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應用建築結構鋼直接再利用循環經濟商業模式之經濟影響與減碳效益

Assessing the Economic Impact and Carbon Reduction Effect of Applying Direct Reuse of Structural Steel Circular Economy Business Model in the Construction Sector

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本論文係李浩維君(學號 R10541201)在國立臺灣大學環境工程學研究所完成之碩士學位論文，於民國 112 年 6 月 21 日承下列考試委員審查通過及口試及格，特此證明

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中文摘要

世界經濟體正面臨資源有限和市場需求增加的壓力。循環經濟是對傳統線性經濟的反思，為解決自工業革命以來經濟發展所產生的負面影響提供了契機。在循環經濟的架構下，直接再利用策略旨在延長實際上未達到生命週期末端即被廢棄的產品使用時間，避免回收再製造過程中耗費額外的能資源投入，以縮短材料的循環路徑。鋼鐵材料因其獨特的性質和世界各地已建置完善的回收系統，而在直接再利用策略的應用中佔據優勢。

本研究透過整合經濟與環境評估模型，剖析鋼鐵材料於營建相關行業中新循環路徑的可行性。以營建業的結構鋼產品為目標，作為應用直接再利用的對象，並透過引入投入產出 (IO) 分析和環境延伸投入產出 (EEIO) 分析，評估直接再利用商業模式的經濟績效和環境影響。研究結果證實，應用直接再利用循環策略可以創造一個高附加值的新產業，同時也有助於減少整個經濟體的碳排放，直接在利用策略亦能夠達到與煉鋼製程替代可比擬的減碳效益。直接再利用循環經濟商業模式預期在未來亦具有應用於其它種類材料的潛力。

關鍵詞：循環經濟、投入產出（IO）分析、環境延伸投入產出（EEIO）分析、直接再利用循環策略、結構鋼

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ABSTRACT

The world economy is under the pressure of limited resources and increasing demand from the market. Circular economy, the rethinking of traditional linear economy, offers an opportunity to deal with the problems. The direct reuse strategy aims to extend the time of utilization with end-of-use products. Steel materials can take advantage of the direct reuse strategy because of its unique property and the well-developed recycling systems around the world.

This research introduces Input-Output (IO) analysis and Environmental Extended Input-Output (EEIO) analysis to evaluate the economic performance and environmental impact of a direct reuse business model. The target of direct reuse was the structural steel products in the construction sector. The results demonstrate that the application of direct reuse circular strategy could create a new industry with high value added rate, and it could also help reduce the carbon emissions from the whole economy. This research demonstrates that the direct reuse strategy has the potential as a valuable circular economy strategy.

Key Words: Circular Economy, Input-Output (IO) Analysis, Environmental Extended Input-Output (EEIO) Analysis, Direct Reuse Circular Strategy, Structural Steel

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1. Introduction

1.1. Research Background & Purpose

Nowadays, the world supply chain is facing the problem of limited resources and increasing demand from the market. In order to solve the problem that resources cannot afford the needs, experts began to study the possibility of circular economy, which is considered as the rethinking of traditional economy. Compared with the traditional linear economic model, circular economy values the circularity of resource, the utilization efficiency and the reduction of waste. Resource regeneration and recovery, product sharing and servitization, repair and remanufacturing are the common examples within the connotation of circular economy. Ideally, circular economy will not only promote a more environmentally friendly future, but it can also reduce production costs and help us coexist with natural resources, in the end, achieve the goal of sustainable management.

The study of Ellen MacArthur Foundation (2021) states that:

The circular economy is a framework for preventing negative impacts of economic activity that lead to the loss of valuable resources and damage to human health and natural systems. GHG emissions is one of these negative effects designed out of the

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system. Others include the pollution of air, land, and water, and the underutilization of assets such as buildings and cars. (p. 21)

Construction industry utilizes a great amount of materials, and steel is especially with the most used. This circumstance makes construction industry one of the largest stock of steel with high embodied energy in the market. While a building reaches its end-of-life, the material used in such a building would be recycled and remanufactured under most of the condition. However, these end-of-use materials may have not reached their end-of-life, which means they would still be valuable in another round of use. But, these deconstructed materials are usually considered as waste and are sent to the treatment sector. The market must input an additional amount of energy and raw materials to deal with these waste which are actually valuable products. Therefore, material utilization efficiency appears to be an important issue in recent years. Since many materials in buildings are beyond efficient utilization under current condition, there has been some emerging business models, like “Direct Reuse of Structural Steel”, aiming to improve the problem of material underutilization.

In addition to the problem of material usage efficiency, it is also worthwhile for us to notice that the industries related to steel production are with high amounts of carbon

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emission. From the report of McKinsey & Company (2022), power sector and industry sector are shown to be the major emitters of carbon dioxide. Steel, cement, plastic and aluminum are defined as the top four harder-to-abate sectors due to the special characteristics of their high-temperature production process and the difficulties of waste treatment (Energy Transitions Commission, 2018). Around 30% of the global carbon dioxide emission is from the industry sector, and the subsector of steel accounts for 26% of the emission from the industry sector (McKinsey & Company, 2022). Steel sector is the largest emitter among the four harder-to-abate sectors. Since Taiwan is one of the top ten steel production country in the world, it is essential for the government to think about the decarbonization in steel sector. Employing carbon reduction technologies to the steelmaking process is one smart choice. However, applying circular economy strategies on the demand side is also another effective way to tackle the emission challenge in steel sector. In order to reach the goal of net-zero in 2050, the suitable strategies must be applied at both technical side and demand side of the market as soon as possible.

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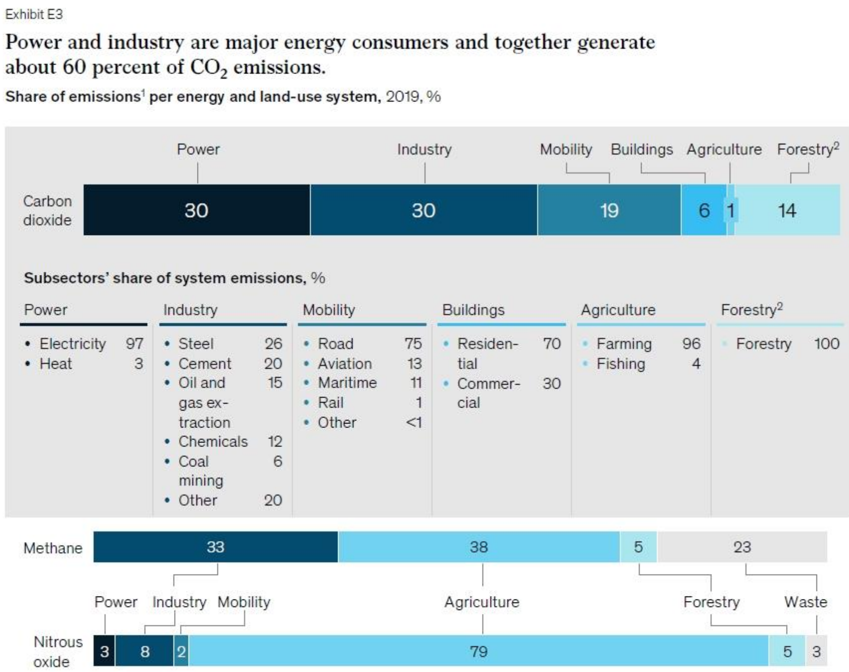

Fig. 1.1 The CO_2 emission contribution of industry
(McKinsey & Company, 2022)

This research will simulate the economic impact and carbon reduction effect of applying "Direct Reuse of Structural Steel" circular economy business model to the construction industry in Taiwan. For the economic impact, the research would apply Input-Output (IO) analysis with the IO transaction table of Taiwan in 2016 to construct an econometric model. Furthermore, this research would evaluate the carbon reduction effect with Environmental Extended Input-Output (EEIO) analysis by comparing the amount of carbon emission before and after the application of the direct reuse business model. The main purpose of this research is to develop an evaluation model of circular strategy and make recommendations to support the potential policy of the nation.

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1.2. Research Framework

Fig. 1.2 represents the framework of this research. After reviewing the papers and reports related to circular economy and the challenges of steel material, the research will focus on one of the emerging circular economy business models, “Direct Reuse of Structural Steel”. Taking the IO transaction table from Directorate General of Budget, Accounting and Statistics, Taiwan in 2016 as a foundation, this research would establish an economic and environmental evaluation model. This research will assess the performance of applying “Direct Reuse of Structural Steel” business model as a new material flow route in the market through Input-Output (IO) analysis. The economic performance could be evaluated through the change in output value, value-added, and value-added rate. Then, Environmental Extended Input-Output (EEIO) analysis would be applied by introducing the carbon emission factors of each industry with the output value of Input-Output (IO) analysis to calculate the amount of carbon emission and evaluate the carbon reduction effect. Finally, both the economic and carbon reduction performance will be discussed, and country level recommendations would be given.

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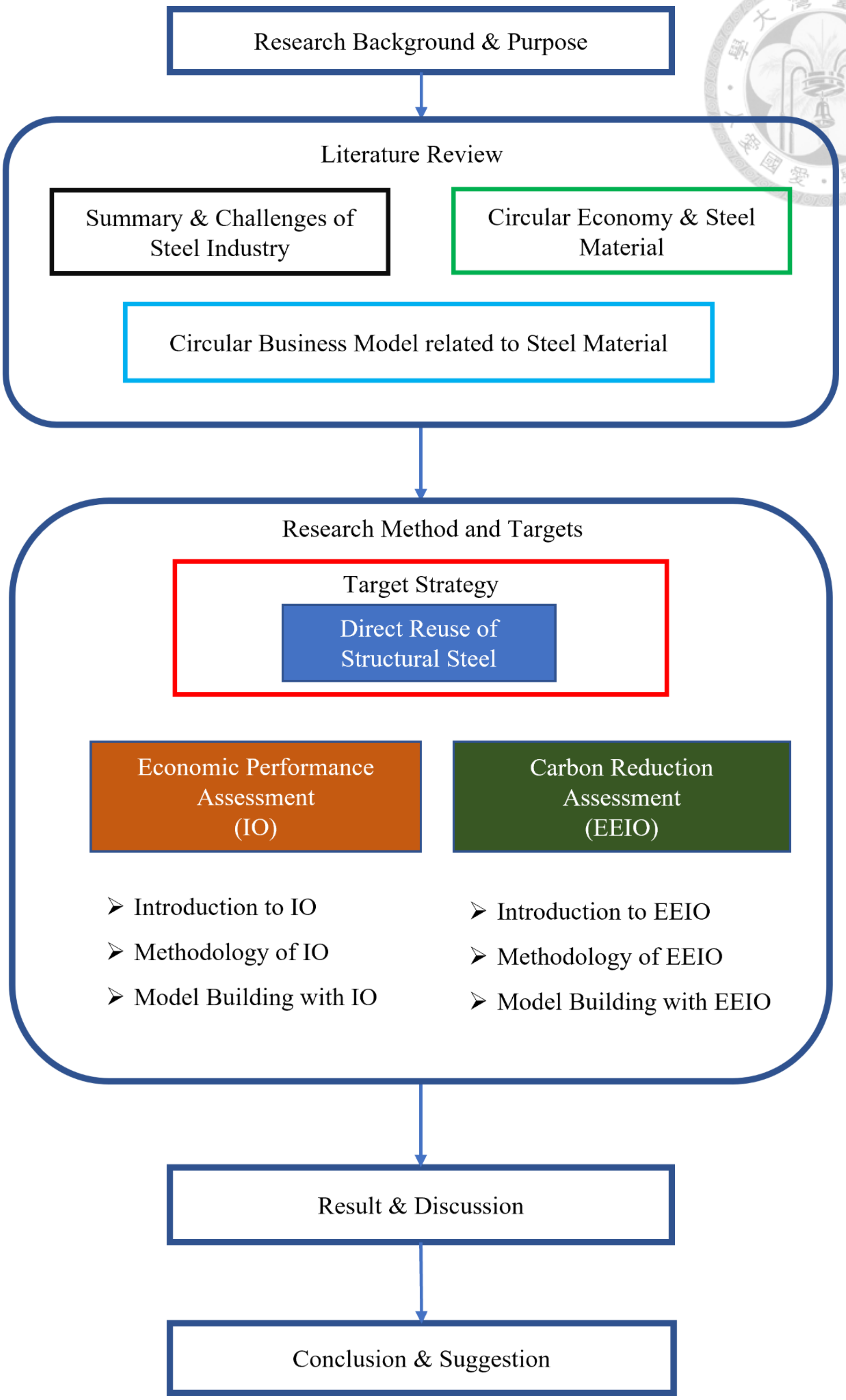

Fig. 1.2 Research Framework

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2. Literature Review

2.1. Summary and Challenges of Steel Material

Steel is a 100% recyclable material that can be remanufactured permanently in a closed material loop. Recycled steel could inherit all the properties of the original steel in a well-designed recycle system without downgrading (World Steel Association, 2015). The world market has developed a mature steel recycling and reproducing system. Most of the recycled steel can be remanufactured by the electric arc furnace (EAF) technology. Through the recycling to remanufacturing process, steel sector is expected to save a significant amount of energy and natural resources input to produce the secondary steel.

Nowadays, there are three major production process to produce steel in the market: Blast Furnace-Basic Oxygen Furnace (BF-BOF) route, Electric Arc Furnace (EAF) route and Direct Reduced Iron to Electric Arc Furnace (DRI-EAF) route (Fan & Friedmann, 2021).

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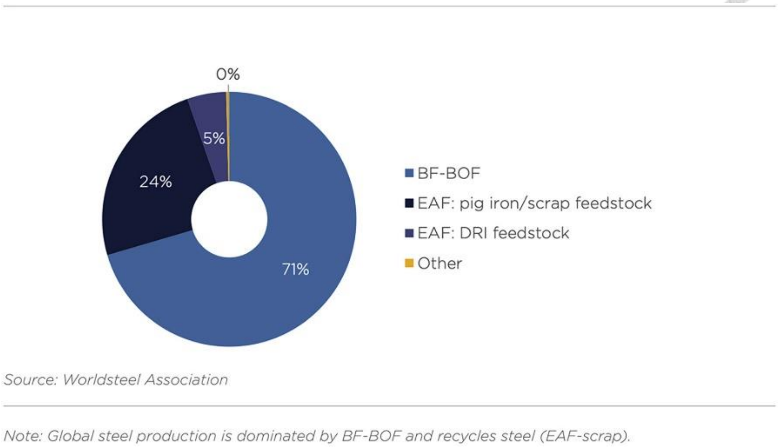

Fig. 2.1 Steel Production by Pathway
(Fan & Friedmann, 2021)

Around 71% of steel is made through BF-BOF process, whose raw material input is mainly iron ore. As the dominant steel-making process, it utilizes a large amount of coal-related materials. Since this process includes mainly the use of fossil fuels, about 70% of the total carbon emission is directly produced from the reduction phase in BF (Fan & Friedmann, 2021). This is also the major primary steel-making process.

Another 24% of steel is made through EAF process, whose raw material input is steel scrap in most cases. This process takes electricity as the only energy sources such that it causes the indirect carbon emission from the power plants (Fan & Friedmann, 2021). Most of the recycling steel scrap is remanufactured through EAF process. EAF process is undoubtedly a representative application of material circulation with steel material.

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The last 5% of steel is made through DRI-EAF process, whose raw material input is iron ore as well. It introduces a new technology, DRI, as the replacement of BF in BF-BOF process. The energy source also contains fossil fuels in DRI. It could directly reduce the iron ore in solid state. After successfully reducing the iron ore in DRI, the reduced iron ore is sent to the EAF to produce the final product (Fan & Friedmann, 2021). DRI-EAF process includes both the direct emission from DRI and the indirect emission from the power plants with EAF. However, it could produce less emission in the reduction stage compared with traditional BF-BOF process. It is said that DRI-EAF process would likely to be the substitution of BF-BOF process of primary steel-making process in the future.

Fig. 2.2 shows the differences among each steelmaking process. Primary steelmaking process (BF-BOF, DRI-EAF) would always produce more carbon emission than secondary steelmaking process (Scrap-EAF). When making 1 ton of steel, on an average bases, BF-BOF process would create 2.2 tons of CO_2; DRI-EAF process would create 1.4 tons of CO_2; and Scrap-EAF process would create 0.3 tons of CO_2 (IEEFA, 2021).

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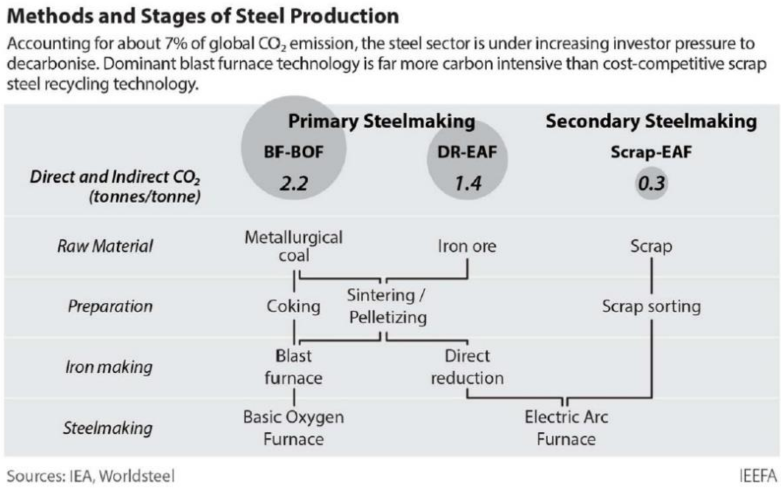

Fig. 2.2 Comparison of Steelmaking Process
(IEEFA, 2021)

From the Greenhouse Gas Inventory Report Taiwan EPA (2022), steel (metal) industry contributes to about 29.84% of the total emission in Industrial Process and Product Use (IPPU) sector, which is preceded only by mining industry (32.86%). Although the emission status would be different across the world, the emission trend of the industrial sector in Taiwan has the similar pattern with the world statistic data shown in Fig. 1.1.

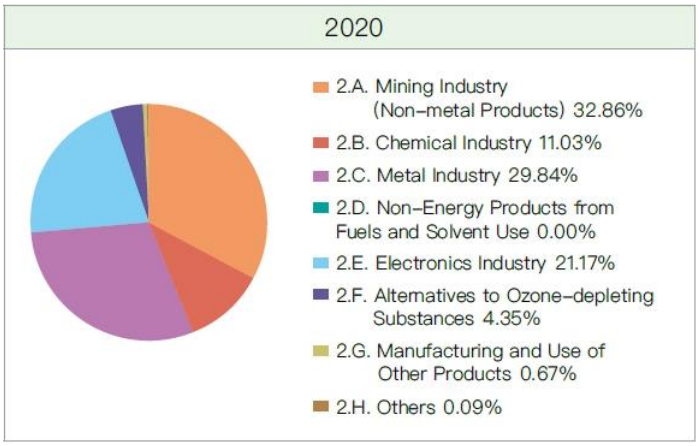

Fig. 2.3 Percentage of Greenhouse Gas Emissions by IPPU Sectors in Taiwan
(Taiwan EPA, 2022)

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The Breakthrough Agenda Report 2022 indicates that the annual near-zero emission steel product is less than 1 million tons now. If the world wants to achieve the climate consensus of Paris Agreement, the world supply chain must reach more than 100 million tons of near-zero emission steel production per year before 2030. Although many new steelmaking infrastructures are under construction or planning around the world, most of them are still based on traditional steelmaking route with high carbon emissions (IEA et al., 2022). Since the steelmaking infrastructure could last for several decades, the carbon emission cannot be reduced efficiently in the near future once the traditional steelmaking route in these ongoing plans are still under operation. Therefore, the steel sector has to adjust its existing plans as soon as possible.

2.2. Circular Economy and Steel Material

Circular economy is a manner of thinking with sustainable symbiosis between economy and environment, which takes environmental sustainability, social responsibility, and economic development into account at the same time, and it would finally achieve the goal of sustainable development. Since Taiwan lacks enough natural resources, the country has to rely on the imported raw materials and make them into products with high value. Through the application of circular economy, the materials

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can be continuously recycled and reused to reduce the cost and energy use, thereby enhancing the international competitiveness of the products in Taiwan. The purpose of circular economy is to make resources economical and profit maximization. In a circular economy, the smaller and simpler the circulation path is, the greater the preservation of product value would be (Taiwan Industrial Development Bureau, 2020).

These years, circular economy has become a popular research topic in the world. However, because the concept of circular economy is evolving with the time and encompasses a lot of ideas as well, it appears that the definition of circular economy is still beyond clear determination. The review article of Rizos et al. (2017) stated that the term “circular economy“ was first formally used in an economic model in 1990s. It described “circular economy” as a new economic model which applies the principles of the first and second laws of thermodynamics on the principle that *“everything is an input to everything else”*.

For another example, the Ellen MacArthur Foundation (2021) suggests that the circular economy is defined as “*a framework for systems solutions and transformation that tackles global challenges”*, which includes the most concerned GHG emission problems. It can also be referred to “*a systems change agenda that presents*

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opportunities to create better growth".

No matter how the researchers in the past describe the meaning of circular economy, it can be confident to say that circular economy represents a transformation concept from the exist economic system with huge problems to a better coexistence future.

According to the reports of Energy Transitions Commission (2018); Material Economics (2018), *"A more circular economy can cut emissions from heavy industry by 56% by 2050"*. Namely, apart from technological innovation, revolution, and substitution, applying circular economy strategies in the hard-to-abate sectors could also become a strong asset to achieve net zero. The main transition target is especially on the demand-side of heavy industry.

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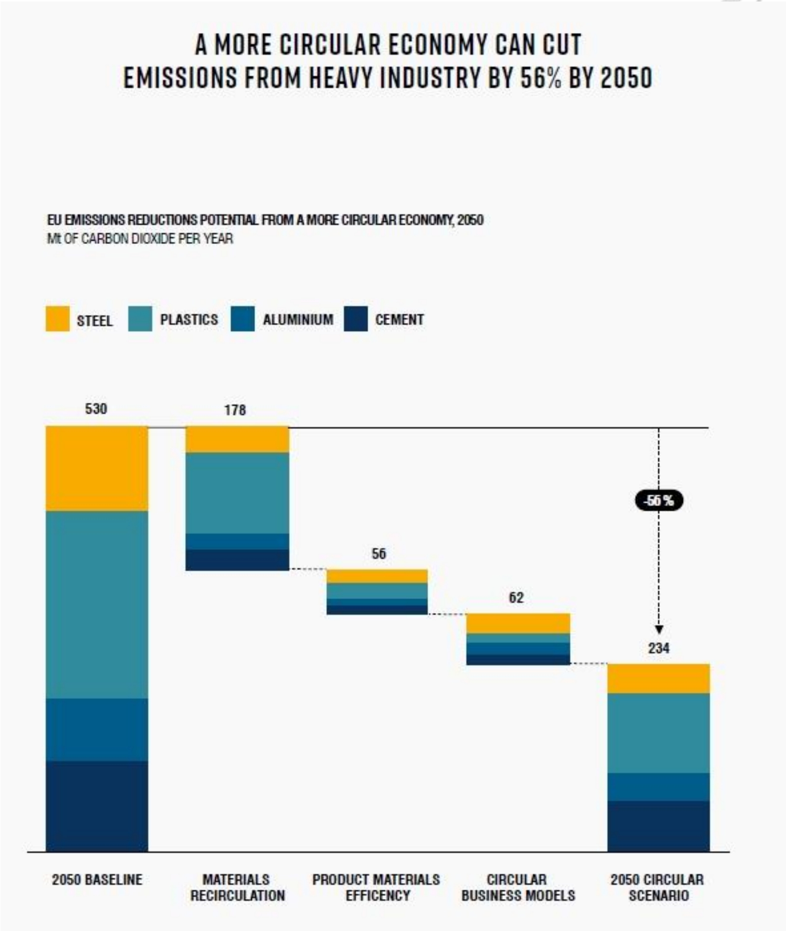

Fig. 2.4 Emission Reduction Potential from A More Circular Economy (Material Economics, 2018)

In heavy industry, “Material Recirculation”, “Product Material Efficiency” and “Circular Business Models” are three major categories of circular economy strategies that could be applied to solve the GHG emission problem from the demand side (Material Economics, 2018).

For the “Material Recirculation” aspect, it could be reached by promoting a more effective material circulation such as ensuring a cleaner scrap flow (Material

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Economics, 2018). Steel scrap is noted as a valuable product in the market. Steel scrap could be used to reproduce steel product with specific technology such as EAF. Unfortunately, steel scrap would unavoidably be contaminated by heavy metals or other impurity substances in existing collection and recycling system. With contaminated steel scrap, it is hard to produce high-value secondary steel product. Therefore, it is essential for the government to redesign the collection and recycling system in order to accomplish a more effective steel recirculation in the future.

For the “Product Material Efficiency” aspect, advanced materials and techniques could be utilized to reduce the demand of raw material. Moreover, reconsidering the product design is also an important part to improve the efficiency of material (Material Economics, 2018). Nowadays, many concepts of design are deviating from actual needs. A large amount of materials are used in the product such as buildings or cars, not to ensure the quality but merely to add more beauty. In the future, it would be better to use the essential amount of material in a product by revolutionizing the existing design.

For the “Circular Business Models” aspect, the business of sharing has become a popular trend in the society (Material Economics, 2018). Car sharing and office sharing are two typical examples of sharing models. Private car and office are not commonly

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under efficiently utilization. In a usual day, people may drive our car to work and then park it in the parking lot until getting off the work. They actually use their cars for less than a few hours a day. The office is in an opposite condition to private car. Companies usually work either in the morning or at night. The office is sitting idle in the rest half of the day. Fortunately, the idea of sharing business model stands out to deal with these problems. Once the share business model is taken into practice, the product could be used by others whenever they need to. In the long run, the product with high-embodied energy could be utilized more efficiently.

In order to deal with the problem of under efficient utilization of material in the market, this research took steel as the target material with an emerging steel-related circular strategies that are still not exist in the economic system of Taiwan as the assessment target. That is, "Direct Reuse of Structural Steel" in construction sector.

2.3. Direct Reuse of Structural Steel in Buildings

Construction sector consumes about 60% of the world's materials and is responsible for about 53% of the world's greenhouse gas emissions. It has been recognized as one of the key sectors in the transition to a circular economy future. A building with a circular concept of design has clear potential to contribute to climate

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change mitigation and resource scarcity. When a building reaches its end of life, the environmental impact related to the great amount of demolition waste could be solved with high-quality recycling and reuse of materials (Holland Circular Hotspot, 2022).

Steel reuse could bring us a lot of opportunities in construction sector. Aside from reducing the environmental costs of raw materials and energy consumption, it can also decrease the production of waste from building demolition. Although the steel reuse approach is a challenging circular strategy right now, it has a great amount of potential for future success. A quantitative evaluation of the steel reuse approach, in terms of mass, energy consumption and carbon dioxide emissions, shows that the more the mass savings, the more the environmental benefits. Compared to traditional approach, the featuring of reused steel is that it could save around 30% of energy and carbon dioxide emissions (Pongiglione & Calderini, 2014). Moreover, from the report of Coelho et al. (2020), steel reuse can be considered at all structural levels.

Most of the past environmentally friendly construction projects are especially focusing on improving the operational aspects, such as better insulation, natural lighting, ventilation etc. These targets have indeed lowered the carbon and energy footprints of the building projects. However, the great part of carbon footprint in

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buildings is actually embodied in the materials used for construction rather than the operation stage (Dunant et al., 2018). In a future with circular economy, all end-of-service-life (EoSL) buildings would likely to be material and product banks and deconstructable to retain high-value materials and products, which will create value, promote innovation and attract investment (Hopkinson et al., 2018). Yet, it should be noted that reuse of steel would change the way that the construction sectors operate and create a new business development (Iacovidou & Purnell, 2016).

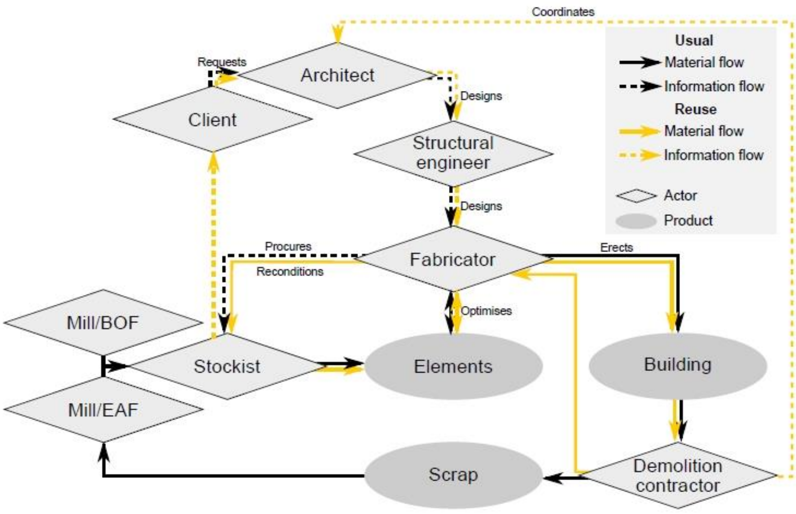

Fig. 2.5 Information and Steel Flow in the Construction Value Chain (Dunant et al., 2018)

Fig. 2.5 demonstrates a result of interview from the construction value chain in UK. The purpose of the interview is to understand the possible route of steel reuse in the future since it is not yet adopted in the value chain. In the original route, all the steel demolished from end-of-service-life buildings become steel scrap. Then, the steel scrap

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is sent to the steelmaking factory to be remelted and remanufactured. However, some of the waste steel from building demolition are still worth acting as structural components in other buildings. It is a pity that people only consider these valuable materials as waste, but not take them into another round of use. Therefore, experts have come up with a new idea of steel flow as a solution to this problem. The yellow solid line in Fig. 2.5 shows that the steel demolished from end-of-service-life buildings with good condition could be sent to the fabricator for testing and reconditioning. Then, it can be used in new construction projects as a replacement of new steel, or go to the market stock for other kinds of utilization.

Generally, there are three major construction structures in Taiwan including Reinforced Concrete (RC), Steel Constructure (SC) which is also known as Steel Structure (SS), and Steel Reinforced Concrete (SRC). RC is the dominant building structure in Taiwan that takes more than 70% of the proportion in the building projects in Taiwan. Steel Constructure (SC)/ Steel Structure (SS) takes the second place. Steel Reinforced Concrete (SRC) has the least market share. Since RC & SRC structure both contain the hybrid structure of steel and concrete which is not easy to separate, it is unavoidable to damage the material when deconstructing the building after end-of-use.

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Therefore, these two design concepts of building would not be the first choice when considering the application of direct reuse strategy of steel.

Steel Structure (SS) buildings, which is a common design concept of a skyscraper, turn out to be an alternative construction route for carbon and energy savings. The strategy of direct reuse steel could be easily applied in a building mainly constructed with steel. By replacing demolition with deconstruction, the steel material which is still valuable could be maintained in steel buildings more perfectly to be reused in the next stage.

Steel structure (SS) is obviously a preferable technique under the direct reuse of structural steel strategy in a future circular economy. As a result, in the following research, an investigation about the amount of steel deconstructed from SS buildings annually in Taiwan would be made as the greatest potential of direct reuse. On the other hand, because there are still some technical difficulties that may not be suitable for the application of direct reuse strategy, materials collected from RC and SRC buildings would not be considered as a source of reusable steel.

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3. Methodology

3.1. Research Process

This research is proposed to assess the economic and environmental impact of one circular economy business model: "Direct Reuse of Structural Steel". The business model would be taken as a newly introduced industry in the market. Since it has relations with other existing industries, the application of an input-output (IO) analysis takes an advantage in the evaluation of the interdependence of the whole market. The goal was to evaluate the impact of the change in steel material flow by adjusting the exist money flow in IO model. Finally, the carbon emission effect would be evaluated through the environmental extended input-output (EEIO) analysis. It would be an representation of the environmental impact in this research.

For the selected circular economy strategy, "Direct Reuse of Structural Steel", this research would first build an IO model with the IO transaction table of Taiwan in 2016. The purpose is to assess the change of the whole economy in 2016 under the direct reuse circular economy strategy. There are 63 industries in the original IO transaction table of Taiwan in 2016. In order to simulate the selected circular strategy, this research separates an existing industry in the market (Structural Steel) from one of the existing

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63 industries in IO transaction table (Fabricated Metal Products). On the other hand, a new industry “Direct Reuse Structural Steel”, which is an emerging future industry not yet existing in the market, would be added as a substitutional product choice for “Structural Steel”. There will be 65 industries after broadening the IO model. After adjusting the technical coefficients and final demands based on the assumptions of the circular strategy, the output value and the value added of the 65 industries could be calculated by IO analysis. The simulation is based on the fact that the sum of the final demand, also known as GDP, does not change. Then, the impact of the new material flow to the economy would be understood. The final process is to calculate the amount of carbon emission as an application of EEIO analysis by introducing the carbon emission coefficients corresponding to each industry. After the analysis through IO model under the scenarios, the final discussion and suggestion could be made by comparing the results from the econometric model and environmental impact assessment model. Fig. 3.1 shows the simplified research process.

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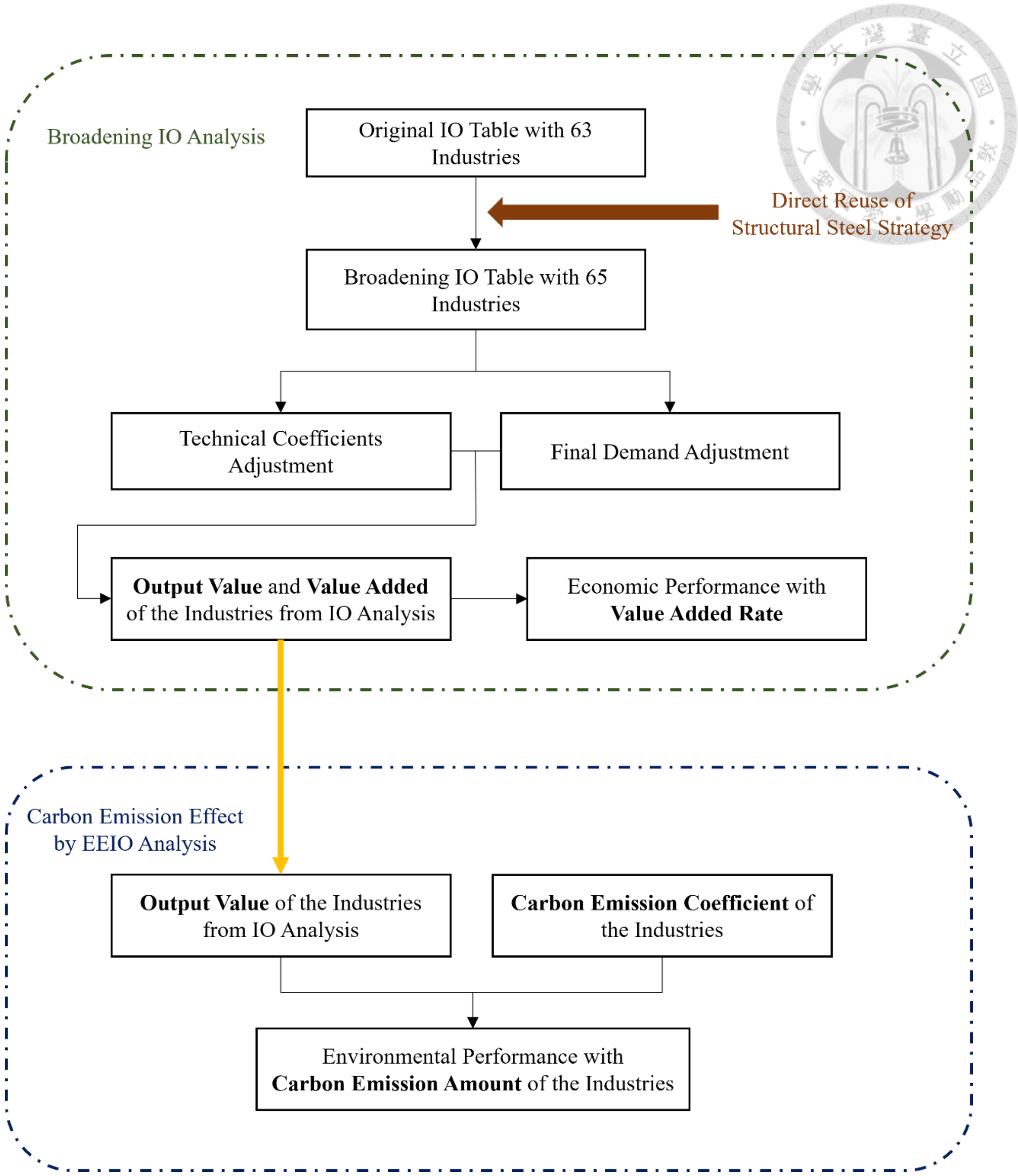

Fig. 3.1 Simplified Research Process

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3.2. Econometric Model

Because the selected circular economy strategy still does not exist in the real world, the corresponding effects cannot be gotten from the reality right away. Therefore, this research has to draw support from econometric model which is feasible to simulate the outcome of specific circular economy strategy. Input-Output (IO) model and its extended series of models are just suitable for this condition. Hou (2019) and Hsieh (2022) both utilized IO & its extended series of models to assess the transformation of plastic-related industries under the circular economy concepts. This research would take the similar form of analysis from these previous research to evaluate the selected circular business model with a hybrid IO & EEIO model. However, the targets industries and the ways of the model construction would be different. The following paragraphs explain the general concepts of input-output models, its extended series of model, and how the original IO transaction table was reformed to analysis the selected strategy.

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3.2.1. Input－Output analysis (IO)

3.2.1.1. Introduction to IO model

Input–Output (IO) model is an analytical framework developed by Professor Wassily Leontief in the late 1930s. It is an econometric model consisting of a system of linear equations, each one of which describes the distribution of an industry’s product throughout the economy. Because the Input–Output framework was proposed to analyze the interdependence of industries in an economy, people usually use the term “Interindustry Analysis” to describe this model as well. Professor Wassily Leontief ultimately received the Nobel Prize in Economic Science in 1973 due to the contribution of developing the Input–Output model (Miller & Blair, 2009).

The basic Input–Output model is generally constructed from the observed economic data for a specific geographic region, such as a nation or a country. It concerns the activity of a group of industries in that specific geographic region. The group of industries both produce goods (outputs) and consume goods from other industries (inputs) in the process of producing each industry’s own output. Input–Output model could present the results of a country's economic activities within a certain period of time (usually one year), and uses a matrix to represent the interdependence of inputs

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and outputs among all the industries in the country (Directorate-General of Budget, 2020; Miller & Blair, 2009).

3.2.1.2. The assumptions and methodology of IO analysis

Economic is a dynamic system with continuous changes. It is hard to find a balance condition at a specific time point in the real world. Therefore, economists have developed many econometric models to simulate the real world, Input–Output (IO) model is one of the valuable models. Since econometric model is a microcosm of the regional economic, there must be some perfect assumptions in order to make the simulation possible. For Input–Output (IO) analysis, there are three major assumptions:

I. The assumption of “single product”: Each industry is assumed to produce only a kind of product in an IO model. There is no possible product substitution among different industries.

II. The assumption of “fixed coefficient”: In an IO model, the technical coefficients (also called the A matrix) is assumed to be fixed in a specific period. It implies that the input and output scale between the industry (as a producer) and the industry (as a consumer) is fixed.

III. The assumption of “fixed ratio”: In an IO model, the ratio between each

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production element for a product is fixed, which means all the technical coefficients on the same column are independent. It implies that the cost scale of each industry is fixed.

(Wang et al., 2022)

To evaluate the economic performance of the industries in a country through an Input-Output model, an IO transaction table (including the final demand & total output), technical coefficients matrix and Leontief inverse matrix are needed to conduct the analysis.

IO Transaction table, as known as IO basic table, is the dataset of the observed economic data in a specific region which is constructed for Input–Output analysis. The concept of an IO transaction table is shown in Table 3.1.

Table 3.1 The Concept of an IO Transaction Table

$\boldsymbol{Supply\ \ i \backslash Demand\ j}$		Producers as Consumers	Final Demand (F)	Total Output (X_i)
		$1 \ \cdots \ j \ \cdots \ n$		
Producers	1 $\vdots$ i $\vdots$ n	$\begin{matrix} Z_{11} & \cdots & Z_{1n} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nn} \end{matrix}$	$\begin{matrix} F_1 \\ \vdots \\ F_n \end{matrix}$	$\begin{matrix} X_1 \\ \vdots \\ X_n \end{matrix}$
Value Added		$L_1 \ \cdots \ L_n$	$\sum X_i = \sum X_j = X$	
Total Outlay (X_j)		$X_1 \ \cdots \ X_n$		

(Lee, 2005; Miller & Blair, 2009)

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In a transaction table, $\mathbf{Z_{ij}}$ represents the total input from industry i (as a consumer) to industry j (as a supplier). $\mathbf{F_i}$ represents the final demand of industry i, which includes the private consumption, government consumption, fixed capital formation, changes in inventories and exports of goods and services of industry i. The sum of final demand for each industry is considered as the Gross Domestic Product (GDP) of the observed regional economy. $\mathbf{L_j}$ represents the value added of industry j, which includes the labor remuneration, operating surplus, capital consumption and indirect tax of industry j. $\mathbf{X_i}$ represents the total output of industry i, which is calculated as the sum of Z_{i1} to Z_{in} and F_i. $\mathbf{X_j}$ represents the total outlay of industry j, which is calculated as the sum of Z_{1j} to Z_{nj} and L_j.

The relations among these symbols can be summarized in the equations below:

$$\left(\sum_{i=1,j=1}^{n} Z_{ij}\right) + F_i = X_i \tag{3.1}$$

$$\left(\sum_{i=1,j=1}^{n} Z_{ij}\right) + L_j = X_j \tag{3.2}$$

$$X_i = X_j \tag{3.3}$$

$$\sum_{i=1}^{n} F_i = GDP \tag{3.4}$$

(n is the number of industries in the observed regional economy)

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Technical coefficients matrix (also known as A matrix), is transformed through the transaction table. The concept of an IO technical coefficients matrix is shown in Table 3.2.

Table 3.2 The Concept of an IO Technical Coefficients matrix

$\boldsymbol{Supply\ \ i \backslash Demand\ j}$		Producers as Consumers
		$1 \quad \cdots \quad j \quad \cdots \quad n$
Producers	1 $\vdots$ i $\vdots$ n	$\begin{matrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{matrix}$
$(a_{ij} = Z_{ij}/X_j)$		

(Lee, 2005; Miller & Blair, 2009)

Technical coefficients represent the necessary supply to the market for one specific industry to all the industries for one unit outlay. That is, the ratio of the essential cost (Z_{ij}) to the total outlay (X_j) for each industry. Technical coefficients are assumed to be stable in a certain period of time, which means one specific industry (as a consumer) would spend a unique and unchanging cost on each industry it needs in the market. It was under the assumption that the technical conditions in the market do not change, so that it would be possible to find a balance point among the whole economic system.

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After the technical coefficients are calculated, Equation 3.1 could be transformed into a new form with the technical coefficients:

$$\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} * \begin{pmatrix} X_1 \\ \vdots \\ X_n \end{pmatrix} + \begin{pmatrix} F_1 \\ \vdots \\ F_n \end{pmatrix} = \begin{pmatrix} X_1 \\ \vdots \\ X_n \end{pmatrix} \tag{3.5}$$

Equation 3.5 could be further translocated into Equation 3.7:

$$\begin{pmatrix} 1-a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 1-a_{nn} \end{pmatrix} * \begin{pmatrix} X_1 \\ \vdots \\ X_n \end{pmatrix} = \begin{pmatrix} F_1 \\ \vdots \\ F_n \end{pmatrix} \tag{3.6}$$

$$\begin{pmatrix} X_1 \\ \vdots \\ X_n \end{pmatrix} = \begin{pmatrix} 1-a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 1-a_{nn} \end{pmatrix}^{-1} \begin{pmatrix} F_1 \\ \vdots \\ F_n \end{pmatrix} \tag{3.7}$$

By simplifying Equation 3.7 with the symbols of matrix, the classic equation of Input-Output (IO) analysis could be reached:

$$\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{F} \tag{3.8}$$

The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is called the Leontief inverse matrix. Leontief inverse matrix represents the variation amount to all the industries due to the final demand increase per unit in one industry. With Equation 3.8, the change of an economic system can be evaluated by adjusting the technical coefficients and the final demand in a convenient manner. That is what Professor Wassily Leontief contributed to the economic research field. In Equation 2.8, X represents the total output vector of the industries; I represents the unit matrix; A represents the

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technical coefficients matrix; $(I - A)^{-1}$ is the Leontief inverse matrix; F represents the final demand vector of the industries.

Aside from the classic IO analysis in the economic field, the basic IO model could also be transformed into the extended series of models, which intend to connect different issues in the society with the economy. For a lot of research related to environmental issues, Waste Input-Output (WIO) analysis and Environmental Extended Input-Output Analysis (EEIO) are two well-known examples of connecting the economic issue with waste management aspect and emission issues. The purpose of applying the extended series of IO analysis is shown in Fig. 3.2.

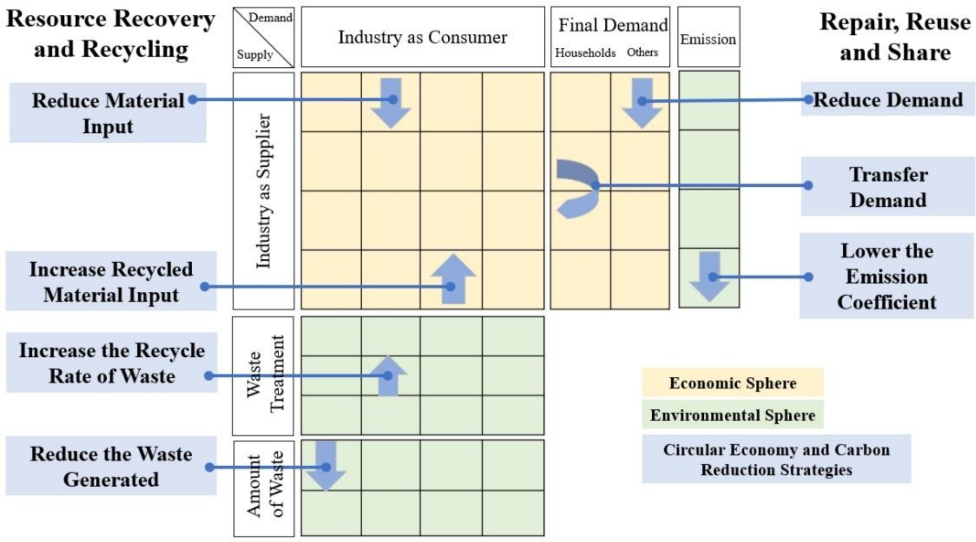

Fig. 3.2 Examples of the Extension with IO Model

By applying circular economy or carbon reduction strategies, the impact to the real world could be in different aspects. For the application in the waste management part, a

WIO model contains both the economic sphere and the environmental sphere of an economy. For example, when a government promote Resource Recovery and Recycling strategy, it may focus on reducing the material input, increasing recycled material input, increasing the recycle rate of waste or reducing the waste generated. The government could make use of WIO analysis to understand the level of mutual influence of the economy and waste management aspect under specific circular economy strategy related to waste issues. In addition, when a government promotes Repair, Reuse and Share strategy, it may focus on reducing the demand, transferring the demand, or lowering the emission coefficients of the industries. An EEIO analysis could help it simulate the circular economy business models related to the change on demand side of the market to observe how the emission of an environmental indicator changes with the economy.

3.2.1.3. The method of constructing an IO model in this research

In this research, the simulation model would be constructed by Excel, and the IO transaction table of Taiwan in 2016 would be introduced as the database of Input-Output (IO) model. This research would focus on the change in economy of the year 2016 before and after the application of Direct Reuse of Structural Steel strategy. There

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are 63 industries in the original IO transaction table of Taiwan in 2016. In order to simulate the selected circular business model, the original IO transaction table has to be broadened into 65 industries. The two newly broadened industries are "Structural Steel Industry (64th)" and "Direct Reuse of Structural Steel Industry (65th)". Table 3.3 shows all the industries included in the broadened IO transaction table.

Table 3.3 Details of the Industries in Broadened IO Transaction Table

Industry No.	**Industry Category**
1	Agricultural Products
2	Livestock
3	Forest Products
4	Fishery Products
5	Mineral Products
6	Food Products and Prepared Animal Feeds
7	Beverages and Tobacco
8	Textiles
9	Wearing Apparel and Clothing Accessories
10	Leather, Fur and Related Products
11	Wood and Bamboo Products
12	Paper and Paper Products
13	Printing and Reproduction of Recorded Media
14	Petroleum and Coal Products
15	Chemical Materials
16	Other Chemical Products
17	Pharmaceuticals and Medicinal Chemical Products
18	Rubber Products
19	Plastic Products
20	Non-metallic Mineral Products
21	Basic Metals
22	Fabricated Metal Products

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Table 3.3 Details of the Industries in Broadened IO Transaction Table (Continued 1)

Industry No.	**Industry Category**
23	Electronic Parts and Components
24	Computers, Electronic and Optical Products
25	Electrical Equipment
26	Machinery and Equipment
27	Motor Vehicles and Parts
28	Other Transport Equipment and Parts
29	Furniture
30	Other Manufactures
31	Electricity and Steam
32	Gas
33	City Water
34	Remediation Activities
35	Construction
36	Wholesale Trade
37	Retail Trade
38	Land Transportation
39	Water Transportation
40	Air Transport
41	Support Activities for Transportation; Warehousing and Storage
42	Postal and Courier Activities
43	Accommodation
44	Food and Beverage Service Activities
45	Publishing, Motion Picture, Video and Music Production and Broadcasting Activities
46	Telecommunications
47	Related Service of Computer and Information
48	Financial Service Activities
49	Insurance
50	Commodity Contracts
51	Real Estate Activities
52	Ownership of Dwellings

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Table 3.3 Details of the Industries in Broadened IO Transaction Table (Continued 2)

Industry No.	Industry Category
53	Professional, Scientific and Technical Activities
54	Rental and Leasing Activities
55	Other Support Service Activities
56	Public Administration and Defense; Compulsory Social Security
57	Education
58	Medical and Health Activities
59	Social Work Activities
60	Arts, Entertainment and Recreation
61	Services of Civil Association and Other Social Services
62	Activities of Households as Employers of Domestic Personnel
63	Other Personal Service Activities
64	Structural Steel
65	Direct Reuse of Structural Steel

The purpose of creating a new "Direct Reuse of Structural Steel" industry is to create a new supply route of structural steel from the structural steel demolished from buildings, according to the research of Dunant et al. (2018) in UK that *"There is an opportunity to introduce a specialized actor in the supply chain responsible for the acquisition, reconditioning and distribution of reused elements."* This research assume that the product of Direct Reuse of Structural Steel (Industry No.65) would be direct reuse structural steel, which could be a substitution of the original structural steel. Therefore, Structural Steel (Industry No.64) would be separated from Fabricated Metal Products (Industry No.22) to adjust the supply proportion of structural steel to the market between the original Structural Steel (Industry No.64) and the new Direct Reuse

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of Structural Steel (Industry No.65).

The 64th & 65th industry corresponded to the reformation of structural steel flow route. The 64th industry – Structural Steel, was separated from one of the original 63 industries Fabricated Metal Products (Industry No.22), and the 65th industry – Direct Reuse of Structural Steel, was created according to the direct reuse structural steel circular strategy. These two industries were added to simulate the circular strategy of the direct reuse of structural steel in construction sector. The structure of the broadened IO transaction table is shown in Table 3.4.

Table 3.4 The Structure of the Broadened Transaction Table

Supply i\Demand j		Producers as Consumers			Final Demand (F)	Total Output (X_i)
		1 ⋯ 63	64	65		
Producers	1 ⋮ 63	$Z_{1,1}$ ⋯ $Z_{1,65}$ ⋮ ⋱ ⋮ $Z_{65,1}$ ⋯ $Z_{65,65}$			F_1 ⋮ F_{65}	X_1 ⋮ X_{65}
	64					
	65					
Value Added		L_1 ⋯ L_{65}			$\sum X_i = \sum X_j = X$	
Total Outlay (X_j)		X_1 ⋯ X_{65}				
1~63 – Original Industries 64 – Structural Steel Industry 65 – Direct Reuse of Structural Steel Industry						

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The design of flow route reformation is based on the building demolition regulations and material trading status in Taiwan, and the reference was the research of (Dunant et al., 2018) in UK. The original material flow and money flow existing in the market related to structural steel is shown in Fig. 3.3 & Fig. 3.4, respectively.

Original Steel Flow Route

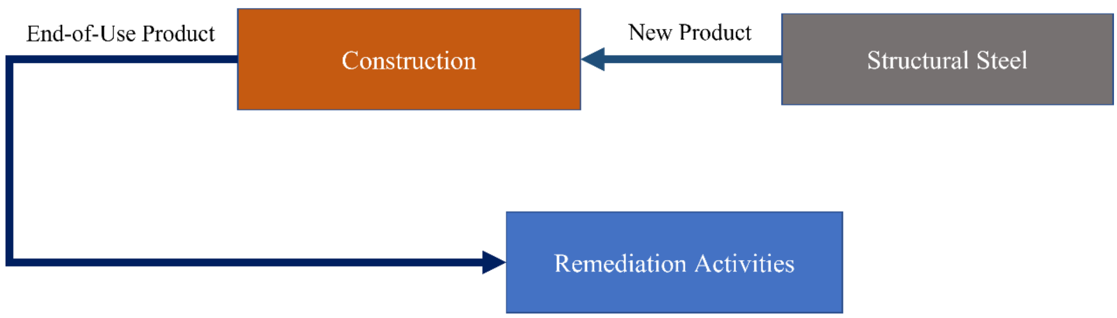

Fig. 3.3 Original Steel Flow Route

Original Money Flow Route

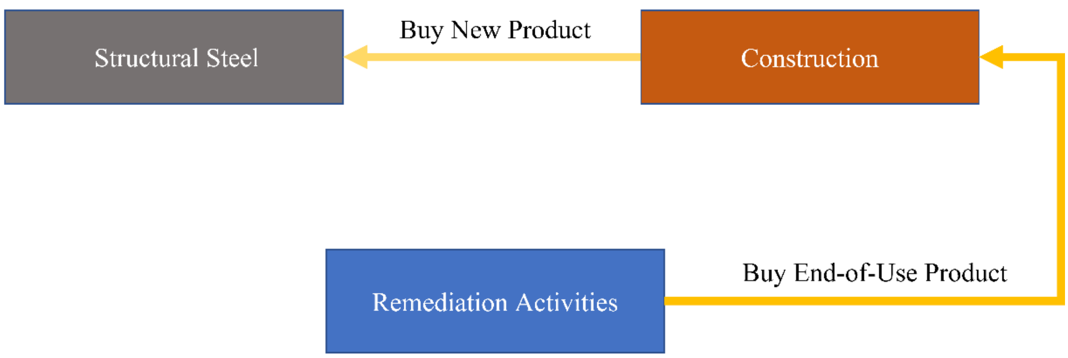

Fig. 3.4 Original Money Flow Route

Originally, the structural steel product was first made by Structural Steel (Industry No.64). Construction (Industry No.35) would buy the new structural steel product to use

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in a building project. When a building is at the end-of-use stage, Construction (Industry No.35) would demolish the building and then the end-of-use structural steel would be sold to Remediation Activities (Industry No.34). Finally, the end-of-use structural steel would be sent to the treatment sector for further recycling and remanufacturing. Under the original condition, Construction (Industry No.35) would have to buy structural steel from Structural Steel (Industry No.64) in a new building project and sell the end-of-use structural steel to Remediation Activities (Industry No.34) a building was demolished.

Fig. 3.5 & Fig. 3.6 exhibit a possible steel flow route and money flow route after applying direct reuse of structural steel strategy, which would be implemented in the IO model under direct reuse scenario in this research.

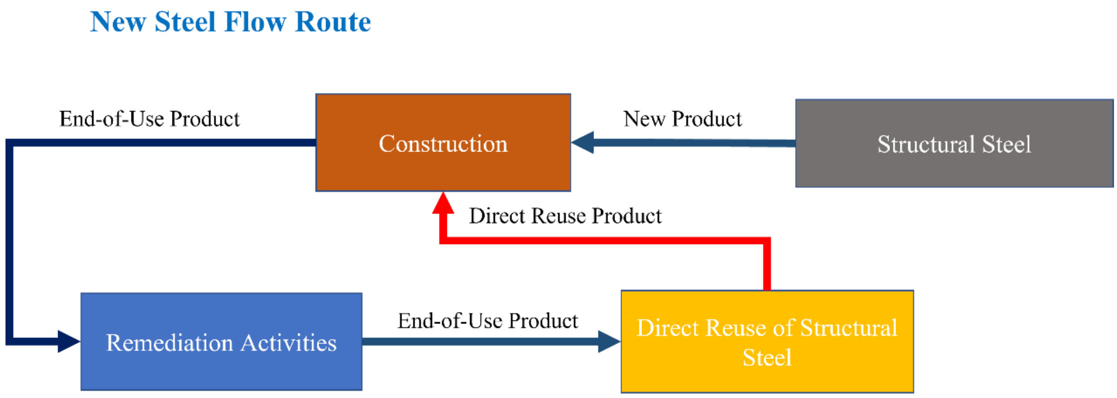

Fig. 3.5 New Steel Flow Route

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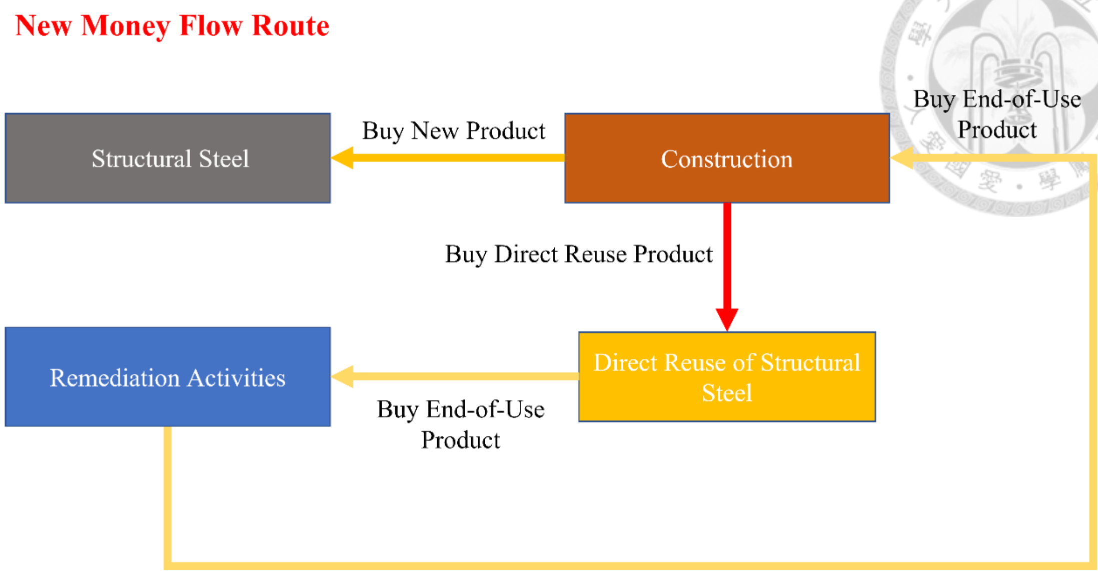

Fig. 3.6 New Money Flow Route

After introducing a new industry, Direct Reuse of Structural Steel (Industry No.65), this research expects that the end-of-use structural steel from a demolished building would be sold to Remediation Activities (Industry No.34) as usual. Direct Reuse of Structural Steel (Industry No.65) would buy the end-of-use structural steel from Remediation Activities (Industry No.34) for further modification. According to the research of Dunant et al. (2018) in UK, Direct Reuse of Structural Steel (Industry No.65) is responsible for the examination, transportation and modification process of the end-of-use structural steel. The complete process was assumed to entrust the related industries to handle with it instead of executing by Direct Reuse of Structural Steel (Industry No.65) itself. However, the end-of-use structural steel would be sent to the to the treatment sector for recycling and remanufacturing as before once it does not pass

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the examination. After Direct Reuse of Structural Steel (Industry No.65) finishes all the process with the end-of-use structural steel, it would be sold to Construction (Industry No.35) again as a replacement for the original structural steel. At the same time, the demand for Structural Steel (Industry No.64) by Construction (Industry No.35) would be expected to decline.

Because Direct Reuse of Structural Steel (Industry No.65) only needs the supply from few other industries, which is very different from the original Structural Steel (Industry No.64), assumptions have been made in this research by referring to previous studies for what the possible cost the new industry it would have. Fig. 3.7 is one of the reference data from a study in UK.

Table 1
Overview of the maximum and minimum costs of various operations necessary for the fabrication and erection of used and new elements. Prices are in £/t, displayed rounded to £ 5.

Operation	Reuse element		New elements	
Operation	min	max	min	max
N — *Distributor (new steel)*	–	–	530	750
– Margin	–	–	110	110
– Steel	–	–	400	600
– Premium for rare	–	–	20	40
O — *Distributor (used steel)*	200	300	–	–
– Margin	110	110	–	–
– Steel	90	190	–	–
R — *Fabrication (recondition)*	220	370	–	–
– Shot-blasting	15	55	–	–
– Removing welds	–	25	–	–
– Removing end plates	85	120	–	–
D — *Striking down*	120	165	–	–
F — *Fabrication*	500	700	500	700
– Administration	50	65	50	65
– Design	55	80	55	80
– Bolts/primer	25	35	25	35
– Erection	120	165	120	165
– Cuts/Welds/Drills/Shot-blasting	248	355	248	355
r, T, t — *Testing and transport*	210	250	20	25
– Testing	145	175	–	–
– Transport	65	75	20	25
Total	**1130**	**1620**	**1050**	**1475**
Reused steel carry			– 1130	– 1620
New – Scrap spread			+185	+185
Spread			**105**	**45**
Spread (relative)			9.29%	2.78%

Fig. 3.7 Costs Comparison between Reuse Element & New Element (Dunant et al., 2018)

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From Fig. 3.7, direct reuse of structural only needs the supply from the distributor, recondition, testing and transport sector. In this research, the final product of Direct Reuse of Structural Steel (Industry No.65) was assumed to be the same as the product of Steel Structural (Industry No.64). Therefore, the price of the product from both industries would be the same as well. The adjustment of the technical coefficients are based on this prerequisite. However, only the technical coefficient of the recondition sector would be adjusted with the reference data of from Fig. 3.7. For other technical coefficients, other assumptions are made for the adjustments.

First, the technical coefficient for the distributor (Remediation Activities – Industry No.34) would be the ratio of the price of end-of-use steel and the price of new structural steel in Taiwan. This was based on the fact that technical coefficient represents the ratio of the money input for a unit outlay.

Second, since direct reuse structural steel only needs to be modified by the Structural Steel (Industry No.64), Direct Reuse of Structural Steel (Industry No.65) does not need other implicit industries' supply in the Fabricated Metal Products (Industry No.22) where Structural Steel (Industry No.64) was separated from. Also, from Fig. 3.7, the ratio between the mean value of R (recondition) and the mean value

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of F (Fabrication) is about 0.25417 times. As a result, the technical coefficient for recondition sector (Structural Steel Industry – No.64) was set to be about 0.25417 times of the original technical coefficient from the demand of Structural Steel (Industry No.64) for Structural Steel (Industry No.64).

Third, when creating the technical coefficients for the new Direct Reuse of Structural Steel (Industry No.65), the technical coefficients related to testing sector (Professional, Scientific and Technical Activities – Industry No.53) and transport sector (Land Transportation – Industry No.38) are assumed to be the same as the technical coefficients from the demand of Structural Steel (Industry No.64) for these industries. It was because the cost for testing and transportation with the same product from different sources are assumed to be the same.

After the technical coefficients (A) and final demands (F) have been adjusted, the total output (X) could be calculated with Equation 3.8 and the reformed economic system of Taiwan after applying the direct reuse of structural steel circular economy business model could be found. The output data could represent indicators to observe whether the strategy has positive impact to our economic and environment. For the economic aspect, the value added rate between the original and new industries would be

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compared to see whether the circular economy strategy would create a new market with more industries and higher value added rate. For the environmental aspect, Environmental Extended Input-Output (EEIO) analysis would be utilized with the total output value X in the next paragraph to see the carbon reduction effect.

3.3. Environmental Impact Assessment Model

3.3.1. Environmental Extended Input-Output analysis (EEIO)

3.3.1.1. Introduction to EEIO analysis

Environmental Extended Input-Output (EEIO) analysis is based on IO transaction table. It is an extending Input-Output analysis method that generally be applied in the field of environment and energy resources. EEIO analysis method could be applied to calculate the hidden, upstream, indirect or embodied environmental impacts associated with consumption activities (Kitzes, 2013). Through the introduction of specific emission coefficients related to each industry, the total impact of the emission from specific environmental issue could be obtained by multiplying the selected coefficients with the total output values of each industry in IO transaction table. Equation 3.9 is a simple concept of EEIO analysis.

$$Emission = ef_i \cdot X \quad (3.9)$$

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3.3.1.2. The method of conducting EEIO analysis in this research

In this research, the energy balances sheet in 2016 from Bureau of Energy, Ministry of Economic Affairs, Taiwan, and the output values in IO transaction table in 2016 from Directorate General of Budget, Accounting and Statistics, Taiwan would be taken as the datasets to calculate the carbon emission coefficients per unit output associated with each industry. This research first matched the industries between the energy balance sheet and IO transaction table, and then took 8 kinds of fossil fuels (including coal, LPG, Naphtha, motor gasoline, diesel fuel, fuel oil, natural gas, and LNG) mainly utilized in the industries with their CO_2 emission index to calculate the total amount of carbon emission from each industry. Then, by dividing the total amount of carbon emission with the output value of each industry, the carbon emission coefficients per unit output of each industry could be reached. In this research, the total carbon emission difference would be gotten by multiplying the difference of output value from IO analysis before and after applying the circular strategy with the carbon emission coefficients per unit output to get as the symbol of the environmental impact.

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4. Result and Discussion

4.1. Data Sources

In order to simulate the greatest potential of the direct reuse of structural steel strategy in construction sector, this research utilized the data collected mainly from the open datasets of the government in Taiwan, and also referred to previous research or corporate materials. The data and the corresponding sources in this research are shown in Table 4.1.

Table 4.1 The Reference Data & Sources

No.	Data	Sources
1	IO Transaction Table	(Directorate General of Budget, 2016)
2	Production Amounts of Structural Steel	(Department of Statistics, 2016)
3	Demolition License by Material	(Ministry of Interior, 2016)
4	H-Beam Price Trend	(Public Construction Commission, 2016)
5	Construction Material Ratio	(Chen, 2011)
6	Energy Balances Sheet	(Bureau of Energy, 2016)
7	CO2 Emission Index	(Bureau of Energy, 2015)
8	The Procurement Price of End-Of-Use Steel	(Feng Hsin Steel Co., 2016)

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4.2. Scenarios and Technical Coefficients Adjustment

Since direct reuse of structural steel circular economy business model is an emerging concept, it does not exist in the market of Taiwan yet. In this research, there are two scenarios:

- Scenario 1: Base line – The existing economy of Taiwan in 2016 without applying direct reuse of structural steel strategy.
- Scenario 2: A circular economy environment – The reformed economy of Taiwan in 2016 after applying direct reuse of structural steel strategy.

Scenario 1 (Base line) would be represented by the original IO transaction table of Taiwan in 2016. To simulate a circular economy future of Scenario 2, part of the technical coefficients and final demands must be adjusted since the steel material flow and money flow has transformed in the market. The concepts of scenario 1 and scenario 2 is shown in Table 4.2.

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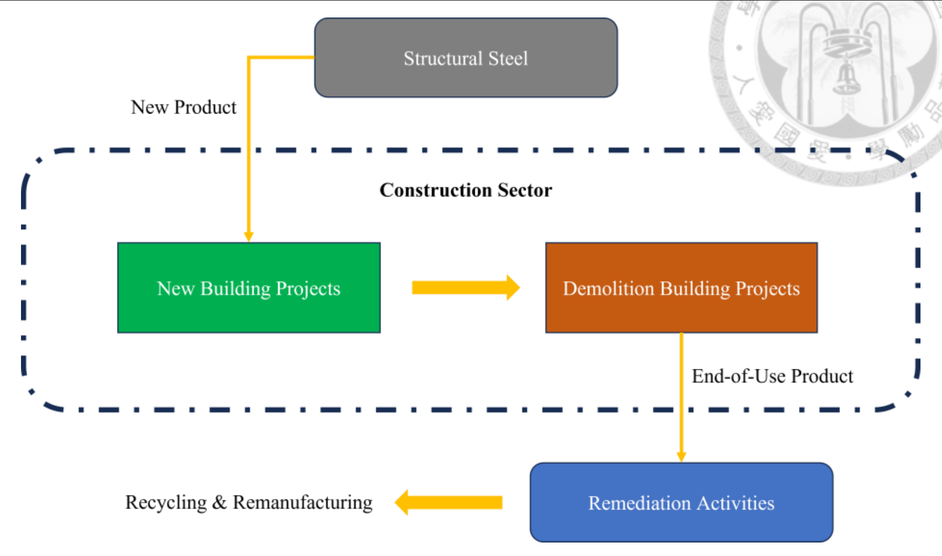
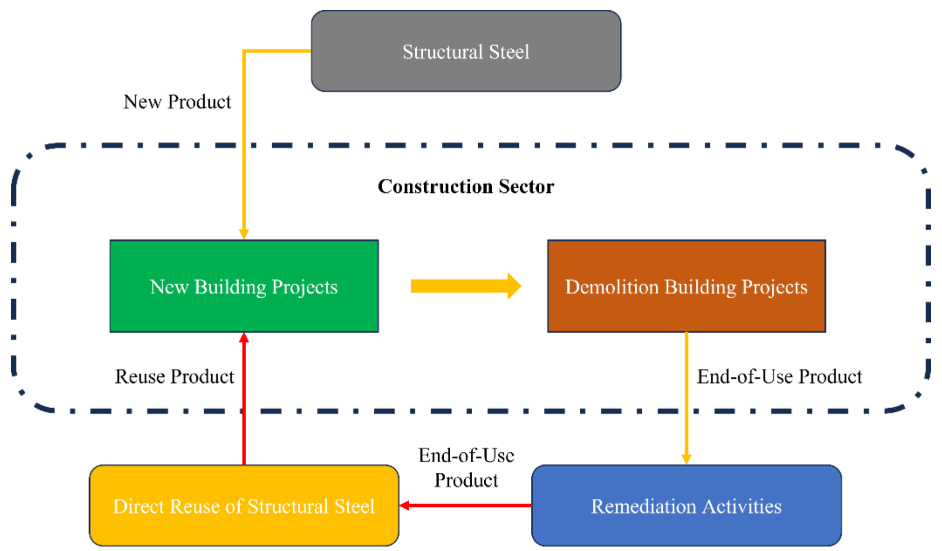
Table 4.2 Concepts of Scenarios

Scenario 1	
Scenario 2	

In order to adjust the final demand and technical coefficients under a circular economy future of Scenario 2, this research referred to the Data & Sources shown in Table 4.1 for the following estimation. From two reference data sources, Demolition License by Material (Reference Data No.3) and Construction Material Ratio (Reference Data No.5), the amount of end-of-use structural steel could be estimated by multiplying the demolition floor area of SS building with the proportion of steel material per unit

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floor area of SS building. According to Reference Data No.3, the demolition license corresponded to SS building issued by the government of Taiwan in 2016 was with total floor area of 345251 (m^2). An estimated amount of 0.172 tons of steel would be used in a SS building per square meter according to Reference Data No.5. Therefore, the amount of end-of-use structural steel generated in 2016 was around 59383.172 tons.

Next, by dividing the estimated amount of end-of-use structural steel with the production amounts of structural steel (Reference Data No.2), the greatest potential of direct reuse structural steel could be estimated. There were around 2552897.565 tons of new structural steel production in 2016. From the estimation, there would be about 2.33% of the final demand for structural steel could be substituted by direct reuse of structural steel. The adjusted distribution ratio of the final demand is exhibited in Table 4.3.

Table 4.3 Distribution Ratio of Final Demands

	Final Demands
Structural Steel (Industry No.64)	97.67% (Originally 100%)
Direct Reuse of Structural Steel (Industry No.65)	2.33% (Originally 0%)

Without discussing about the non-useable proportion of end-of-use structural steel, Table 4.3 represents the greatest potential of the substitution on the final demand for

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structural steel in the whole market. It turns out that 2.33% of the final demand for Structural Steel (Industry No.64) would be separated to Direct Reuse of Structural Steel (Industry No.65).

After adjusting the proportion of final demand, the technical coefficients of Structural Steel (Industry No.64) and Direct Reuse of Structural Steel (Industry No.65) also have to be adjusted under a circular economy future of Scenario 2. There are demands for the supply of Structural Steel (Industry No.64) in many industries. Construction (Industry No.35) is merely one of it. Since the direct reuse structural steel was assumed to only substitute the original structural steel in Construction (Industry No.35), the technical coefficients, which represents the demand for Structural Steel (Industry No.64) and Direct Reuse of Structural Steel (Industry No.65) from Construction (Industry No.35), could not be directly adjusted as the proportion exhibit in Table 4.3. On the contrary, the technical coefficients distribution ratio would be computed by the equations shown in Table 4.4.

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Table 4.4 Computation of Technical Coefficients Distribution Ratio

Demand Ratio from Construction for Direct Reuse of Structural Steel (D_{CD})
$\boldsymbol{D_{CD}} = \dfrac{\boldsymbol{EOU_{generated}}}{\boldsymbol{SS_{production}} * (\boldsymbol{Input_{I35\ for\ I64}}/\boldsymbol{T})}$
Demand Ratio from Construction for Structural Steel (D_{CS})
$\boldsymbol{D_{CS} = 1 - D_{CD}}$
Parameter Explanation
$\boldsymbol{EOU_{generated}}$ = Amount of end − of − use structural steel generated (2016) $\boldsymbol{SS_{production}}$ = Production amount of structural steel (2016) $\boldsymbol{T}$ = Sum of the original market share for Structural Steel (money) $\boldsymbol{Input_{I35\ for\ I64}}$ = Demand from Construction for Structural Steel (money)

After introducing the actual values of the corresponding parameters, the demand ratio of technical coefficients from Construction (Industry No.35) for Structural Steel (Industry No.64) and Direct Reuse of Structural Steel (Industry No.65) would be obtained. The result is shown in Table 4.5.

Table 4.5 Technical Coefficients Adjustment Outcome (Construction - Industry No.35)

	Construction (Industry No.35)
Structural Steel (Industry No.64)	97.28% (Originally 100%)
Direct Reuse of Structural Steel (Industry No.65)	2.72% (Originally 0%)

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For the technical coefficients of Direct Reuse of Structural Steel (Industry No.65), Direct Reuse of Structural Steel (Industry No.65) would only need the supply from Remediation Activities (Industry No.34), Structural Steel (Industry No.64), Professional, Scientific and Technical Activities (Industry No.53) and Land Transportation (Industry No.38). The assumptions of these corresponded technical coefficients have been described in section 3.1.2.3. Table 4.6 demonstrates the method of adjustment in the technical coefficients of Direct Reuse of Structural Steel (Industry No.65) in IO model.

Table 4.6 Technical Coefficients Adjustment (Industry No.65)

	Direct Reuse of Structural Steel (Industry No.65)
Remediation Activities (Industry No.34)	Ratio of the price of end-of-use steel and the price of new structural steel
Structural Steel (Industry No.64)	About 0.25417 times of the original technical coefficient from the demand of Structural Steel (Industry No.64) for Structural Steel (Industry No.64)
Professional, Scientific and Technical Activities (Industry No.53)	The same as the original technical coefficient from the demand of Structural Steel (Industry No.64) for Professional, Scientific and Technical Activities (Industry No.53)

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Table 4.6 Technical Coefficients Adjustment (Industry No.65) (Continued)

	Direct Reuse of Structural Steel (Industry No.65)
Land Transportation (Industry No.38)	The same as the original technical coefficient from the demand of Structural Steel (Industry No.64) for Land Transportation (Industry No.38)

After the final demands and technical coefficients have been adjusted under the assumption of Scenario 2, the impact in both the economy and the environment could be gotten with the application of Equation 2.8. The impact could explain whether this circular strategy is worth adopting by comparing the outcome of Scenario 2 with Scenario 1.

4.3. The Economic Performance

Examining the impact of an emerging circular economy business model to the market was one of the intentions in this research. Only if a strategy is more beneficial than harmful to the economy would it be successfully introduced to the market. In this section, the output value, value added and value added rate would be taken as the objective economic indicators to evaluate the economic performance. Apart from focusing on the substitutional effect of Direct Reuse of Structural Steel (Industry No.65) to Structural Steel (Industry No.64), the effect of reducing the demand for raw materials and energy was another important factor that must be followed. This research would

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also pay attention to the change in economic performance of upstream industries, Basic Metals (Industry No.21) and Electricity and Steam (Industry No.31), which are related to steel material source and energy source, respectively. The change in economic performance of upstream industries could present whether the demand for natural resources and energy would decline under a circular economy like the corresponded reports had claimed.

Scenario 1 (Base line)

Under the base line scenario, the economy was exactly the same as the existing economy of Taiwan in 2016. There was no application of direct reuse strategy in any of the industries. The total output value under the base line scenario was 46896375 million NT dollars, and the total value added under the base line scenario was 26768537 million NT dollars. Table 4.7 shows the economic performance under base line scenario, including the target industries with substitution effect of structural steel and their upstream industries related to steel material and energy.

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Table 4.7 Economic Performance under Scenario 1 (Base line)

Industry	Final Demand (million $NT)	Output Value (million $NT)	Value Added (million $NT)	Value Added Rate (%)
The Whole Economy				
All	26768537	46896375	26768537	-
Structural Steel Related Industries with Substitution Effect				
Structural Steel	12095.26	66428	17481.92	26.32%
Direct Reuse of Structural Steel	-	-	-	-
Upstream Industries Related to Steel Material and Energy				
Basic Metal	378808	2036381	827919	40.66%
Electricity and Steam	273457	696885	314835	45.18%

Scenario 2 (A circular economy environment)

Under a circular economy scenario, the economy was reformed from the existing economy of Taiwan in 2016. Direct reuse strategy was applied in construction sector with structural steel. It was expected that the demand for the upstream industries of Structural Steel (Industry No.64) would decline due to the substitutional effect of Direct Reuse of Structural Steel (Industry No.65).

Under scenario 2, the economic repercussion effect could be observed with the data from Leontief inverse matrix. For each unit substitution in the final demand of the 64^{th} industry (Structural Steel) by the 65^{th} industry (Direct Reuse of Structural Steel), the other industries would be affected by the economic repercussion effect in their

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output values. Fig. 4.1 exhibits the most affected industries and the level of change in their output value under a unit final demand substitution of the 64th industry (Structural Steel) by the 65th industry (Direct Reuse of Structural Steel).

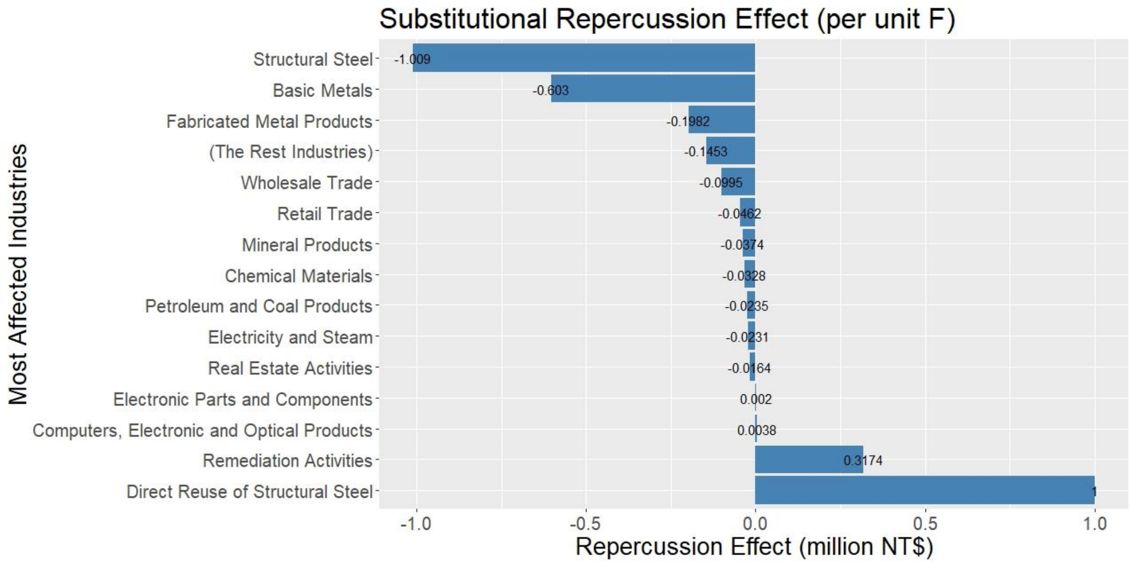

Fig. 4.1 Repercussion Effect per unit Final Demand Substitution by the 65th Industry

When the original final demand per unit for Structural Steel (Industry No.64) is substituted by a unit final demand for Direct Reuse of Structural Steel (Industry No.65), other industries would be affected by the interdependence repercussion effect, which could be observed only after the operation of the classic equation (Equation 3.8) of Input – Output model. While most of the industries would have a decline on their output values, there are still some industries that would be benefit from the demand substitution of the two industries. Aside from the direct substitution of the demand for

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Structural Steel (Industry No.64), the upstream industries related to raw material sources, energy sources and trade would also be indirectly but largely affected, and observed declines on their output values.

After the calculation through Equation 3.8 with Leontief inverse matrix and the reformed final demands, the total output value under a circular economy scenario was 46894967.03 million NT dollars, and the total value added under a circular economy scenario was 26768537 million NT dollars. Moreover, the newly introduced industry, Direct Reuse of Structural Steel, was with value added rate of 72.65%. Table 4.8 shows the economic performance under a circular economy scenario as the result of economic repercussion effect.

Table 4.8 Economic Performance under Scenario 2 (A circular economy)

Industry	**Final Demand (million $NT)**	**Output Value (million $NT)**	**Value Added (million $NT)**	**Value Added Rate (%)**
The Whole Economy				
All	26768537	46894967.03	26768537	-
Structural Steel Related Industries with Substitution Effect				
Structural Steel	11813.91	64868.94	17071.62	**26.32%**
Direct Reuse of Structural Steel	281.35	1545.18	1122.51	**72.65%**
Upstream Industries Related to Steel Material and Energy				
Basic Metal	378808	2035449.31	827540.21	40.66%
Electricity and Steam	273457	696849.30	314818.87	45.18%

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From the data shown in Table 4.7 and Table 4.8, the final demand of the whole economy and upstream industries do not change between scenario 1 and scenario 2, only 2.33% of the final demand separated from Structural Steel (Industry No.64) was given to Direct Reuse of Structural Steel (Industry No.64) in scenario 2. The value added rates of upstream industries and Structural Steel (Industry No.64) do not change between scenario 1 and scenario 2 as well. It turns out that the newly introduced industry created under the assumption of scenario 2, Direct Reuse of Structural Steel (Industry No.65), was with value added rate of 72.65%. Compared with the original Structural Steel (Industry No.64) with value added rate of 26.32%, Direct Reuse of Structural Steel (Industry No.65) was obviously more profitable for per unit output.

Table 4.9 Difference between Scenario 1 & Scenario 2 (S2-S1)

Industry	**Output Value (million $NT)**	**Value Added (million $NT)**	**Output Value Change Rate (%)**
The Whole Economy			
All	-1407.97	0	-
Structural Steel Related Industries with Substitution Effect			
Structural Steel	-1559.06	-410.30	-2.35%
Direct Reuse of Structural Steel	1545.18	1122.51	-
Upstream Industries Related to Steel Material and Energy			
Basic Metal	-931.69	-378.79	-0.0458 %
Electricity and Steam	-35.70	-16.13	$-5.12 * 10^{-3}$ %

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The difference of economic performance between scenario 2 and scenario 1 is shown in Table 4.9. The whole economy would loss around -1407.97 million NT dollars of the total output values under scenario 2. The sum of the value added does not change. However, there are some declines and some increase in the actual value added among all the industries, which means the value added of some industries have been transferred to other industries. The application of direct reuse of structural steel circular economy business model would not significantly affect the upstream industries related to raw material and energy with the economy of Taiwan in 2016. There is only a slight reduction rate in both the output value and the value added of these industries. It was because of the fact that the substitution percentage of structural steel by Direct Reuse of Structural Steel (Industry No.65) is merely 2.33% under the greatest potential assumption with the economy of Taiwan in 2016. The most affected industries in value added between scenario 2 and scenario 1 is shown in Fig. 4.2.

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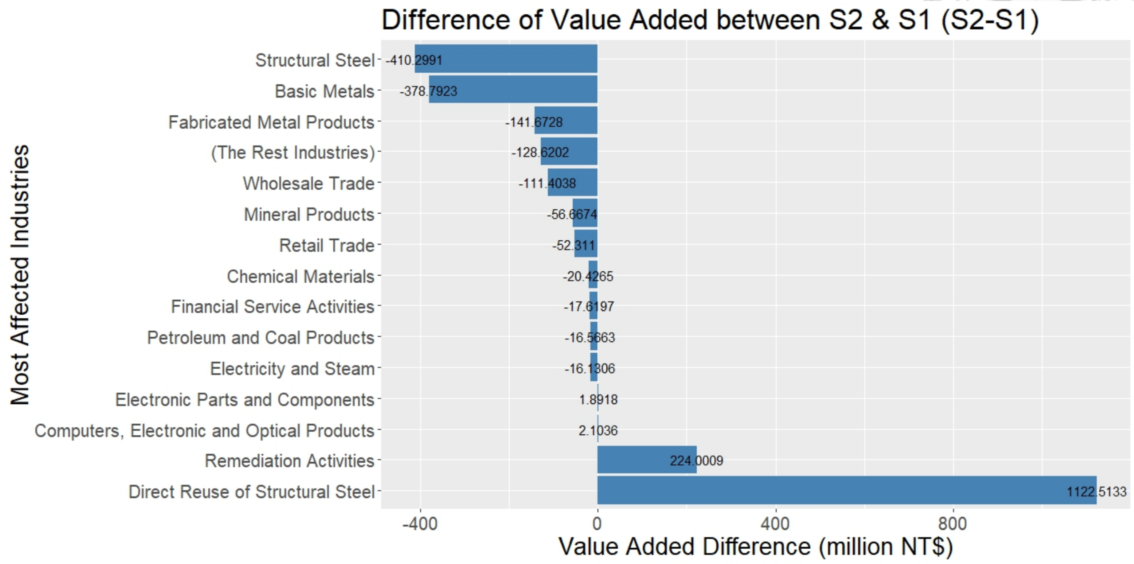

Fig. 4.2 Difference of Value Added between Scenario 2 and Scenario 1

The industries with the most decline on their value added could be categorized into the following groups:

- <u>The industry being substituted</u> — Structural Steel (Industry No. 64), which was substituted by Direct Reuse of Structural Steel (Industry No. 65) would have the most decline because it was directly affected by the final demand substitution.

- <u>The raw material related industries</u> — The value added of Basic Metals (Industry No. 21), Mineral Products (Industry No. 5) and Chemical Materials (Industry No. 15) are also declined due to the direct reuse strategy. Since the demand for new products decrease in the market, these raw material related industries would be indirectly affected as well.

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- <u>The manufacturing related industries</u> — Fabricated Metal Products (Industry No. 22) is with the same condition as the raw material related industries. Less demand, less value added.
- <u>The trading related industries</u> — Wholesale Trade (Industry No. 36) and Retail Trade (Industry No. 37) would also have decline on their value added since direct reuse strategy create a new material flow route that would not pass the original sales route.
- <u>The energy related industries</u> — The value added of Petroleum and Coal Products (Industry No. 14) and Electricity and Steam (Industry No. 31) are declined due to the reducing demand for remanufacturing. This could become a supporting argument that direct reuse strategy could avoid the unnecessary energy input.

Aside from the industries that would have decline on their value added, there are four industries that would be benefit from the direct reuse strategy, including Direct Reuse of Structural Steel (Industry No. 65), Remediation Activities (Industry No. 34), Computers, Electronic and Optical Products (Industry No. 24) and Electronic Parts and Components (Industry No. 23). Direct Reuse of Structural Steel (Industry No. 65) and

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Remediation Activities (Industry No. 34) were directly affected based on the redesign of material flow. The other two industries might be benefit from the repercussion effect while the economy reformed.

In summary, direct reuse of structural steel strategy would bring the market a new industry with high value added rate of 72.65%. Although the introduction of Direct Reuse of Structural Steel (Industry No.65) would reduce the demand for raw materials, manufacturing, trading and energy, the actual effect was comparably small since the substitution proportion of the final demand for structural steel by Direct Reuse of Structural Steel (Industry No.65) was merely 2.33%.

4.4. Carbon Reduction Effect

In addition to the economic performance, evaluating the environmental impact of circular economy business model is another important part of this research. With the introduction of the data in energy balances sheet, the direct carbon emission per unit outlay from each industry could be calculated. In this section, the carbon emission amount would be taken as the objective environmental indicators to evaluate the environmental performance.

Under the base line scenario, the economy was exactly the same as the existing

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economy of Taiwan in 2016. The total amount of direct carbon emission from all the industries was estimated to be about $2.0605 * 10^8$ tons. Under a circular economy scenario, direct reuse strategy was applied in construction sector with structural steel. The total amount of direct carbon emission from all the industries was estimated to be about $2.0604 * 10^8$ tons. The total carbon emission difference between scenario 2 and scenario 1 was about 11395.75 tons. Table 4.10 shows the carbon emission under base line scenario and a circular economy scenario, including the target industries with substitution effect of structural steel and the upstream industries related to steel material and energy.

Table 4.10 Carbon Emission under Scenario 1 & Scenario 2

Industry	**Scenario 1 (ton)**	**Scenario 2 (ton)**	**Difference (2-1) (ton)**
The Whole Economy			
All	$2.0605 * 10^8$	$2.0604 * 10^8$	-11395.75
Structural Steel Related Industries with Substitution Effect			
Structural Steel	30153.95	29446.24	-707.71
Direct Reuse of Structural Steel	-	0	-
Upstream Industries Related to Steel Material and Energy			
Basic Metal	6937897.81	6934723.56	-3174.25
Electricity and Steam	129787204.18	129780554.52	-6649.66

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Since Direct Reuse of Structural Steel (Industry No.65) does not contain an actual manufacturing process that would utilize fossil fuels and create carbon emission directly, the direct carbon emission per unit outlay of Direct Reuse of Structural Steel (Industry No.65) was assumed to be zero. Electricity and Steam (Industry No.31) and Basic Metal (Industry No.21) are with the largest amount of carbon emission reduction under scenario 2. It was not out of the expectation in this research because the direct reuse of structural steel strategy reduces the demand for steel materials and the energy utilized to produce new steel product. Fig. 4.3 demonstrates a clearly picture of the industries with the greatest amount of carbon reduction and increase.

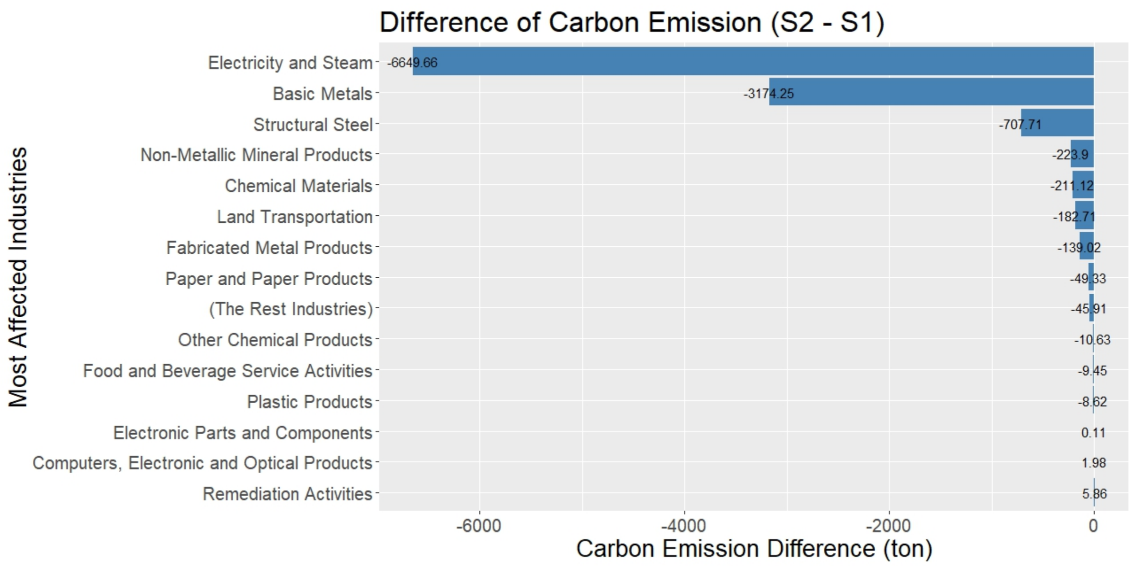

Fig. 4.3 Difference of Carbon Emission between Scenario 2 and Scenario 1

From Fig. 4.3, most of the industries would have decline on their carbon emissions. Although there are three industries that would have increase on their carbon emissions,

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these industries would not significantly affect the carbon reduction effect of the whole economy under scenario 2.

From another point of view, Fig. 4.4 exhibits the percentage of carbon reduction effect of the most contributed industries between scenario 2 and scenario 1.

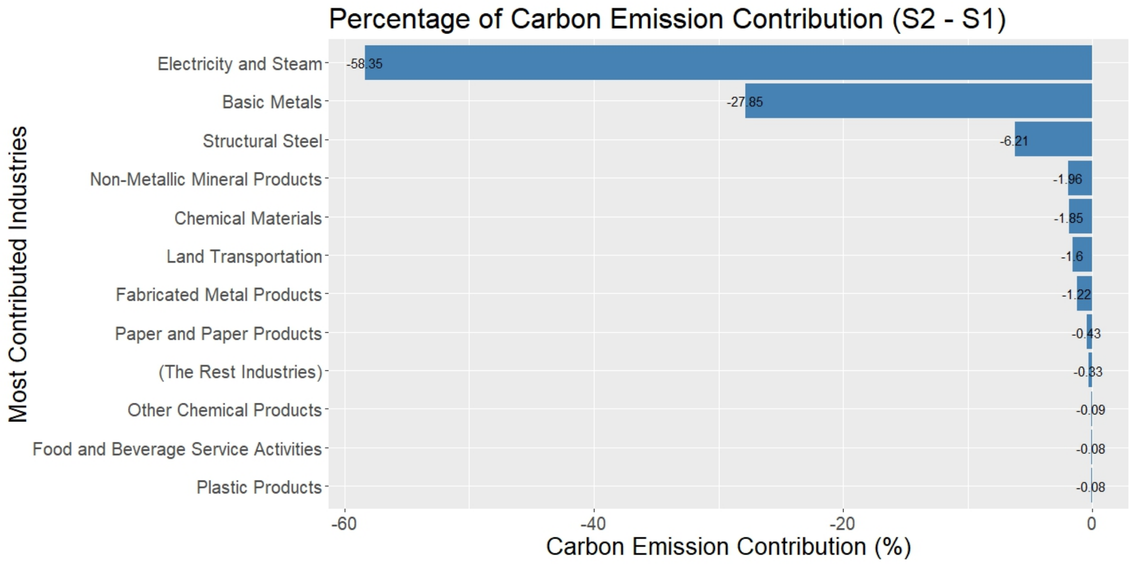

Fig. 4.4 Percentage of Carbon Emission Difference between Scenario 2 and Scenario 1

The top 3 industries in Fig. 4.4, including Electricity and Steam (Industry No.31), Basic Metal (Industry No.21) and Structural Steel (Industry No.64), totally contribute to more than 92% of the total carbon reduction effect between scenario 2 and scenario 1. It supports the expectation from previous research that circular economy could actually help reduce the carbon emission as a different approach from technology revolution. However, the change rate of the total carbon emission between scenario 2 and scenario 1 was only about -0.0055%. It is quite a small contribution to the carbon reduction of

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the whole economy.

From another perspective, there are about 59383.172 tons of end-of-use structural steel generated in 2016 under the greatest potential assumption, and the corresponded carbon reduction effect was 11395.75 tons. It implies that when a unit ton of new structural steel product was substituted by direct reuse one, the market could reduce 0.1919 tons of the carbon emission as shown in Table 4.11.

Table 4.11 Carbon Reduction per unit ton of direct reuse structural steel utilization

	Carbon Reduction Effect (ton)
Direct Reuse Structural Steel Utilization (Per ton)	0.1919

From Fig. 2.2, the carbon reduction effect was estimated to reduce 0.8 tons of carbon emission per ton of steel production while applying technology substitution from BF-BOF to DRI-EAF. This research reached a positive result that the carbon reduction effect of applying direct reuse strategy on structural steel is equal to a quarter of the carbon reduction effect of technology substitution from BF-BOF to DRI-EAF. Applying a circular economy strategy on the demand side has been proved to have contribution to carbon reduction of the whole economy. Once the direct reuse strategy could be implemented under the suitable circumstances, the carbon reduction contribution would be expected to be more significant in the market.

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In summary, although carbon reduction could be achieved through a more circular economy as the report of Material Economics (2018) exhibits. It does not mean that only with the application of one circular strategy would create a significant amount of carbon reduction. Instead, the accumulation effect of different circular strategies will be the key point of a successfully decarbonized future.

4.5. Discussion

The economic evaluation with IO analysis proved that the corresponded direct reuse industry created under the direct reuse circular strategy is a high value added rate industry with money incentives. From the result EEIO analysis, it also turned out that direct reuse circular economy strategy could help reduce the carbon emissions from both the manufacturing sector and electricity sector. These are good supports for the government to promote the application of such a direct reuse business model. However, there are still some problems that the government may have difficulty to take direct reuse strategy in construction sector in the near future.

The scarcity of end-of-use structural steel

From the result of economic and environmental performance evaluation, the contribution of direct reuse circular economy strategy in construction sector of Taiwan

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was not big enough to have a significant influence on the market of Taiwan. The scarcity of end-of-use structural steel may be the main reason of this outcome. This research takes only the structural steel in SS buildings as the target of direct reuse which may be too conservative. SS buildings occupy only around 10%~20% of the existing buildings in the society. Most of the existing buildings in the stock of society, however, are constructed with RC technique. The buildings constructed with SS technique have become popular just from a few decades ago. Therefore, the ratio of end-of-use structural steel generated and new structural steel production was obviously very small. According to the estimation in this research, the greatest potential of direct reuse was merely around 2.33 % in the economy of 2016. The material source of Direct Reuse of Structural Steel (Industry No.65) was not stable yet. Only if there are enough supply of end-of-use structural steel from the buildings within the stock of the society, Direct Reuse of Structural Steel (Industry No.65) would operate in the market successfully. Thus, in this stage, the government must pay more attention on other preparations for this emerging business model.

Transition for building design

Aside from the issue of insufficient on the supply side, the government should also

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make new policy about building redesign as soon as possible. Nowadays, most of the materials in buildings are hard to remain their original quality after demolished from end-of-life buildings. If a building could be designed as conveniently deconstructable, the material collected from such a building would be more valuable for direct reuse. The building demolition process has to be redesigned as well. People should not consider the material from end-of-life buildings as waste like before, but a valuable product that could be sent into a second round of utilization. These revolution takes time to achieve, however, it is a must in a circular economy future. In the private sector, some companies have been observed starting to develop databases of material when constructing a new building. With this database, companies would have a chance to know the actual amount of materials in the stock of society. It may also help the government to have a clear understanding of the amount of reusable materials stored in the stock while the databases reach a mature status. Although the government has the greater power to influence the market, sometimes it would also be benefit from the revolutions appear in the market. It implies that a circular economy future should rely on both the public and private sector’s contribution simultaneously. Without either one of it, no transition would be accomplished no matter how beneficial a strategy is.

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Regulations and standards

The most important issue related to the direct reuse strategy is the regulations of law. However, according to Anastasiades et al. (2021), the latest ISO 20887 is the only standard that addresses the reuse of building elements in new constructions. It still needs further development since ISO 20887 does not address the practical implementation of the circular reuse of components. The obstructing of standardization may be as the result of protectionism on the contractors' side, protectionism on the manufacturers' side, or the designers. It was because they do not want to change the existing market or doubt the safety and risk of reuse components.

There haven't been any kinds of material direct reuse strategy that is ongoing in the market of Taiwan as well. Take steel reuse for example, companies are limited to reuse end-of-use steel in specific ways, remanufacturing is the dominant reuse strategy of waste steel reuse in the meantime. Without regulations from the government, companies would not know whether an end-of-use product is suitable for direct reuse. People would also doubt the strength and toughness of direct reuse materials. Since safety is the core issue of a building, the government should make the direct reuse standards to ensure that these reuse components would be strong enough to support the whole

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building within second round of life. Formulating regulations is what the government must do to prepare a suitable environment before the new circular business model is taken into action.

Industries being negatively affected

From the economic performance analysis, the result shows that some of the existing industry would have decline on their value added after the application of direct reuse strategy. The government should take this side effect seriously because these affected industries might become the obstacle in the introduction of direct reuse strategy. Although it is impossible for all the actors to be benefit from a new policy, the government still has to make compensation or provide a possibility of industrial upgrading. For the best case, these industries could also take this challenge as a chance to revolve into a more efficient actor in the market. Otherwise, a stagnant economy would be unable to progress.

Distinguishing limitation on steelmaking process

From EEIO analysis, the result demonstrated that the upstream steelmaking industry, Basic Metals (Industry No.21), would have a significant reduction on its carbon emission after applying direct reuse strategy. However, it is worth noting that

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direct reuse strategy would reduce only the amount of steel production by EAF technology, which mainly utilized electricity as its energy sources. The carbon emission coefficient per unit output value of Basic Metals (Industry No.21) was obtained by combining the carbon emission from different steelmaking processes. Since Input-Output model took several industries with the same product produced as a single industry, it is difficult to distinguish among different steelmaking processes while calculating the carbon emission. As a result, the amount of carbon emission from Basic Metals (Industry No.21) may be slightly overestimated. On the other hand, the amount of carbon emission from Electricity and Steam (Industry No.31) may be more than the calculation result obtained from the EEIO analysis.

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5. Conclusion

The concept of direct reuse is proposed to create a shorter material recirculation loop. It has the potential to be applied in different kinds of materials. This research takes the steel material in construction sector as the target to investigate the effect of direct reuse strategy. Under the greatest reuse potential, about 2.33% of the demand for structural steel (59383.172 tons) from the market could be substituted with the direct reuse product. The total output value of the economy would decline as the result of applying direct reuse strategy. Nevertheless, the total value added of the economy stays the same as before, which means the profit from industrial production and operation of the market would not decline under direct reuse strategy. However, the value added from some of the industries would actually be transferred to other industries. From the environmental point of view, there would be total amount of 11395.75 tons reduction in carbon emissions after the direct reuse circular strategy was applied.

The redesign of material flow successfully avoids the unnecessary input of money, resources and energy by replacing the remanufacturing process with the direct reuse strategy. The economy and environment would truly be benefit from the reduction of the demand for primary materials and products. Although some of the existing

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industries would have a decline on their output values when a circular business model was introduced to the market, these industries could take the challenge as a chance to upgrade their value of intangible assets. There would not be an exactly perfect status of the economic system no matter how much improvement people would make. The only thing people can do is to improve the negative impact of economic activities as far as possible. In the future, the recognition from the stakeholders would be much more important than the profit earned by the business. Sacrifice is unavoidable needed to reach a sustainable future. But, the government could play as the supporter to make the industries an easier transition.

With the contribution from both the government and the society, direct reuse circular economy business model would improve the utilization efficiency of the end-of-use material. This research provides an evaluation with an emerging direct reuse business model, which is proved to be worth introducing to the market. It is just the first step forward. With the accumulation of different direct reuse strategy, the total effect would be more significant. In the end, the market could be expected to create shorter loops of material recirculation under the concept of circular economy.

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APPENDIX A

Economic Performance of the Whole Economy

Table A.1 exhibits the economic performance of the whole economy under scenario 1 and scenario 2, including the output value, value added and value added rate.

Table A.1 Economic Performance of the Whole Economy

	Scenario	S1	S1	S2	S2	
No.	**Industry**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Value Added Rate (%)**
1	Agricultural Products	479009	372761	479008.3614	372760.503	0.778192059
2	Livestock	190151	42964	190150.7127	42963.93508	0.225946748
3	Forest Products	10483	10234	10482.81737	10233.82171	0.976247257
4	Fishery Products	101450	53565	101449.9558	53564.97665	0.527994086
5	Mineral Products	862067	844971	862009.1861	844914.3326	0.980168595
6	Food Products and Prepared Animal Feeds	930402	354846	930400.4877	354845.4232	0.38138998
7	Beverages and Tobacco	217154	158069	217153.9374	158068.9545	0.727911989
8	Textiles	469535	174002	469532.4746	174001.0641	0.370583663
9	Wearing Apparel and Clothing Accessories	231139	119686	231138.5241	119685.7536	0.51780963
10	Leather, Fur and Related Products	94174	60281	94173.26224	60280.52776	0.640102364
11	Wood and Bamboo Products	81977	45679	81973.61556	45677.11413	0.557217268
12	Paper and Paper Products	297325	125961	297315.6986	125957.0595	0.423647524
13	Printing and Reproduction of Recorded Media	126938	47632	126935.4205	47631.03206	0.375238305

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Table A.1 Economic Performance of the Whole Economy (Continued 1)

	Scenario	S1	S1	S2	S2	
No.	**Industry**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Value Added Rate (%)**
14	Petroleum and Coal Products	1100184	501856	1100147.683	501839.4337	0.456156425
15	Chemical Materials	2488018	1002036	2487967.282	1002015.574	0.402744675
16	Other Chemical Products	584365	351278	584349.9292	351268.9405	0.60112772
17	Pharmaceuticals and Medicinal Chemical Products	205448	152136	205447.9638	152135.9732	0.740508547
18	Rubber Products	134665	67679	134663.0944	67678.04229	0.502573052
19	Plastic Products	583348	251228	583339.1645	251224.1949	0.430665743
20	Non-metallic Mineral Products	469100	213933	469079.6262	213923.7085	0.456049883
21	Basic Metals	2036381	827919	2035449.308	827540.2077	0.406563899
22	Fabricated Metal Products	1075477	497500.0794	1075170.737	497358.4066	0.462585513
23	Electronic Parts and Components	6085060	3698805	6085063.112	3698806.892	0.60785021
24	Computers, Electronic and Optical Products	2923398	1051423	2923403.849	1051425.104	0.359657837
25	Electrical Equipment	862202	415756	862190.6539	415750.5289	0.482202547
26	Machinery and Equipment	1741433	1036154	1741425.555	1036149.57	0.595000784
27	Motor Vehicles and Parts	713893	370271	713891.6054	370270.2767	0.518664562
28	Other Transport Equipment and Parts	519057	247408	519055.9927	247407.5199	0.476649
29	Furniture	110507	45797	110506.9504	45796.97943	0.414426235
30	Other Manufactures	496526	240338	496523.5484	240336.8133	0.484039104

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Table A.1 Economic Performance of the Whole Economy (Continued 2)

	Scenario	S1	S1	S2	S2	
No.	**Industry**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Value Added Rate (%)**
31	Electricity and Steam	696885	314835	696849.295	314818.8694	0.451774683
32	Gas	87722	27599	87719.66725	27598.26607	0.31461891
33	City Water	42719	23629	42716.47374	23627.60266	0.553126244
34	Remediation Activities	164767	75247	165257.4908	75471.00094	0.456687322
35	Construction	1437649	383278	1437642.928	383276.3811	0.26660054
36	Wholesale Trade	3034272	2198272	3034118.229	2198160.596	0.724480864
37	Retail Trade	1485787	1087842	1485715.553	1087789.689	0.732165512
38	Land Transportation	469979	280902	469976.6014	280900.5664	0.597690535
39	Water Transportation	203505	20671	203504.9252	20670.9924	0.1015749
40	Air Transport	387311	182398	387309.4091	182397.2508	0.47093421
41	Support Activities for Transportation; Warehousing and Storage	352980	267689	352969.5947	267681.1089	0.758368746
42	Postal and Courier Activities	67403	39007	67401.35711	39006.04924	0.578713114
43	Accommodation	248736	203433	248732.4645	203430.1085	0.817867136
44	Food and Beverage Service Activities	973227	504266	973221.5942	504263.1991	0.518138112
45	Publishing, Motion Picture, Video and Music Production and Broadcasting Activities	298988	158270	298986.0882	158268.988	0.529352349
46	Telecommunications	438601	260482	438592.2579	260476.8081	0.593892855
47	Related Service of Computer and Information	442740	291763	442736.1169	291760.4411	0.658993992

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Table A.1 Economic Performance of the Whole Economy (Continued 3)

	Scenario	S1	S1	S2	S2	
No.	Industry	Output Value (Million NT$)	Value Added (Million NT$)	Output Value (Million NT$)	Value Added (Million NT$)	Value Added Rate (%)
48	Financial Service Activities	824012	625125	823988.7745	625107.3803	0.758635797
49	Insurance	611387	407810	611382.617	407807.0764	0.667024323
50	Commodity Contracts	215431	138159	215429.0328	138157.7384	0.641314388
51	Real Estate Activities	639661	334934	639635.6919	334920.7484	0.523611726
52	Ownership of Dwellings	1328648	1167741	1328648	1167741	0.878894184
53	Professional, Scientific and Technical Activities	1414274	924057	1414262.002	924049.1607	0.653379048
54	Rental and Leasing Activities	383242	323115	383233.8524	323108.1307	0.843109576
55	Other Support Service Activities	328652	227643	328638.5114	227633.657	0.69265667
56	Public Administration and Defense; Compulsory Social Security	1476264	1064108	1476259.315	1064104.623	0.720811454
57	Education	869842	731689	869840.5398	731687.7717	0.841174604
58	Medical and Health Activities	634305	413689	634304.9701	413688.9805	0.652192557
59	Social Work Activities	48822	29960	48821.99608	29959.99759	0.613657777
60	Arts, Entertainment and Recreation	240814	165234	240812.9053	165233.2488	0.686147815
61	Services of Civil Association and Other Social Services	130384	69852	130383.586	69851.77819	0.535740582
62	Activities of Households as Employers of Domestic Personnel	104121	104121	104121	104121	1

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Table A.1 Economic Performance of the Whole Economy (Continued 4)

	Scenario	S1	S1	S2	S2	
No.	**Industry**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Output Value (Million NT$)**	**Value Added (Million NT$)**	**Value Added Rate (%)**
63	Other Personal Service Activities	525951	322067	525939.5581	322059.9935	0.612351721
64	Structural Steel	66428	17481.92061	64868.94095	17071.62154	0.263170961
65	Direct Reuse of Structural Steel	0	0	1545.18214	1122.513252	0.726460152

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APPENDIX B

Carbon Emissions of the Whole Economy

Table B.1 exhibits the carbon emission amount of the whole economy under scenario 1 and scenario 2, including the carbon emission and the carbon emission coefficients.

Table B.1 Carbon Emissions of the Whole Economy

	Scenario	S1	S2	
No.	**Industry**	**Carbon Emission (tons)**	**Carbon Emission (tons)**	**Carbon Emission Coefficients** $(\frac{\text{kg-CO2}}{\text{per unit Output Value}})$
1	Agricultural Products	158924.9099	158924.698	331.7785468
2	Livestock	63088.02245	63087.92712	331.7785468
3	Forest Products	3478.034506	3477.973914	331.7785468
4	Fishery Products	1053860.528	1053860.069	10387.97958
5	Mineral Products	94874.84022	94868.47751	110.0550656
6	Food Products and Prepared Animal Feeds	774134.1951	774132.9368	832.0427032
7	Beverages and Tobacco	180681.4012	180681.3491	832.0427032
8	Textiles	1259207.45	1259200.678	2681.818076
9	Wearing Apparel and Clothing Accessories	619872.7482	619871.472	2681.818076
10	Leather, Fur and Related Products	56078.21525	56077.77593	595.4744967
11	Wood and Bamboo Products	10681.72665	10681.28565	130.3015071
12	Paper and Paper Products	1576927.936	1576878.604	5303.717937
13	Printing and Reproduction of Recorded Media	20719.35117	20718.93013	163.2241817
14	Petroleum and Coal Products	0	0	0
15	Chemical Materials	10356630.7	10356419.58	4162.602804
16	Other Chemical Products	412293.1172	412282.4841	705.5404023

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Table B.1 Carbon Emissions of the Whole Economy (Continued 1)

	Scenario	S1	S2	
No.	**Industry**	**Carbon Emission (tons)**	**Carbon Emission (tons)**	**Carbon Emission Coefficients** $\left(\frac{\text{kg-CO2}}{\text{per unit Output Value}}\right)$
17	Pharmaceuticals and Medicinal Chemical Products	0	0	0
18	Rubber Products	267101.4607	267097.681	1983.451236
19	Plastic Products	569098.7007	569090.081	975.5732439
20	Non-metallic Mineral Products	5155117.355	5154893.46	10989.37829
21	Basic Metals	6937897.811	6934723.56	3406.974339
22	Fabricated Metal Products	488195.9281	488056.9048	453.9343269
23	Electronic Parts and Components	213261.4474	213261.5565	35.04672878
24	Computers, Electronic and Optical Products	992095.9251	992097.91	339.3639611
25	Electrical Equipment	0	0	0
26	Machinery and Equipment	42561.28336	42561.1014	24.44037948
27	Motor Vehicles and Parts	96010.02578	96009.83822	134.4879776
28	Other Transport Equipment and Parts	69806.92618	69806.7907	134.4879776
29	Furniture	14399.22864	14399.22217	130.3015071
30	Other Manufactures	787178.234	787174.3473	1585.37163
31	Electricity and Steam	129787204.2	129780554.5	186239.0555
32	Gas	3106.932297	3106.849676	35.41793732
33	City Water	510.3094474	510.2792694	11.94572549
34	Remediation Activities	1968.261353	1974.120621	11.94572549
35	Construction	167748.1905	167747.4819	116.682299
36	Wholesale Trade	0	0	0
37	Retail Trade	0	0	0
38	Land Transportation	35800942.49	35800759.78	76175.62166
39	Water Transportation	515927.317	515927.1274	2535.207081
40	Air Transport	0	0	0
41	Support Activities for Transportation; Warehousing and Storage	39819.51156	39818.33774	112.8095404

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Table B.1 Carbon Emissions of the Whole Economy (Continued 2)

	Scenario	S1	S2	
No.	**Industry**	**Carbon Emission (tons)**	**Carbon Emission (tons)**	**Carbon Emission Coefficients** $(\frac{\text{kg-CO2}}{\text{per unit Output Value}})$
42	Postal and Courier Activities	0	0	0
43	Accommodation	434937.3143	434931.1322	1748.590129
44	Food and Beverage Service Activities	1701775.125	1701765.673	1748.590129
45	Publishing, Motion Picture, Video and Music Production and Broadcasting Activities	0	0	0
46	Telecommunications	12811.89421	12811.63885	29.21081851
47	Related Service of Computer and Information	12932.79779	12932.68436	29.21081851
48	Financial Service Activities	4890.013563	4889.875734	5.934396056
49	Insurance	3628.212602	3628.186591	5.934396056
50	Commodity Contracts	1278.452877	1278.441203	5.934396056
51	Real Estate Activities	3796.001716	3795.851527	5.934396056
52	Ownership of Dwellings	4553821.073	4553821.072	3427.409723
53	Professional, Scientific and Technical Activities	0	0	0
54	Rental and Leasing Activities	0	0	0
55	Other Support Service Activities	0	0	0
56	Public Administration and Defense; Compulsory Social Security	622067.3614	622065.3871	421.3794832
57	Education	0	0	0
58	Medical and Health Activities	0	0	0
59	Social Work Activities	7265.960217	7265.959634	148.8255339
60	Arts, Entertainment and Recreation	35839.27213	35839.1092	148.8255339
61	Services of Civil Association and Other Social Services	19404.46842	19404.4068	148.8255339
62	Activities of Households as Employers of Domestic Personnel	15495.86342	15495.86342	148.8255339

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Table B.1 Carbon Emissions of the Whole Economy (Continued 3)

	Scenario	S1	S2	
No.	**Industry**	**Carbon Emission (tons)**	**Carbon Emission (tons)**	**Carbon Emission Coefficients** $(\frac{\text{kg-CO2}}{\text{per unit Output Value}})$
63	Other Personal Service Activities	0	0	0
64	Structural Steel	30153.94947	29446.23905	453.9343269
65	Direct Reuse of Structural Steel	0	0	0

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