has verified the necessity of implementing emission standards. It is necessary to establish regulatory measures, such as guidelines for the implementation of BAT/BEP. Furthermore, it is imperative to take into account the restrictions pertaining to emissions from wastewater and industrial leftovers. We categorized firms according to their machinery's horsepower; however, a more precise criterion for future categorizations could be their output capacity.

The United Nations Environment Programme (UNEP) recognizes ferrous and non-ferrous metal industries as major contributors to the production of dioxins, which the Stockholm Convention designates as U-POPs. According to Thailand's 2nd National Implementation Plan for Persistent Organic Pollutants (NIP/POPs), metal fabrication is responsible for roughly 277.8 g-TEQ of dioxin emissions each year. This accounted for 21% of the country's total dioxin emissions in 2017, putting it third in terms of contribution after waste incinerators and open-air burning. However, the Thai metal sector does not have well-defined U-POP criteria. Precise criteria are essential for managing dioxin emissions from scrap metal operations, particularly PCDDs and PCDF emissions. The second NIP/POPs plan (2023-2027) is in accordance with Thailand's 13th National Economic and Social Development Plan. Its objective is to set environmental quality standards, which include limitations on the discharge of POPs and criteria for contamination in food and water. It is imperative to enact legislation over the next 1-2 years to establish precise limits for dioxin and furan emissions in metal factories. There are two suggested methods for implementing PCDD/PCDF standards: the Single Notification Approach (SNA) and the Dual Notification Approach (DNA). The SNA suggests a unified notification for emission restrictions and data reporting, with a compliance period of five years. In contrast, the DNA requires two notifications spread out over five years, allowing for more time to adjust but resulting in a delay in implementing the standards. It is advisable to create a thorough emissions database with financial backing from UNIDO. The SNA is favored for its compatibility with BOI measures, which allows for the prompt adoption of standards and smooth transition into compliance while also creating a valuable emissions database for future legislative acts.

The suggested regulations seek to decrease PCDD and PCDF emissions by providing economic incentives to assist industries in adopting cleaner technologies and sustainable practices. Option C was chosen as the preferred policy because of its successful promotion of BAT/BEP implementation among enterprises of all sizes, its provision of financial incentives and subsidies for green certifications, and its alignment with existing initiatives from commercial banks and government agencies. This option grants industries a three-year grace period to comply with emission restrictions. Modifications to Option C involve providing non-monetary aid to complying small and medium enterprises (SMEs) to cooperate with non-compliant ones, as well as supplying technical support to scrap collectors to obtain cleaner technology. The BAT/BEP fund requires a substantial amount of funding due to the high number of companies involved in

the scrap business. This funding is necessary to verify and categorize these enterprises based on their adherence to emission restrictions. Private firms have the option to apply for subsidies from the Environmental Fund. We recommend offering fiscal incentives like tax deductions for investments in BAT/BEP, along with import tariff exemptions for necessary equipment. However, these recommendations are still pending approval from the cabinet. The policy recognizes the differing capabilities of SMEs compared to large manufacturers. It classifies businesses based on their size in order to provide customized support. The evaluation of 173 ferrous factories classified 115 as small and medium-sized, and 58 as medium and big-sized. Out of the 475 non-ferrous recycling facilities, 317 fall under the small and medium-sized categories, while 158 are considered large.

Challenges, Concerns & Recommendations

Metal recycling plants have to set aside money every year to pay for stack sampling and analysis of PCDD/PCDF emissions. The expenses for sample collection, which include travel costs and man-days, amount to approximately 10,000 THB for Bangkok and its surrounding areas. In other provinces, these prices can exceed 20,000 THB. Additionally, the analysis of PCDD and PCDF incurs a cost of around 50,000 THB. In total, the expenses range from 60,000 to 70,000 THB. Adhering to these laws may result in higher production expenses as manufacturers must make adjustments to their operations in order to decrease emissions and monitor PCDD and PCDF levels to comply with upcoming standards. In order to provide assistance for these transitions, the government has the option of using economic measures such as tax incentives, subsidies, or grants. Furthermore, securing external support from entities like the GEF through UNIDO could alleviate the financial burden of these charges. The anticipated total yearly costs for 648 factories amount to approximately 45,360,000 THB. Companies that comply with regulations may benefit from improved product quality and opportunities to enter environmentally conscious markets. Possible future actions may involve granting exemptions to factories that consistently meet compliance standards, thus reducing the need for yearly monitoring and potentially transitioning to inspections every two years.

According to the database of the DIW, by July 2023, a total of 648 metal smelting facilities will be required to adhere to the PCDD/PCDF standard legislation. This includes 173 plants that melt ferrous metals and 475 plants that melt non-ferrous metals. If these plants need to be measured annually, the demand for testing will grow by 648 samples each year. During conversations with officials from UAE-Idea Advance Analytical Limited (UIA), a prominent laboratory service in Thailand specializing in dioxin and furan analysis, it was discovered that the present maximum capacity may be increased to around 500 samples per year. Typically, there are around 220 samples per year under typical circumstances. Hence, in the event of future requirements for additional samples, the organization has the capacity to handle about 280 samples annually. By including supplementary analysis sets for sample extraction and employing more chemists, the analytical laboratory has the potential to enhance its production capacity to 1,000 samples per year. In addition, there are two additional firms in Thailand, SGS (Thailand) Co., Ltd. (SGS) and ALS Laboratory Group (Thailand) Co., Ltd. (ALS), that offer dioxin and furan analysis facilities identical to UIA. Furthermore, the National Dioxin Institute, which operates within the Department of Climate Change and Environment under the Ministry of Natural Resources and Environment, is another government organization capable of doing analysis on dioxins and furans. By utilizing analytical capability to conduct dioxin and furan analysis, it was determined that these resources could accommodate around 1,000 extra samples annually. This is enough for analysing samples from metal smelting factories that are required

to adhere to the standard value legislation. Presently, there is an estimation of around 648 locations that necessitate frequent measurement and analysis on an annual basis, in accordance with the enforcement of the legislation.

The incoming administration should prioritize five crucial sectors to boost and elevate the Thai steel industry. Firstly, the sector must address unfair trade practices to combat competition from both local producers and imported goods, particularly from countries like China known for their dumping tactics. Furthermore, it is crucial to address the issue of excess production capacity in the national steel sector. Presently, the utilization rates for flat steel and long steel stand at a mere 24% and 33%, respectively, in stark contrast to the global average of 74.3%. Furthermore, it is crucial to manage elevated energy expenses, since they have a substantial influence on production costs and competitiveness. In addition, getting ready for environmental initiatives like the EU-CBAM necessitates the establishment of production methods and perhaps shifting to sustainable power and advanced technologies like hydrogen-based steel production in order to uphold export competitiveness. In addition, it is necessary to implement procedures to prevent the entry of products that do not meet the required standards into Thailand in order to avoid any additional difficulties with imports.

Another important focus is the promotion of public-private partnerships (PPP), where the government is urged to endorse domestic products in investment projects that are estimated to be worth around 1.12 trillion baht until 2027. Some segments within the steel sector may constrain immediate modifications, but both locally and globally, we expect a more extensive embrace of Net Zero objectives in the future. This comprehensive approach should include all sectors, promoting incremental adjustments in the Thai steel industry to reduce possible expenses associated with steel pricing and carbon taxes while ensuring continued access to sources of funding. Implementing such measures will contribute to the sustained profitability and competitiveness of the business sector.

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Conflict of Interest

Conflict of Interest and Authorship Conformation Form.

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